Climate change implications for New Zealand

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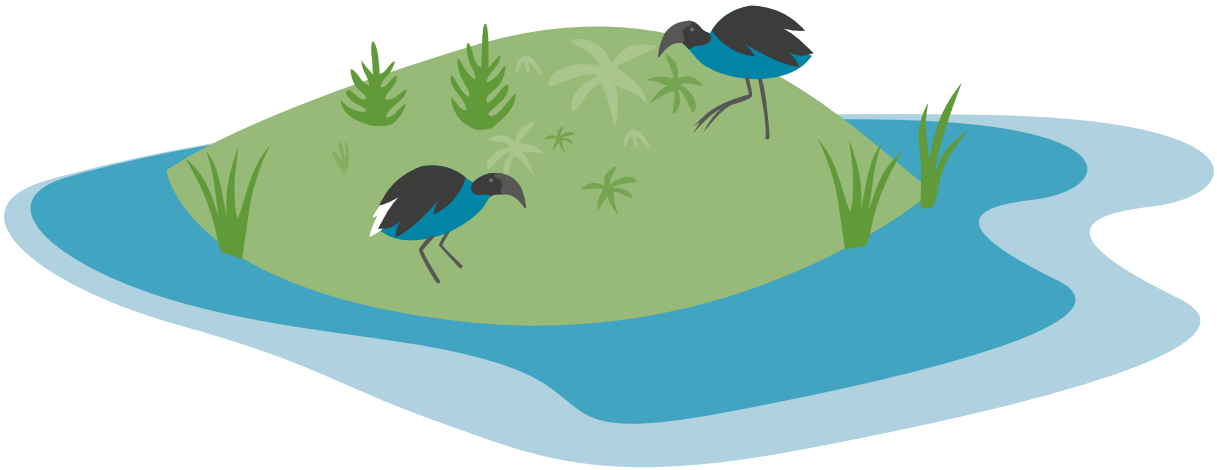
Te Apārangi

Contents

Introduction

New Zealand is being affected by climate change and impacts are set to increase in magnitude and extent over time. This report from the Royal Society of New Zealand summarises the most recent findings about climate risks, uncertainties, impacts and implications for New Zealand.

To understand New Zealand's sensitivities to climate change, it is important to identify the key aspects of society, geography and ecology which expose us to climate-related risks. Concepts of risk and vulnerability to climate change also require careful consideration to enable New Zealanders to be climate-ready, and resilient. The remainder of the report presents six key risks that New Zealand faces from climate change: these are risks to our coastal margins; flooding from rivers; availability of and competition for freshwater; changes to our surrounding oceans; threats to unique ecosystems; and flow-on effects from climate change impacts and responses elsewhere, which will affect New Zealand through our strong international connectivity.



New Zealand's sensitivities to climate change

New Zealanders live on coasts and floodplains

Most of New Zealand's main population centres are on the coast or on the floodplains of major rivers. The aging population in these areas is likely to increase significantly over the next few decades[1]. For Māori especially, there are numerous cultural heritage and food gathering sites in coastal areas which are deeply connected with identity and well-being. Our major urban centres rely upon water supply and storm-water systems designed for today's climate conditions making them sensitive to changing climate extremes. Economic activity relies upon interconnected systems such as transport networks, energy utilities, and water supplies which all rely upon service provision uninterrupted by climate extremes and rising sea and groundwater levels.

New Zealanders rely on the availability of freshwater

New Zealand's economy is tied to climate sensitive primary industries strongly linked to freshwater availability: agriculture, forestry, and tourism. The total Māori asset base is even more heavily invested in these sectors, making it potentially more sensitive to climate-induced changes in water availability[2]. Many rural communities are also dependent on non-reticulated water resource systems, such as rain water tanks for their fresh water supplies.

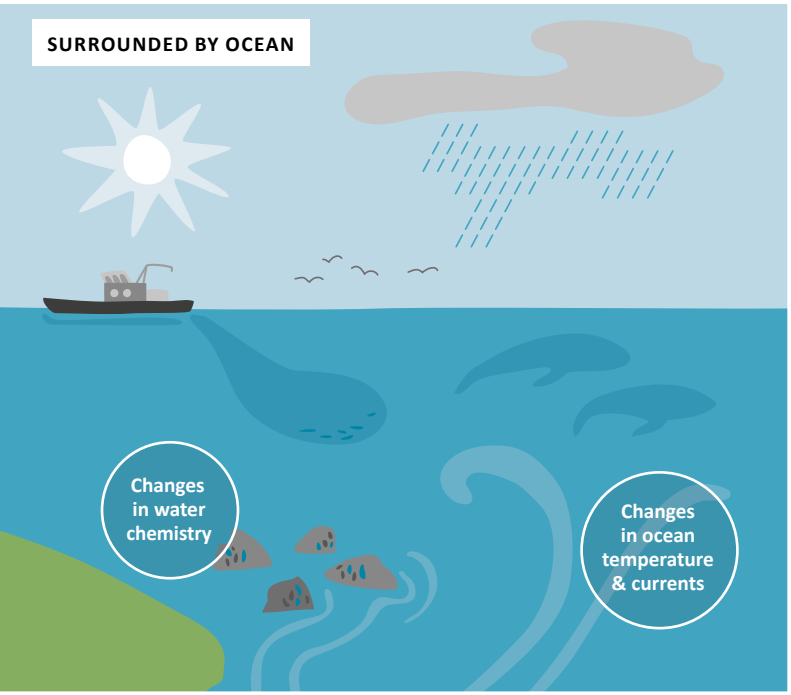
New Zealand is surrounded by ocean

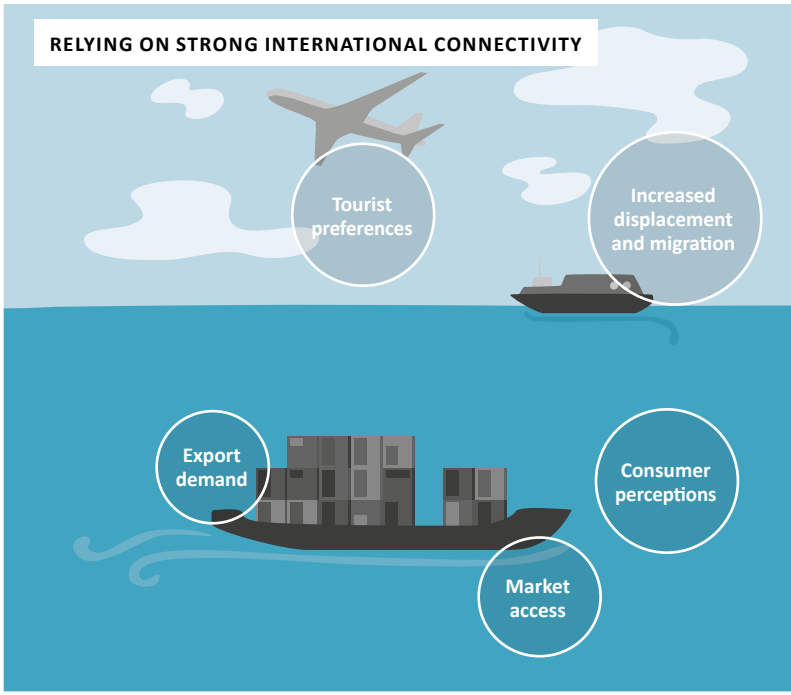
New Zealand's weather and climate are strongly driven by the oceans around it, and the ocean is an important source of economic, social and cultural well-being.

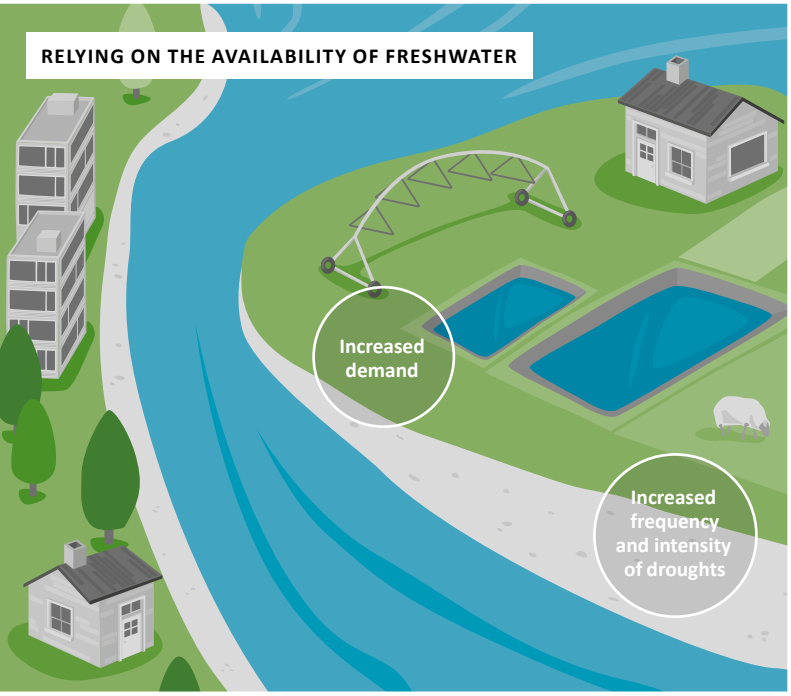
1 Royal Society of New Zealand (2014). Our Futures: Te Pae Tawhiti. http://www.royalsociety.org.nz/our-futures/.

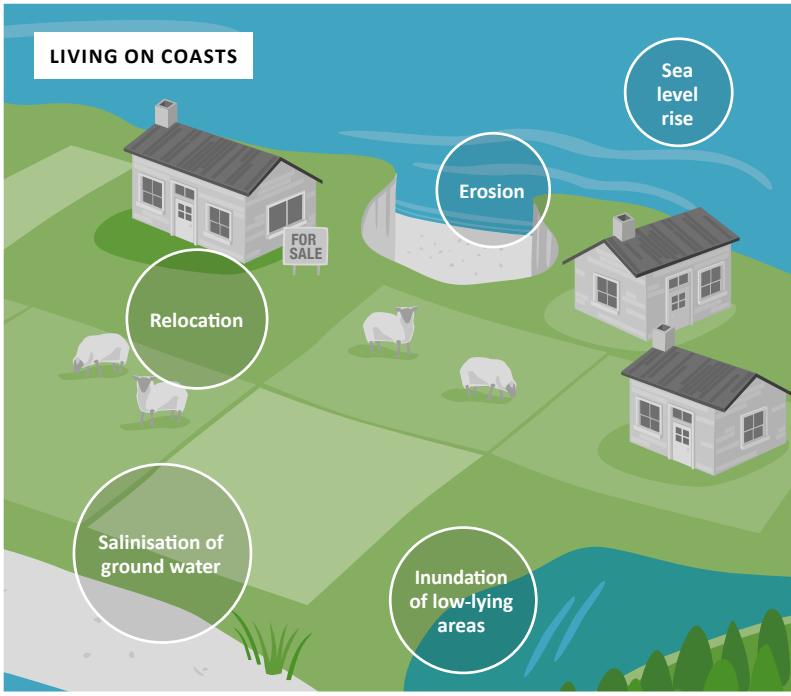
2 King D.N., Penny G. & Severne C. (2010). The climate change matrix facing Māori society. In: Climate change adaptation in New Zealand: Future scenarios and some sectoral perspectives. Nottage R.A.C., Wratt D.S., Bornman J.F. & Jones K. (Eds). New Zealand Climate Change Centre. pp.100–111.

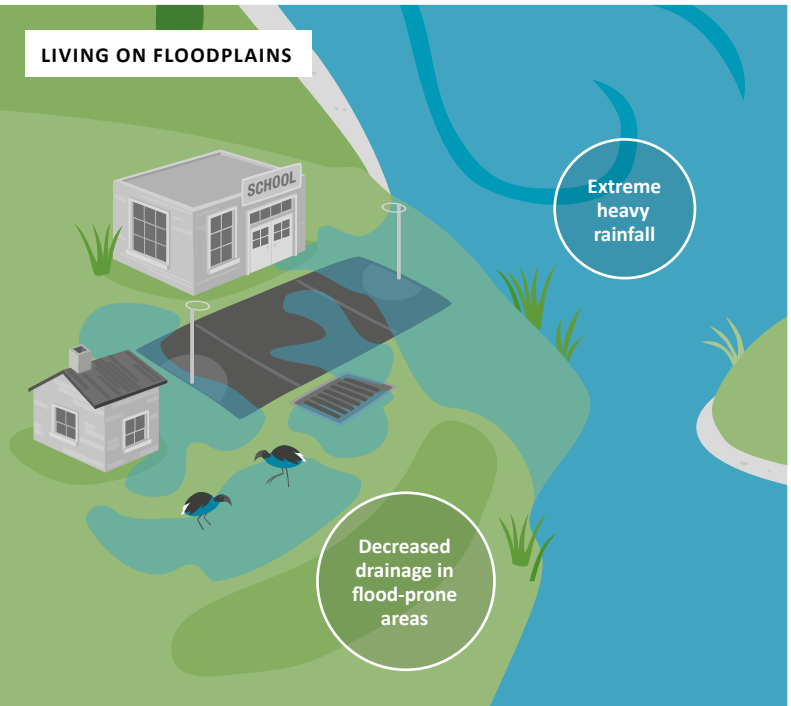
Implications for New Zealand

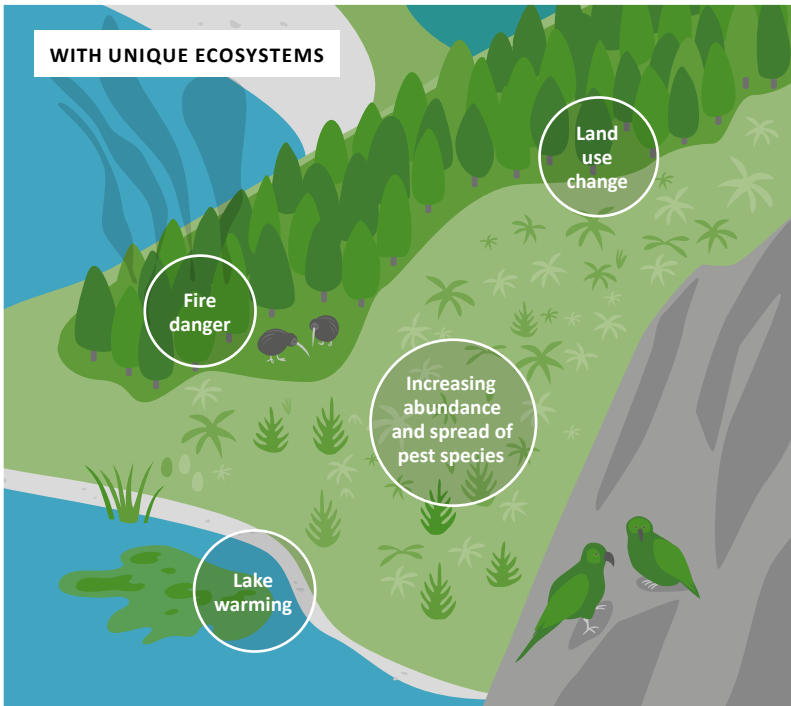












New Zealand has unique ecosystems

New Zealand has many unique indigenous ecosystems, and land and aquatic managed ecosystems that are critical to the country's economic, social and cultural well-being. Native ecosystems are already under pressure from a range of pests and pathogens, and changes in land use and water quality. Māori economic, social and cultural systems are also strongly tied to these ecosystems.

New Zealand relies on strong international connectivity

New Zealand is an open economy with important trading links in Europe, Australia, the US and more recently China. New Zealand also has a diverse population with high levels of migration. A quarter of New Zealand's residents were born overseas. Our international connectivity makes us vulnerable to climate change impacts in other countries, through effects on trade and on international travel and tourism. Climate change-related impacts on trading-partner economies have the potential to affect our ability to sell our goods overseas.

How the changing risks associated with climate change play out socially, culturally, and economically and how they interact with demographic and other changes in future is complex. New Zealand's decision making approaches, rights and obligations for addressing climate-related risks are specific to our country, and must balance an array of devolved responsibilities that cross national, regional and local government arrangements[3].

Three considerations to understand the risk from climate change: hazard, exposure, vulnerability

Risks associated with climate change result from a combination of three factors: changes in the frequency and severity of climate-related hazards; the consequences in terms of exposure of people, infrastructure and ecosystems to those hazards; and their vulnerability to those hazards (i.e. 'the propensity or predisposition to be adversely affected') which includes concepts of sensitivity and susceptibility to harm as well as the lack of capacity to cope and adapt[4]. Age, education, income levels, housing type, and social-cultural networks all contribute to vulnerability; and have been widely shown to influence how different groups can respond to climate stresses and risks[5]. Consequently, recognising that hazards, exposure and vulnerability determine the actual risk from climate change, allows more effective ways of managing those risks, than focusing only on changes in the physical climate.

In other words, risk is the product of hazard, exposure and vulnerability, as illustrated in Figure 1. Hazards are the domain of climate science, while exposure and vulnerability are socio-economic factors determined by human values and preferences.

3 Reisinger A., Wratt D., Allan S., and Larsen H. (2011). The role of local government in adapting to climate change: lessons from New Zealand. In: Climate Change Adaptation in Developed Nations: From Theory to Practice [Ford J.D. and Berrang-Ford L. (eds.)]. Advances in Global Change Research Vol. 42, Springer Science, Dordrecht, Netherlands, pp. 303-319; Lawrence J., Sullivan F., Lash A., Ide G., Cameron C., and McGlinchey L. (2013). Adapting to changing climate risk by local government in New Zealand: institutional practice barriers and enablers. Local Environment: The International Journal of Justice and Sustainability, doi:10.1080/13549839.2013.839643.

4 IPCC (2014). Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part B: Regional Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Barros V.R., Field C.B., Dokken D.J., Mastrandrea M.D., Mach K.J., Bilir T.E., Chatterjee M., Ebi K.L., Estrada Y.O., Genova R.C., Girma B., Kissel E.S., Levy A.N., MacCracken S., Mastrandrea P.R., and White L.L. (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 688 pp.

5 King, D.N., Dalton, W., Bind, J., Srinivasan, M.S., Duncan, M., Skipper, A., Ashford-Hosking, D., Williams, B., Renata, H., and Baker, M. (2012). Coastal Adaptation to Climate Variability and Change: Examining Māori community risk, vulnerability and endurance at Manaia Settlement, Hauraki-Waikato, Aotearoa-New Zealand. NIWA Client Report: AKL2012-029. 142 pp.

While the types of climate change impacts and the most exposed locations are generally known[6], the magnitude, frequency and timing of the impacts cannot be, although we generally know the direction of the change. For example, we know that sea level will continue to rise for centuries and that heavy rainfall will become more frequent[7], but that the amount of change is still uncertain. In a nutshell, the challenge for decision makers is that they confront, simultaneously, both the certainty that climate change is inevitable and uncertainties about the extent of climate change.

Experience shows that uncertainties around climate changes can result in decision-making being postponed until changes are clearer. This 'wait and see' approach is in itself risky, since the direction and rough magnitude of climate changes, and the associated increases in key risks, are well understood. Experience from non-climate issues shows that people often respond to issues of increased risk, such as discovering they have an elevated chance of a heart attack, without knowing the precise probability of it occurring or the exact impact it might have on them.

Choosing not to make lifestyle changes until the risk of a heart attack is known precisely would not be considered a wise approach by most people, and is not encouraged by the health sector. In the same way, being aware of the changing risks from climate change enables governments, regions, businesses and individuals to take decisions now to manage them, even though the exact amount of climate change will remain uncertain. Taking action on the basis of climate change risk helps ensure that New Zealand's society and environment can be resilient by responding flexibly to changing climatic as well as social, economic and environmental conditions.

When we think about acting on risk, we need to keep in mind that the likelihood of damaging events and the consequences of their occurrence are both important, as risk is often described as the product of likelihood and consequence. Even though some outcomes are not very likely, they may warrant proactive management because of the consequences. Having your house burn down is not likely, but the consequences would be devastating. So, we are proactive and fit smoke alarms and take out house insurance, just in case. Climate change itself mainly alters the likelihood of damaging climate-related outcomes, but human responses to climate change play a large role in determining our exposure and vulnerability to such outcomes. Where outcomes from climate change have potentially devastating consequences, they warrant our proactive attention even if their occurrence is not considered likely.

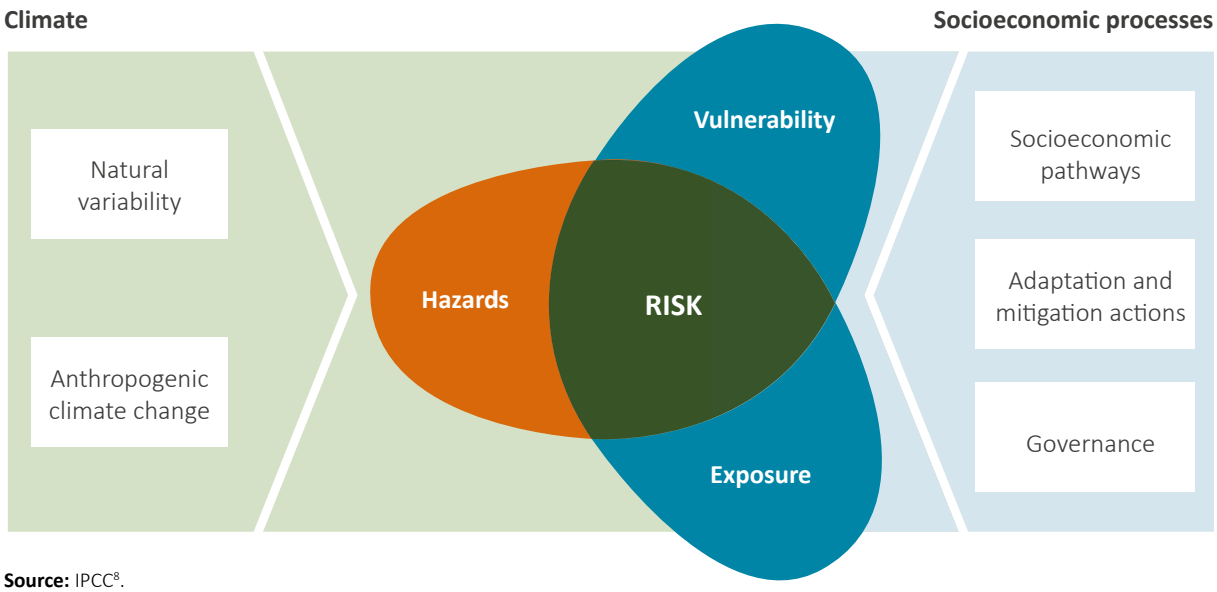
We must also recognise that the choice of taking action or not taking action comes with different risks. The challenge is to ensure that any decisions with long-lasting consequences are well informed by the range of pressures they could experience over their lifetime, and to plan ahead to ensure flexibility in response to changing conditions.

6 IPCC (2013). Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 1535 pp; IPCC, 2014: Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. [Field C.B., Barros V.R., Dokken D.J., Mach K.J., Mastrandrea M.D., Bilir T.E., Chatterjee M., Ebi K.L., Estrada Y.O., Genova R.C., Girma B., Kissel E.S., Levy A.N., MacCracken S., Mastrandrea P.R., and White L.L. (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 1132pp.

7 IPCC (2012). Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation. A Special Report of Working Groups I and II of the Intergovernmental Panel on Climate Change [Field, C.B., V. Barros, T.F. Stocker, D. Qin, D.J. Dokken, K.L. Ebi, M.D. Mastrandrea, K.J. Mach, G.-K. Plattner, S.K. Allen, M. Tignor, and P.M. Midgley (eds.)]. Cambridge University Press, Cambridge, UK, and New York, NY, USA, 582 pp; IPCC, 2013: Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 1535 pp.

Figure 1: Schematic illustration of the concept of (climate-related) risk as the interaction of climate-related hazards with the vulnerability and exposure of human and natural systems.

Changes in both the climate system (left) and socioeconomic processes including adaptation and mitigation (right) are drivers of hazards, exposure, and vulnerability.



Source: IPCC[8].

8 IPCC (2014). Summary for policymakers. In: Climate Change 2014: Impact, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Field C.B., Barros V.R., Dokken D.J., Mach K.J., Mastrandrea M.D., Bilir T.E., Chatterjee M., Ebi K.L., Estrada Y.O., Genova R.C., Girma B., Kissel E.S., Levy A.N., MacCracken S., Mastrandrea P.R., and White L.L. (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, pp.1–32.

Key aspects of global climate change

What is already happening?

Warming of the climate system is unequivocal, and since the 1950s, many of the observed changes are unprecedented over decades to millennia. The atmosphere and oceans have warmed, the amounts of snow and ice have diminished, and sea level has risen[9].

Global surface temperatures have warmed, on average, by around one degree Celsius since the late 19th century[10]. Much of the warming, especially since the 1950s, is very likely a result of increased amounts of greenhouse gases in the atmosphere, resulting from human activity. The rate of change is far from uniform, as shown in Figure 2.

9 IPCC (2013). Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 1535 pp.

10 Met Office web site, http://www.metoffice.gov.uk/news/release/archive/2015/one-degree.

Arctic regions and the higher latitude continents of the Northern Hemisphere have warmed much faster than the global average, while the southern oceans south of New Zealand latitudes have warmed more slowly. Generally, continental regions have warmed more than the ocean surface at the same latitudes.

Changes in many extreme weather and climate events have been observed since about 1950. Some of these changes have been linked to human influences, including a decrease in cold temperature extremes, an increase in warm temperature extremes, an increase in extreme high sea levels and an increase in the number of heavy precipitation events in a number of regions[11].

Global sea levels have risen around 19 cm since the start of the 20th century, and are almost certain to rise at a faster rate in future (Figure 3). Sea-level rise comes about as a combination of expansion of the water column as it warms, the input of fresh water from the melting of land-based ice (glaciers and ice sheets), and changes in land water storage (e.g. groundwater and lakes)[12]. Sea levels also respond to movements in the earth's crust and to global wind patterns, so rates of sea level rise vary geographically. Since 1993, the rate of global mean sea level rise has been around 3.3 mm per year, roughly double the rate observed in the mid-20th century.

Recent research shows that many parts of the West Antarctic, and some areas of the East Antarctic, are susceptible to melting from beneath by warm ocean water. Because many parts of the ice sheets are grounded below sea level, they are vulnerable to an instability that could cause irreversible loss of ice and the addition of several metres to global sea levels[13]. The exact amount of warming required to trigger irreversible melting is unknown, but may be as little as one more degree. Whatever the limit, irreversible melt becomes more likely as temperatures rise, thus increasing the risk if exposure and vulnerability do not change. The 2°C warming "guardrail" proposed as a safe limit by the governments of the world is an attempt to limit such risks, but is not guaranteed to be risk-free.

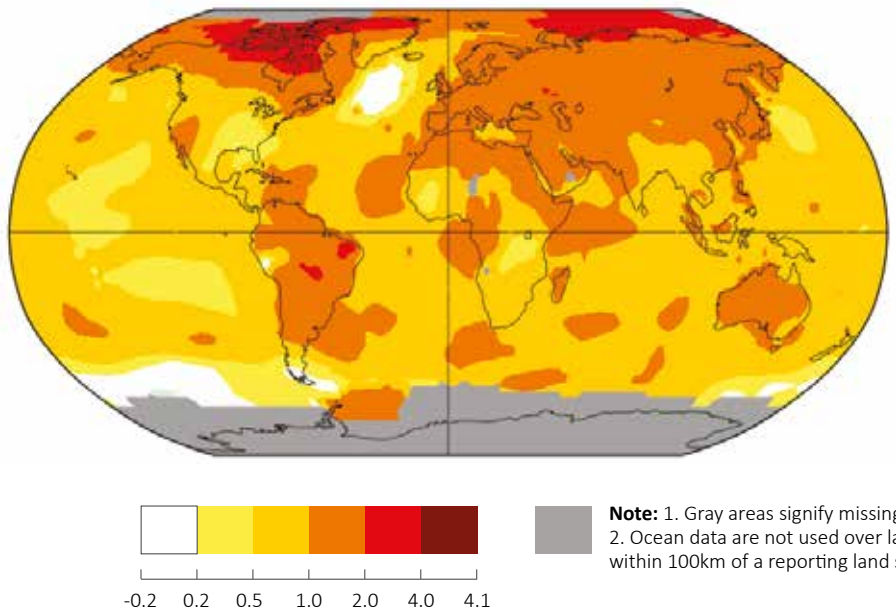
11 IPCC (2014). Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, R.K. Pachauri and L.A. Meyer (eds.)]. IPCC, Geneva, Switzerland, 151 pp.

12 IPCC (2013). Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, Chapter 13, Table 13.1.

13 See footnote 12, Box 13.2.

Figure 2: Change in average surface air temperature (°C) over the past century.

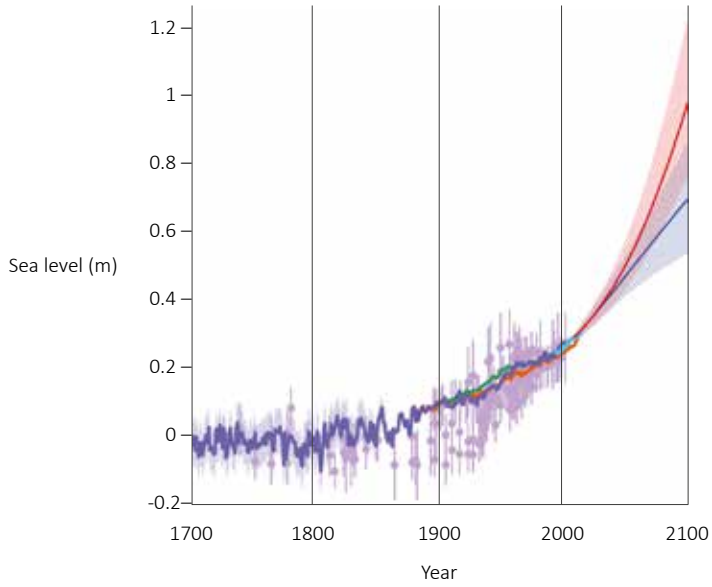
Colour shading indicates the difference in temperature between the 2006-2015 10-year average and the 1906-1935 30-year base period. Colour scale as indicated at the bottom. Grey shading indicates missing or insufficient data.



Source: NASA[14].

Figure 3: Observed and projected global mean sea level change (metres) since 1700, from tide gauges, satellite measurements, and climate model projections, all relative to pre-industrial values.

(Blue) low-carbon world scenario 'RCP2.6'; (Red) high carbon world scenario 'RCP8.5'.



Source: IPCC[15].

14 NASA GISS web site, http://data.giss.nasa.gov/gistemp/maps/.

15 IPCC (2013). Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, Fig 13–27.

What might the future hold?

Surface temperature is projected to rise over the 21st century under all assessed emission scenarios. It is very likely that heat waves will occur more often and last longer, and that extreme precipitation events will become more intense and frequent in many regions. The ocean will continue to warm and acidify, and global mean sea level will continue to rise[16].

Relatively small changes in average climate can have a big effect on the frequency of occurrence or likelihood of extreme events, as illustrated in Figure 4. As temperatures rises, what were once rare hot days can occur much more frequently, while rare cold days (e.g. frosts) may cease to be observed. A similar change would also occur for rainfall, where the occurrence of heavy rainfalls becomes more frequent as the climate warms and the total amount of moisture in the atmosphere increases.

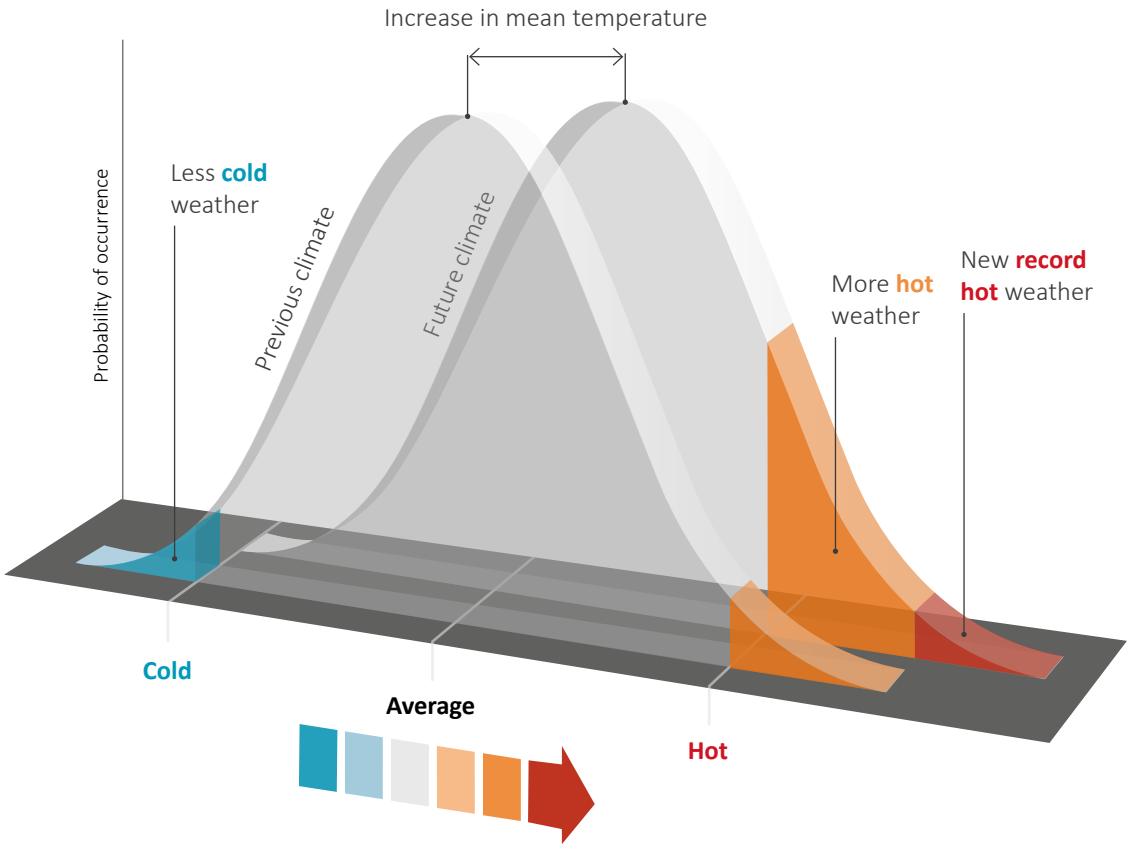
How the future plays out depends critically on the emissions of greenhouses gases that enter the atmosphere over coming decades. Two possible futures to consider are labelled here as the 'Low-carbon' world (the Representative Concentration Pathway (RCP) 2.6 scenario in the IPCC Fifth Assessment Report (AR5)), where emissions are capped in the next 10 years and decline to zero well before the end of the century, and the 'High-carbon' world (the RCP8.5 scenario in the IPCC AR5), where emissions continue at close to current levels right through this century. Actual future outcomes may lie anywhere within, but also potentially outside, those contrasting scenarios depending on global developments. Figure 5 illustrates the time sequence and pattern of temperature change under the two future scenarios. In this report, we use these two contrasting scenarios, where possible, to illustrate the range of potential future changes and their implications, but in some cases, only mid-range scenarios (with emissions and associated climate change roughly mid-way between the low- and high-carbon worlds) were available.

It is important to recognise that, even if all greenhouse gas emissions were to stop immediately, there is a certain amount of further climate change that cannot be avoided because of the slow response times of the oceans and ice sheets. Sea levels would continue to rise, by up to 50cm above current sea levels, over the next two centuries or more. Global average temperatures would drop slightly as methane concentrations decrease, but temperatures would remain elevated above pre-industrial levels for centuries, as carbon dioxide concentrations decrease gradually[17].

16 IPCC (2014). Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, R.K. Pachauri and L.A. Meyer (eds.)]. IPCC, Geneva, Switzerland, summary for policy makers.

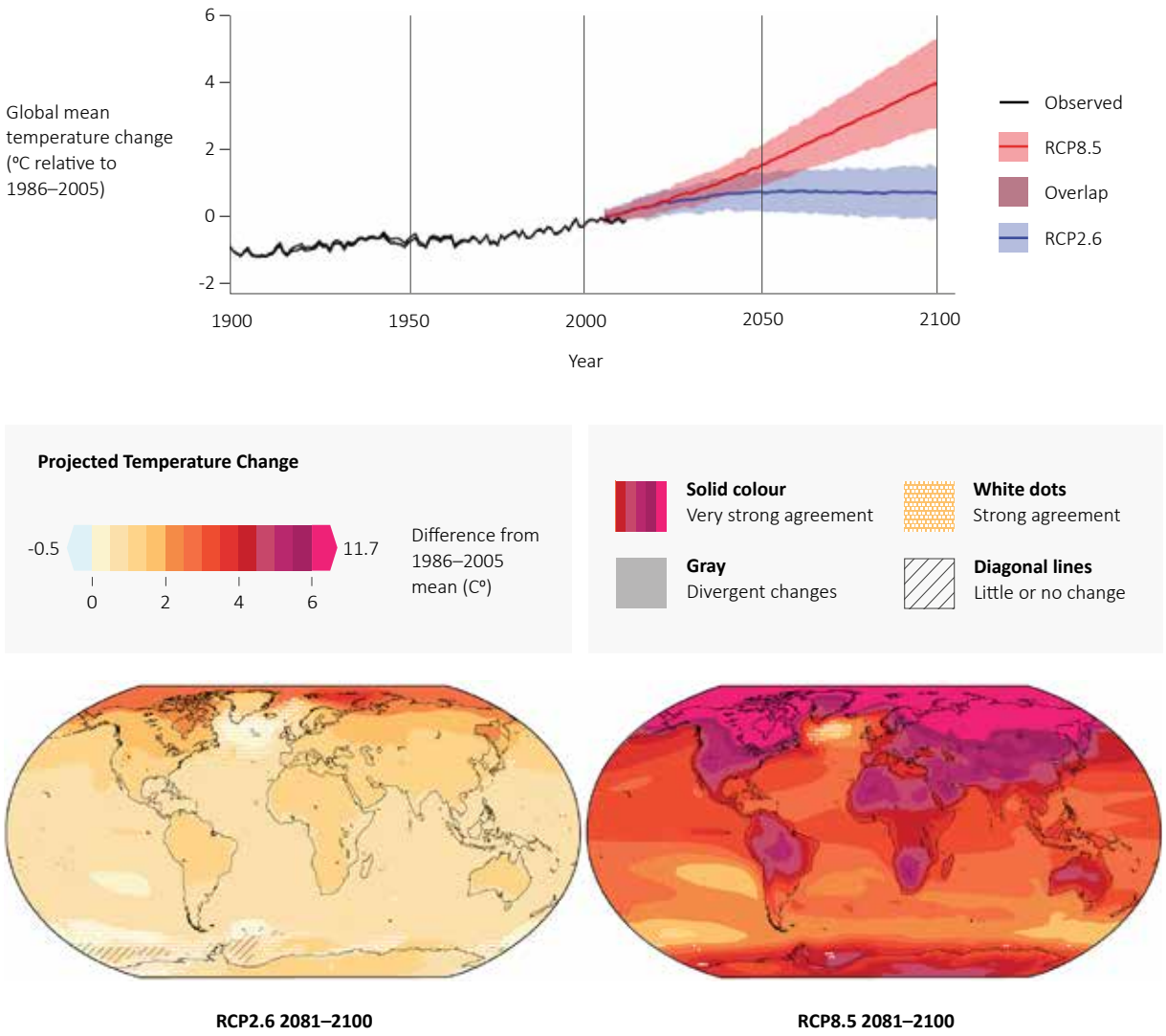
17 IPCC (2013). Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, Chapters 12 and 13.

Figure 4: Schematic illustration of how the frequency of occurrence of temperature extremes changes as average temperatures rise[18].



18 Reisinger A. (2009). Climate Change 101: An Educational Resource. Institute of Policy Studies and New Zealand Climate Change Research Institute, School of Government, Victoria University of Wellington.

Figure 5: Top – Observed and projected global mean temperature change to 2100 (top graph) under the low carbon (RCP2.6) and high carbon (RCP8.5) scenarios; Bottom – Century-scale patterns of temperature change (2081–2100 minus 1986–2005) for the low and high carbon scenarios.



Source: IPCC[19].

19 IPCC (2014). Summary for policymakers. In: Climate Change 2014: Impact, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Field C.B., Barros V.R., Dokken D.J., Mach K.J., Mastrandrea M.D., Bilir T.E., Chatterjee M., Ebi K.L., Estrada Y.O., Genova R.C., Girma B., Kissel E.S., Levy A.N., MacCracken S., Mastrandrea P.R., and White L.L. (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, pp.1–32.

High-carbon world

Climate change will amplify existing risks and create new risks for natural and human systems. Risks are unevenly distributed and are generally greater for disadvantaged people and communities in countries at all levels of development[20].

With continued strong emissions of greenhouse gases, global mean temperature rises are likely to be in the range 2.6 to 4.8°C by 2100, relative to 1986–2005[21]. Such levels of warming would move the climate system into a state not seen for at least several hundred thousand years. Rainfall patterns would change significantly, with subtropical regions drying further and higher latitudes seeing large increases in precipitation. The broad picture is that the wet get wetter and the dry get drier. This applies regionally, but also seasonally, with the drier seasons likely to become drier and the wet seasons wetter. The frequency of heatwaves and drought would increase markedly in many parts of the globe, along with an increased frequency of heavy rainfall events in most regions.

Rapid warming would be expected to continue in the Arctic and over the high northern continents (around 8–10°C in the high carbon world), leading to complete loss of summertime sea ice.

Rainfall would be expected to decrease by around 30% in and near subtropical regions, for a 4°C warming. Near the equator and at high latitudes, rainfall increases of 40% or more are projected.

Globally, food security and fresh water availability would be seriously compromised which may lead to political instability and increased risk of violent conflict. By the end of the century, increased temperature and humidity is likely to make working outside difficult in some parts of the world. A large fraction of species would face increased extinction risk during and beyond the 21st century, especially as climate change interacts with other stressors, such as habitat fragmentation[22].

With strong warming, sea level rise would be expected to accelerate, and be in the range of 0.52 to 0.98 m by 2100, relative to 1986–2005. Much greater sea level rise associated with ice sheet melt is possible but the timing and magnitude remains uncertain. During the last interglacial period (116–129 thousand years ago) when the world was at least 2 degrees warmer than present, global mean sea levels were 5–10 metres higher than today.

20 IPCC (2014). Summary for policymakers. In: Climate Change 2014: Impact, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Field C.B., Barros V.R., Dokken D.J., Mach K.J., Mastrandrea M.D., Bilir T.E., Chatterjee M., Ebi K.L., Estrada Y.O., Genova R.C., Girma B., Kissel E.S., Levy A.N., MacCracken S., Mastrandrea P.R., and White L.L. (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, pp.1-32.

21 See footnote 20, RCP8.5.

22 See footnote 20.

Low-carbon world

For a low carbon world (RCP2.6), substantial emissions reductions would be required over the next few decades, going to near zero (or below) net anthropogenic emissions of CO_2 and other long-lived greenhouse gases by the end of the century. Emissions may need to become negative from late-century (it is likely that CO_2 would have to be actively removed from the atmosphere to achieve this goal, e.g. by energy production using biomass which absorbs CO_2 from the atmosphere as it grows, then capturing CO_2 emitted during combustion and storing it underground). Global mean warming would likely flatten off a little under 2°C above pre-industrial temperatures. There would still be significant change in the frequency of extreme events, including heat waves, floods and droughts, and associated climate-related risks, but well below the level seen in the high-carbon world. Warming would likely reach 3–4°C in and near the Arctic (Figure 5). Global mean sea level is likely to rise by between 0.28 and 0.61 m by 2100 and would continue to rise slowly for many centuries, even as greenhouse gas concentrations decrease. Greater sea level rise, of up to 7 m over 1000 years or more, is possible. The threshold for near-complete loss of the Greenland ice sheet is estimated to be between 1°C and 4°C global mean warming above pre-industrial temperatures[23].

Even in the 'low carbon' world, the level of climate change would still be very significant for most regions and peoples. Rainfall increases or decreases of 10% or more would be common across the globe. The occurrence of heatwaves would increase, as would the incidence of forest fires in many locations. The precise levels of climate change sufficient to trigger abrupt and irreversible changes remain uncertain, but the risk associated with crossing such thresholds increases with rising temperature[24].

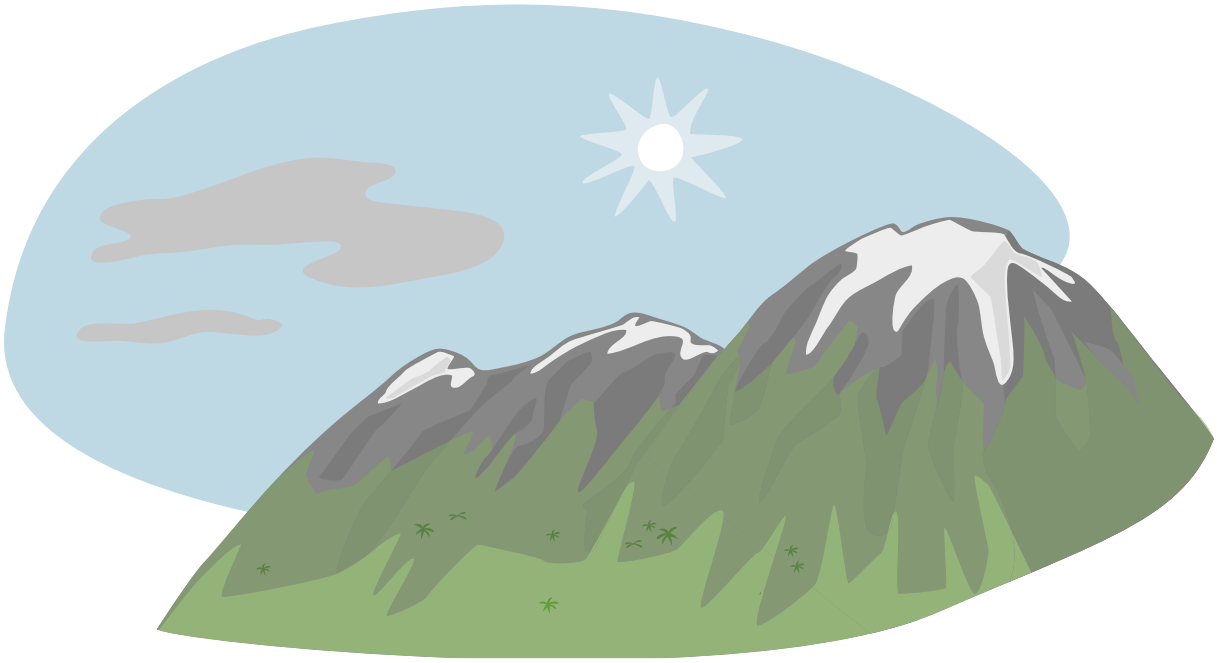
In summary, a low-carbon world would reduce but not eliminate many key climate-related risks. Adaptation to those climate changes would still be necessary and may entail substantial changes for some sectors and regions, but would be more feasible than in a high-carbon world.

23 IPCC (2013). Summary for Policymakers. In: Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, US.

24 See footnote 23.

Key aspects of climate change for New Zealand

New Zealand climate is changing. The Australasian region continues to show long-term trends toward higher surface air and sea surface temperatures, more hot extremes and fewer cold extremes, and changed rainfall patterns. Warming is projected to continue through the 21st century along with other changes in climate.



Warming is expected to be associated with rising snow lines, more frequent hot extremes, less frequent cold extremes, and increasing extreme rainfall related to flood risk in many locations. Annual average rainfall is expected to decrease in the northeast South Island and northern and eastern North Island, and to increase in other parts of New Zealand. Drought frequency could double or triple in eastern and northern New Zealand by 2040, and fire weather is projected to increase in many parts of New Zealand. Regional sea level rise will very likely exceed the historical rate (1971–2010), consistent with global mean trends. Without adaptation, further changes in climate, atmospheric carbon dioxide (CO_2), and ocean acidity are projected to have substantial impacts on water resources, coastal ecosystems, infrastructure, health, agriculture, and biodiversity[25].

What is already happening?

Over New Zealand, temperatures are rising and there is some evidence of changing rainfall patterns. Averaged over the country, temperatures have risen around 1°C in the past century and there has been a matching but slightly smaller rise in ocean surface temperatures around our coasts. Rainfall totals have increased in the southwest of the South Island and have decreased in the north of the North Island[26], although there is a lot of variability from year to year. Some heavy rainfall events already carry the fingerprint of a changed climate, in that they have become more intense due to higher temperatures allowing the air to carry more moisture[27]. Sea levels around the coasts have risen an average of 17 cm in the past century[28], a change that matches the global average rise.

25 Reisinger A., Kitching R.L., Chiew F., Hughes L., Newton P.C.D., Schuster S.S., Tait A., & Whetton P. (2014). Australasia. In: Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part B: Regional Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Barros V.R., Field C.B., Dokken D.J., Mastrandrea M.D., Mach K.J., Bilir T.E., Chatterjee M., Ebi K.L., Estrada Y.O., Genova R.C., Girma B., Kissel E.S., Levy A.N., MacCracken S., Mastrandrea P.R., & White L.L. (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA,. https://ipcc-wg2.gov/AR5/report/- Chapter 25, Australasia.

26 See footnote 25.

27 Dean S. M., Rosier S., Carey-Smith T., and Stott P. A. (2013). The role of climate change in the two-day extreme rainfall in Golden Bay, New Zealand, December 2011 [in "Explaining Extreme Events of 2012 from a Climate Perspective"]. Bull. Amer. Meteor. Soc., 94, S61–S63.

28 Hannah J. & Bell R.G. (2012). Regional sea level trends in New Zealand. Journal of Geophysical Research: Oceans 117: C01004.

What might the future hold?

New Zealand will generally follow global changes but with some differences. For example, New Zealand can expect temperatures to rise less than the global average due to ocean buffering (Figure 6); sea level rise is likely to be around 10% more than the global average; and rainfall patterns will be strongly influenced by New Zealand's topography, meaning that rainfall will change differently in different parts of the country.

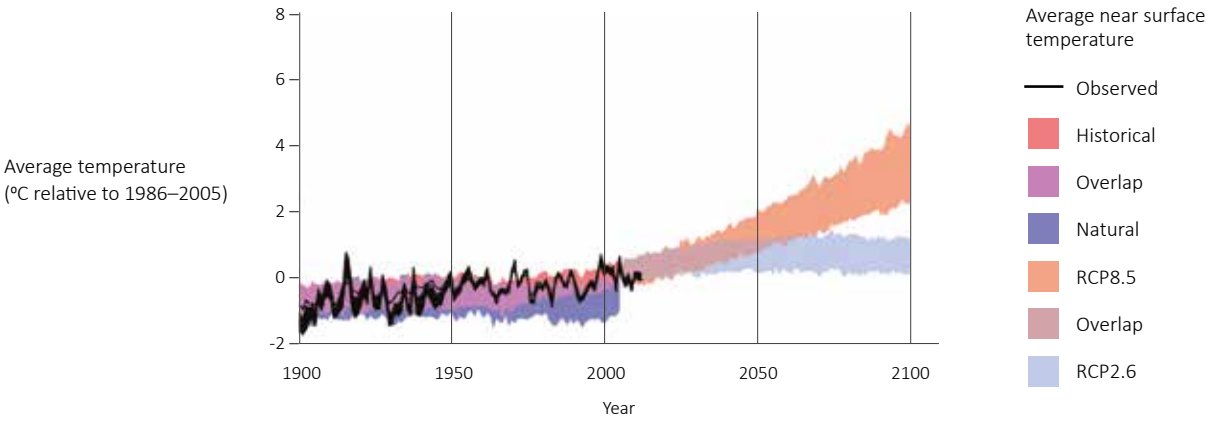
How the future plays out depends critically on the emission of greenhouses gases that enter the atmosphere over coming decades. For the two possible futures outlined above, both will mean changes from New Zealand's current climate, with the main difference being the rate and amount of change.

High-carbon world

In a high carbon world, we can expect temperatures to rise by between another 2.5 and 5°C this century, averaged across the country (Figure 6). Annual average rainfall is projected to decrease by about 10% in the east and north of the country, with droughts currently considered as severe (i.e. those droughts that typically occur only once every 20 years or so) becoming several times more frequent in those areas. Western regions would see annual average rainfall increase by up to 10% or more, especially in the south (Figure 7). Sea-level rise is expected to accelerate, to reach between 0.6 and 1.1 m by 2100, relative to 1986–2005 levels (global mean rate plus 10%, approximately). As noted earlier, sea levels could rise further this century depending on the response of the major ice sheets, and would keep rising at a high rate for many centuries after that. Ocean water would continue to become more acidic (less alkaline), possibly reaching levels of acidity not seen for tens of millions of years.

Figure 6: Changes in average New Zealand temperature under different emissions scenarios.

Note: Shading denotes the 5th to 95th percentile range of climate model simulations driven with 'historical' changes in anthropogenic and natural drivers, historical changes in 'natural' drivers only, a low-carbon world (RCP)2.6 emissions scenario, and a high carbon world (RCP8.5) scenario.

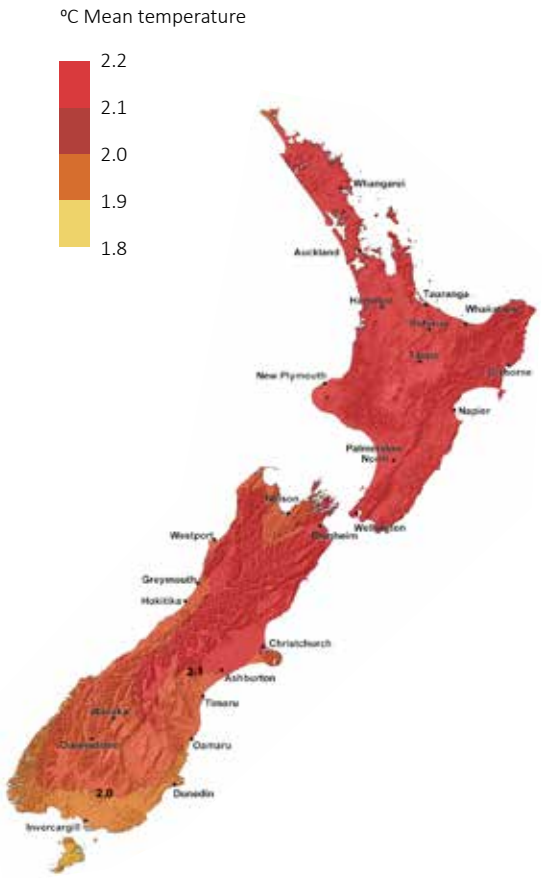


Source: IPCC[29].

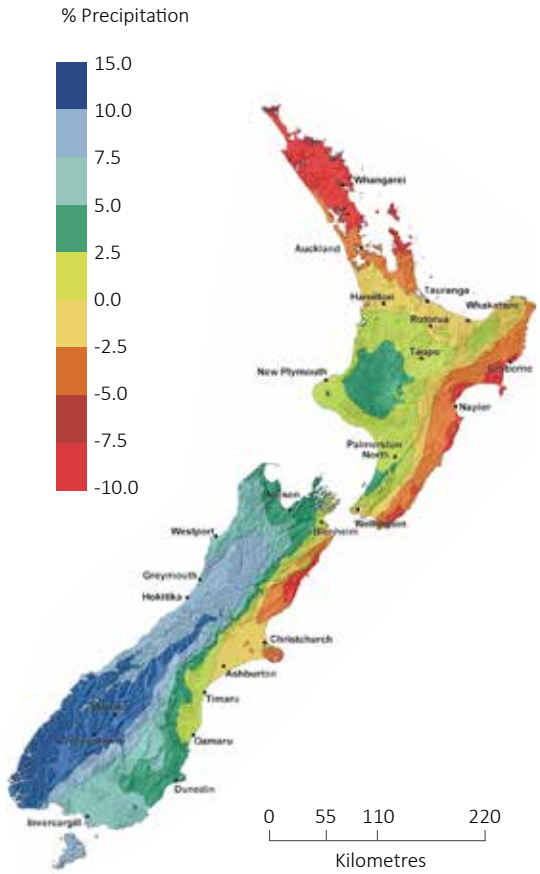
29 IPCC, 2014: Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part B: Regional Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Barros V.R., Field C.B., Dokken D.J., Mastrandrea M.D., Mach K.J., Bilir T.E., Chatterjee M., Ebi K.L., Estrada Y.O., Genova R.C., Girma B., Kissel E.S., Levy A.N., MacCracken S., Mastrandrea P.R., and White L.L. (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 688 pp. https://ipcc-wg2.gov/AR5/report/- Chapter 25. Figures 25-2.

Figure 7: Average changes in annual mean temperature (left, degrees Celsius) and precipitation (right, percent) during 2080–2099 compared to 1980–1999, for a climate change scenario midway between low- and high-carbon futures.

Projected Annual Mean Temperature Change between 1980–1999 and 2080–2099



Projected Annual Mean Precipitation Change between 1980–1999 and 2080–2099



Source: Ministry for the Environment[30].

30 Ministry for the Environment (2008). Preparing for Climate Change: A guide for local government in New Zealand. https://www.mfe.govt.nz/sites/default/files/preparing-for-climate-change-guide-for-local-govt.pdf.

Low-carbon world

In a low carbon world, temperatures would still climb as some level of climate change is already locked in due to current and past emissions. New Zealand temperatures would rise by up to another 1°C this century, averaged across the country. Even this level of further warming would likely lead to drying (in the annual average) in the east and north of the country with increased drought risk, plus averaged rainfall increases of a few percent in western areas, especially in the South Island. Sea levels would continue to rise by another 0.3 to 0.6 m by 2100, but continue to rise beyond 2100, even if global temperatures have stabilised, as land-based ice will continue to melt and the oceans would continue to warm as they adjust to a warmer atmosphere. Ocean water would also become more acidic, but at a slower rate than has been seen in the past few decades.

Regional variability and extreme events

Temperature rise is expected to be relatively uniform across the country, while rainfall changes are expected to exhibit an east-west gradient with increases on averages in the west and decreases in the east and north (Figure 7).

Warming will increase the number of high heat days (Figure 8) and will reduce the number of frost days. In the high-carbon world, many places will see more than 80 days per year above 25°C by 2100, whereas currently most parts of the country typically see between 20 and 40 days per year above 25°C.

Extreme heavy rainfall events are expected to become more frequent in most parts of the country, by a factor of up to four, especially those regions where an increase in average rainfall is expected.[31]

The occurrence of extreme sea level and coastal flooding events changes rapidly as mean sea levels rise. For example, with a 30 cm rise in sea level, the current '1 in 100 year' extreme sea level event would be expected to occur once every year or so in many coastal regions.[32]

Learn more

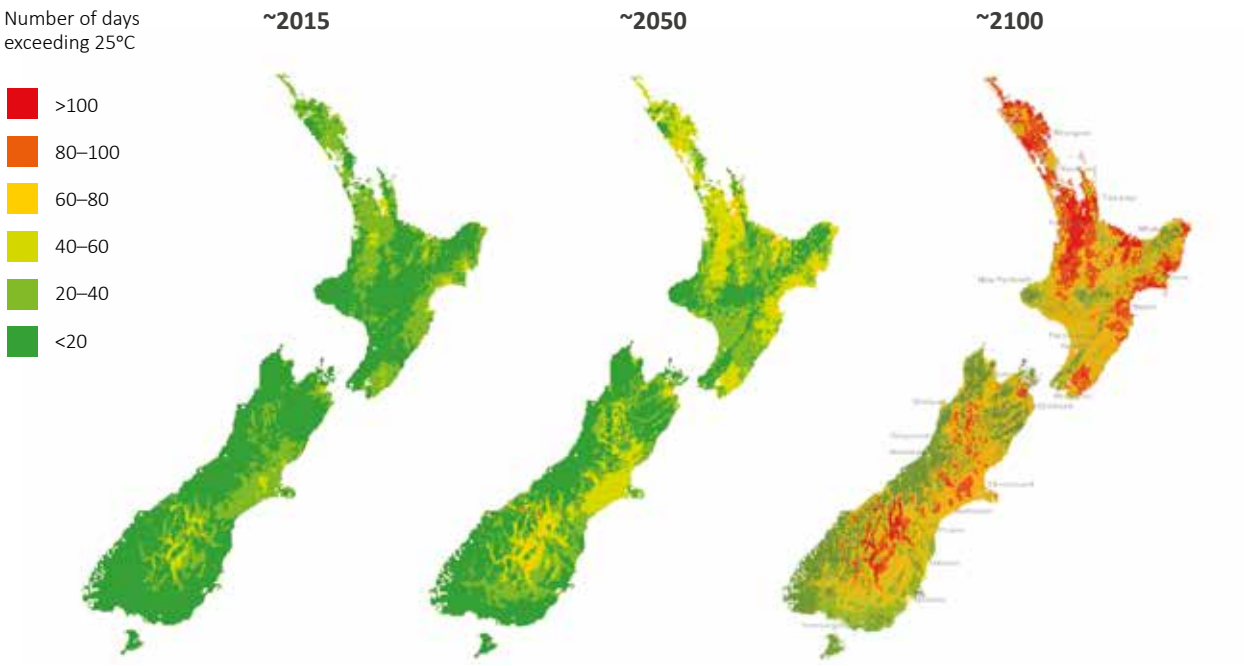
For more information on climate change effects upon New Zealand, see:

- IPCC information on Australasia. In: Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part B: Regional Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. http://www.ipcc.ch/pdf/assessment-report/ar5/wg2/WGIIAR5-Chap25_FINAL.pdf.
- Ministry for the Environment web page on *Climate change impacts in New Zealand.* http://www.mfe.govt.nz/climate-change/how-climate-change-affects-nz/climate-change-impacts.
- New Zealand Climate Change Centre summary of IPCC AR5 for New Zealand. https://www.nzclimatechangecentre.org/research/ipcc-fifth-assessment-report-new-zealand-findings.

31 Ministry for the Environment (2008), "Preparing for Climate Change". Report prepared by NIWA.

32 Parliamentary Commissioner for the Environment (2015). Preparing New Zealand for rising seas: Certainty and Uncertainty. http://www.pce.parliament.nz/publications/preparing-new-zealand-for-rising-seas-certainty-and-uncertainty.

Figure 8: Estimated number of days with maximum temperatures exceeding 25°C, for the current climate (~2015), mid-21st century (~2050) and late 21st century (~2100), under the high carbon scenario (RCP8.5).

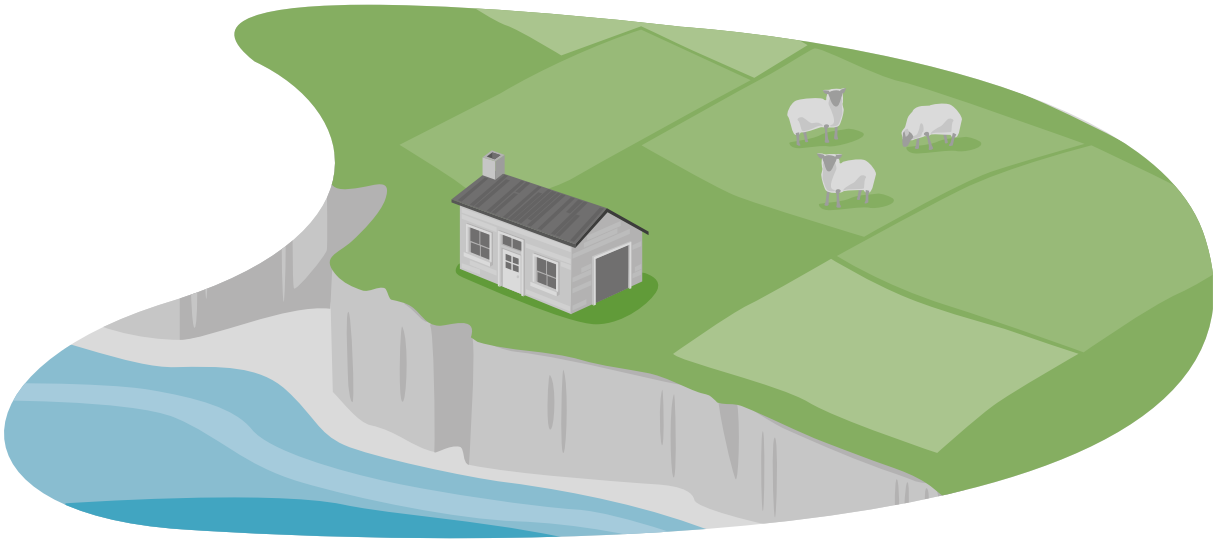


Source: Bodeker Scientific[33].

33 These statistics were derived from a large number of projections of future climate that appropriately incorporate uncertainty around our understanding of the many processes that connect changes in greenhouse gas emissions to changes in climate. Produced by Bodeker Scientific, building on regional climate model simulations performed by NIWA, through the MBIE-funded Climate Change Impacts & Implications (CCII) programme (C01X1225).

Key risks for New Zealand

This report highlights six key risks from climate change to New Zealand: inundation and erosion of coasts, flooding from river systems, pressure on fresh water resources, changes in the ocean, threats to land-based and freshwater ecosystems, and repercussions of global changes for New Zealand. While these cover not all implications and risks associated with climate change, they are considered to pose some of the largest risks to New Zealand (taking into account hazards, exposure and vulnerability, as well as the scale of likely impacts and their probability of occurrence), and could affect large sections of New Zealand society.

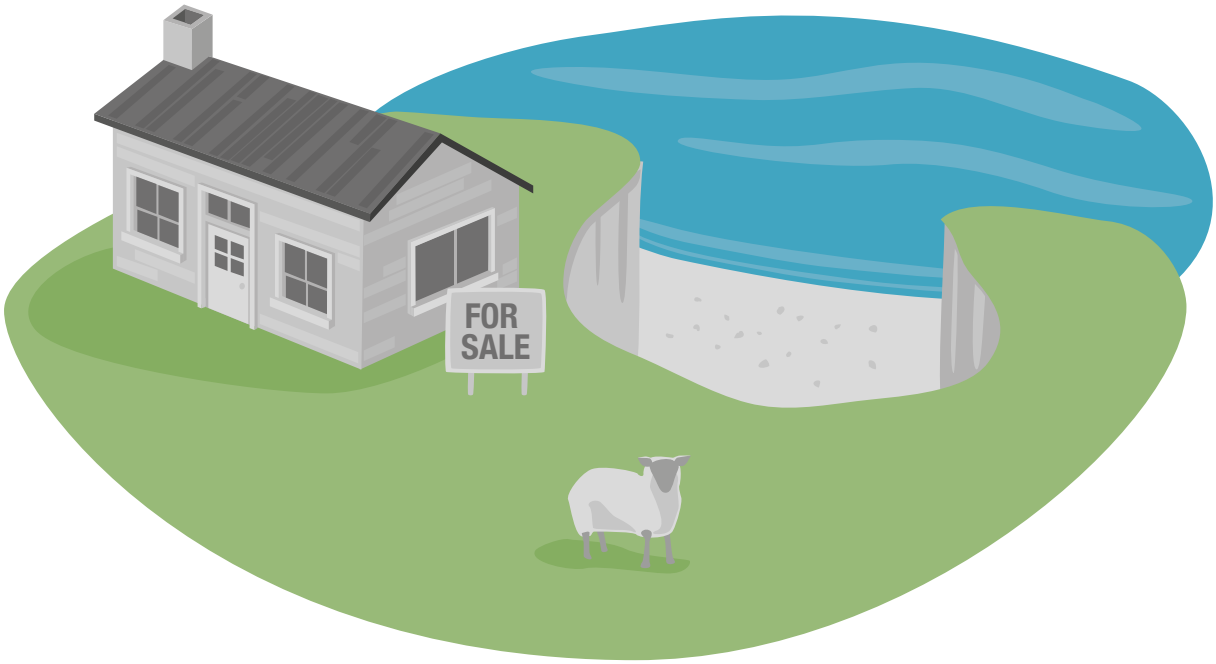


Climate change will have other important implications (for example for human health, energy generation and distribution, transport and infrastructure), but these are not discussed in detail in this report as they were not considered to be *key risks* at the same scale and with the same implications for near-term decision-making as the six areas covered in this report. There is a growing body of research which shows that climate change generally acts to increase existing tensions and stresses, for example on food and water supplies, or on land use. How to best manage those stresses, and how the different identified risks interact with and affect wider changes in the social fabric of the country is not considered directly here but will be critical especially where transformational changes are necessary.

This report also does not focus on possible benefits of climate change. Key examples of potential benefits include longer seasons for pasture growth, increased forest growth where soil conditions and rainfall are not limiting, reduced electricity demand for winter heating and potentially lower winter mortality. While not irrelevant, many of those benefits will be limited geographically or to some sectors, and often come with counterbalancing negative consequences (for example, higher temperatures and CO_2 concentrations stimulate growth of pests and weeds at least as much as existing pastures). Also, the existence of benefits to some parts of society does not remove the need to proactively identify and subsequently manage downside key risks from climate change for New Zealand as a whole. This report does not attempt to present a comprehensive analysis of all potential impacts and implications of climate change but deliberately focuses on those areas that could present the biggest challenges to New Zealand and that require our collective attention.

Coastal change: New Zealanders live mainly near coasts

Shoreline ecology, public infrastructure, residential and commercial assets, community values and the future use of coastal-marine resources will be severely affected by changes to coasts due to sea level rise, and storm surge, and secondary effects such as erosion and flooding.



What climate trends will affect New Zealand's coasts?

The key drivers of coastal change include (i) rising sea levels leading to increasing frequency and volume of inundation by storm-tides, wave run-up and overtopping[34]; and (ii) changing atmospheric circulation patterns linked to stronger storms and changes in wind and wave energy at the coast. Rising sea levels will also influence groundwater near the coast, leading to semi-permanent or permanent inundation of low-lying areas, and the potential for salt-water intrusion into freshwater systems such as shallow aquifers[35]. At the same time, rainfall patterns are also expected to change which will lead, in some cases, to increased occurrences of flooding at coastal-river margins.

As an example of what we might expect, recent analyses of return periods for extreme sea-levels along the Otago Coast determined that the sea level difference between 2-year and 100-year storm surges is about 32 cm, and that the difference between 20-year and 500-year high sea level events is about 25 cm[36]. Consequently, by 2050, sea level rise of 30 cm (mid-range estimate) will make the 100-year event an almost annual event and a currently very rare 500-year event becomes a 20 year event.

34 Rouse H.L., Bell R.G., Lundquist C., Blackett P., Hicks D.M., and King D.N. (submitted). Coastal adaptation to climate change in Aotearoa-New Zealand. Submitted to NZJMFR August 2015.

35 Parliamentary Commissioner for the Environment (2014). Climate change and rising seas: Understanding the science. November 2014.

36 Parliamentary Commissioner for the Environment (2015). Preparing New Zealand for rising seas: Certainty and Uncertainty.

What is already happening?

Climate-induced coastal change is a significant risk for New Zealand due to existing location of populations and their services near the coast and to intensifying coastal development While only 2–2.5% of the total New Zealand land area lies below 10 m in the coastal margin (relative to mean high water), around 16% of the population live in this zone[37]. Sea levels in New Zealand have risen an average of 17 cm in the last 100 years[38], in line with global trends. Some studies have suggested that the rate of rise may be increasing, and is currently around 3 mm/yr[39]. Episodes of extreme coastal flooding are already occurring, such as recurring flooding of Auckland's north-western motorway and Tamaki Drive (a principal arterial route to the eastern suburbs of Auckland) in 2001, 2011 and 2012 due to storm surges coinciding with king tides. In South Dunedin, the high water table means that increasingly frequent very high tides will lead to frequent surface ponding and a lack of drainage for storm water[13].

What might the future hold?

In a high carbon world, we can expect sea levels around the New Zealand coast to rise by between 0.6 and 1.1 m by 2100 and continuing to rise beyond 2100. A 0.8 m rise in sea level would mean that the current 1-in-100-year high tide level will be exceeded during more than 90% of high tides (i.e. almost daily). In addition to sea-level rise, the projected changes to the frequency and intensity of storms will mean greater potential for erosive storm events at the coast, with storm surges on top of already higher mean sea levels[40]. Given the large proportion of existing capital investment on low lying coastal land and the ongoing intensification of development along coastal margins, some areas will be highly sensitive to climate driven changes. Mapping exercises have shown[41] that the east coasts of both North and South Islands are more sensitive to erosion and inundation caused by climate change, because of a combination of factors such as wave exposure, relatively low tidal ranges, sediment budget deficits, and proximity to tidal inlets. Conversely, west coast shores are less sensitive to climate-driven change, mainly because they are already regularly exposed to high wave energy.

It is expected that the interplay of these different circumstances will lead to significant changes in our coastal environment, ranging from inundation and erosion of coastal margins to the landward migration of beaches and coastal ecosystems. Such changes are already resulting in coastal 'squeeze' up against public and private infrastructure and assets, and pose significant implications for different sectors, systems and groups across society. See *Ecosystem changes* for more information on changes to coastal ecosystems.

37 Based on the 2006 New Zealand census (http://www.stats.govt.nz/Census/2006CensusHomePage.aspx); Bell R. & Wadhwa S. (2014). National coastal susceptibility: Vulnerable areas and demographics. National Institute of Water & Atmospheric Research Ltd. June 2014.

38 Hannah J. & Bell R. (2012) Regional sea level trends in New Zealand. Journal of Geophysical Research: Oceans 117: C01004.

39 Church, J.A., P.U. Clark, A. Cazenave, J.M. Gregory, S. Jevrejeva, A. Levermann, M.A. Merrifield, G.A. Milne, R.S. Nerem, P.D. Nunn, A.J. Payne, W.T. Pfeffer, D. Stammer and A.S. Unnikrishnan, 2013: Sea Level Change. In: Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

40 Parliamentary Commissioner for the Environment (2015). Preparing New Zealand for rising seas: Certainty and Uncertainty.

41 Goodhue N., Rouse H.L., Ramsay D., Bell R.G., Hume T.M., and Hicks D.M. (2012). Coastal adaptation to climate change: mapping a New Zealand coastal sensitivity index. A report prepared as part of the Coastal Adaptation to Climate Change Project under contract (C01X0802) to FRST/MSI. NIWA, Hamilton, New Zealand.

What are the implications?

The implications of climate change for coastal populations are expected to vary widely, depending on the diverse natural characteristics and physical drivers that shape the coast, the uneven distribution of impacts, assets and values at risk and their vulnerability and the differentiated make-up of communities themselves[42]. Rising sea levels will lead to inundation of low-lying coastal areas, erosion and destabilisation of different coastal landforms, rising water tables and salination of freshwater. There is increasing risk of damage to public and private infrastructure, particularly as the intensification of development increases along coastal margins in both urban and rural areas. Economic activity is already impacted and will be further impacted from extreme weather events, especially because of the long narrow geography of New Zealand affecting movements of goods and access to markets. New Zealanders also rely on the use of the coast for recreation and tourism, to supplement household food supplies, and for cultural resources. Future coastal changes are expected to impact such activities and the costs and values associated with these resources, including well-being and cultural affirmation[43].

New Zealand currently has guidance from the Ministry for the Environment to help local government to plan for the risks posed by coastal climate change[44]. Rather than providing a specific climate change scenario or sea-level rise value to be accommodated in planning, the guidance recommends assessing the acceptable risk. In making risk assessments, the guidance encourages councils to use a base level of 50 cm of sea-level rise by 2100, and to consider the consequences of at least 80 cm and an additional 1 cm of rise per year beyond 2100, plus the potential for increased size and frequency of storm surges.

Consideration of higher sea level rise is especially important for long-lived infrastructure designed to be in place well beyond 2100. Guidance has also been developed to help councils consider how to work with coastal communities to develop strategies or plans to adapt to these risks[45]. However, studies suggest that without clear legislative guidance, litigation is likely to increase as rising sea levels affect coastal properties and adaptation responses constrain development on coastal lands (e.g. Figure 9).

Coastal risks will be challenging and complex to resolve. Councils will likely face increased costs because some public infrastructure such as roads, waste-water systems, and buildings will almost certainly be affected. Some Māori communities are also likely to be disproportionately affected by such changes because of their socio-economic characteristics and the physical location of valued infrastructure and places on exposed, erosion-prone coastal lands. Given these diverse circumstances, there will be an increasing need to plan for how we adapt to such changes, such as deciding whether to 'hold the line' (protect), accommodate the changes with changing land-use, or relocate in response to known risks or actual climate change impacts[46].

42 Ministry for the Environment (2008). Coastal Hazards and Climate Change. A Guidance Manual for Local Government in New Zealand (2nd edition); King DN, Penny G, Severne C 2010. The climate change matrix facing Māori society. In: Climate change adaptation in New Zealand: Future scenarios and some sectoral perspectives. Nottage R.A.C., Wratt D.S., Bornman J.F., & Jones K. (Eds). New Zealand Climate Change Centre. pp.100–111.

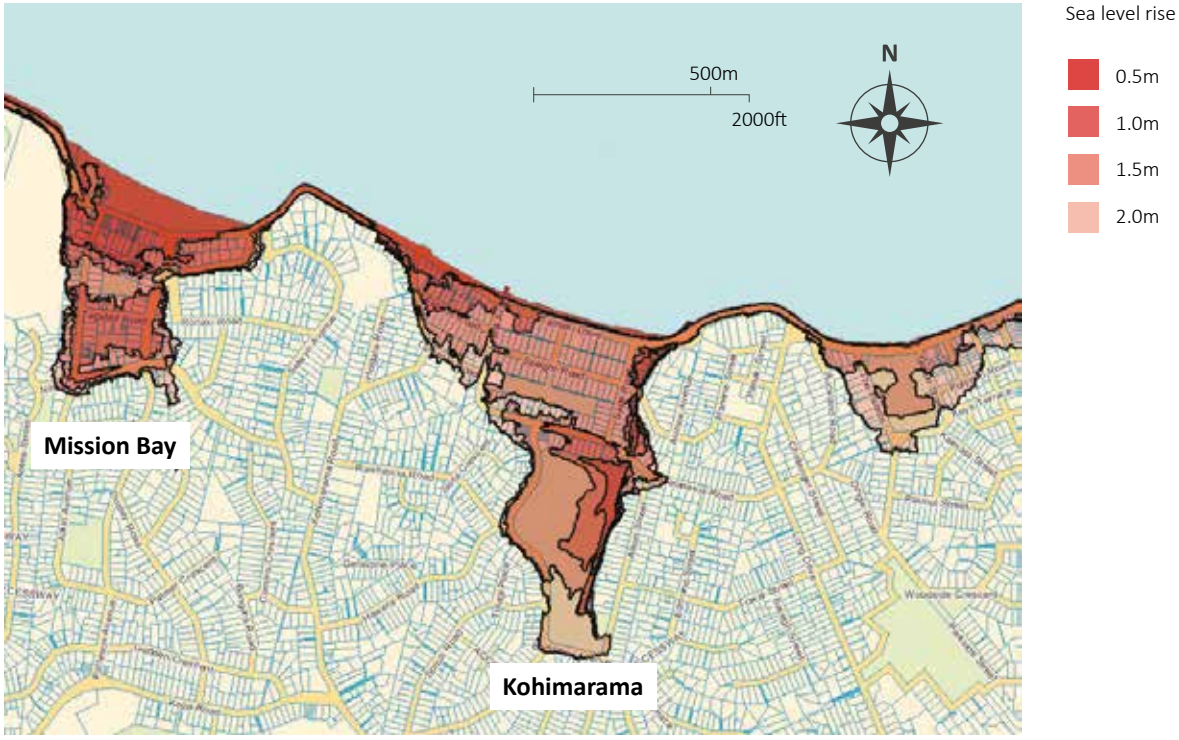
43 King D.N., Dalton W., Home M., Duncan M., Srinivasan MS., Bind J., Zammit C., McKerchar A., Ashford-Hosking D., and Skipper A. (2011). Māori community adaptation to climate variability and change: Examining risk, vulnerability and adaptive strategies with Ngāti Huirapa at Arowhenua Pā, Te Umu Kaha (Temuka), New Zealand. NIWA Client Report: AKL2011-015. 133pp.

44 Coastal hazards and climate change: A guidance manual for local government in New Zealand" http://www.mfe.govt.nz/publications/climate-change/coastal-hazards-and-climate-change-guidance-manual-local-government-ne-0.

45 Britton R., Dahm J., Rouse, H.L., Hume T.M., Bell R.G., and Blackett P. (2011). Coastal Adaptation to Climate Change: Pathways to Change. A report prepared as part of the Coastal Adaptation to Climate Change project, for MSI contract C01X0802.

46 Councils are required to provide up-to-date information on properties within their districts either using the LIM or the district plan. Such information includes characteristics of the land including potential erosion, avulsion, falling debris, subsidence, slippage, alluvion, or inundation (Local Government Official Information and Meetings Act 1987-s44A(2)(a)).

Figure 9: Inundation extent in a highly populated Auckland area for a 1-in-100 extreme sea level event, for different amounts of sea level rise.



Source: Reisinger et al. 2015[47].

47 Reisinger A., Lawrence J., Hart G., and Chapman R. (2015). From coping to resilience: the role of managed retreat in highly developed coastal regions. In 'Climate Change and the Coast: Building Resilient Communities.' (Eds Glavovic B., Kaye R., Kelly M., & Travers A.) (Taylor and Francis: London).

Key knowledge gaps

- Improved probabilistic methods of estimating joint hazard risks (such as storm surge and sea-level rise or additive coastal and fluvial flood drivers).
- Improved integration of information from scientists, policy analysts, and decision-makers on assessing, planning and responding to sea level rise issues.
- On-going analysis of the comparative climate change risks facing different coastal communities (e.g. Māori) around New Zealand.
- How to engage with the most vulnerable populations within coastal communities, and how to build capacity to use scientific knowledge for adaptation.

Learn more

For more information on coastal changes:

- For a simple introduction to sea-level rise science, see the Parliamentary Commissioner for the Environment's *Changing climate and rising seas: understanding the science*. http://www.pce.parliament.nz/media/1258/changing-climate-and-rising-seas-web.pdf.
- For an overview of coastal adaptation issues and options for Aotearoa-New Zealand, see Rouse et al.'s *Coastal adaptation to climate change in Aotearoa-New Zealand*. https://www.niwa.co.nz/sites/default/files/niwa_report_akl2012-029_0.pdf.
- For guidance to help local government to manage coastal climate change risks, see the Ministry for the Environment's *Coastal Hazards and Climate Change. A Guidance Manual for Local Government in New Zealand* (2nd edition) and *Preparing for coastal change: A guide for local government in New Zealand*. http://www.mfe.govt.nz/climate-change/climate-change-resources/guidance-local-government.
- For guidance to help councils and communities to develop adaptation plans, see Britton et al.'s *Pathways to Change*. https://www.niwa.co.nz/sites/default/files/pathways_to_change_nov2011.pdf.
- For information on current levels of coastal sea level rise in New Zealand, see Statistics New Zealand's *Environmental indicators Te Taiao Aotearoa* web pages: http://www.stats.govt.nz/browse_for_stats/environment/environmental-reporting-series/environmental-indicators/Home/Marine/coastal-sea-level-rise.aspx.

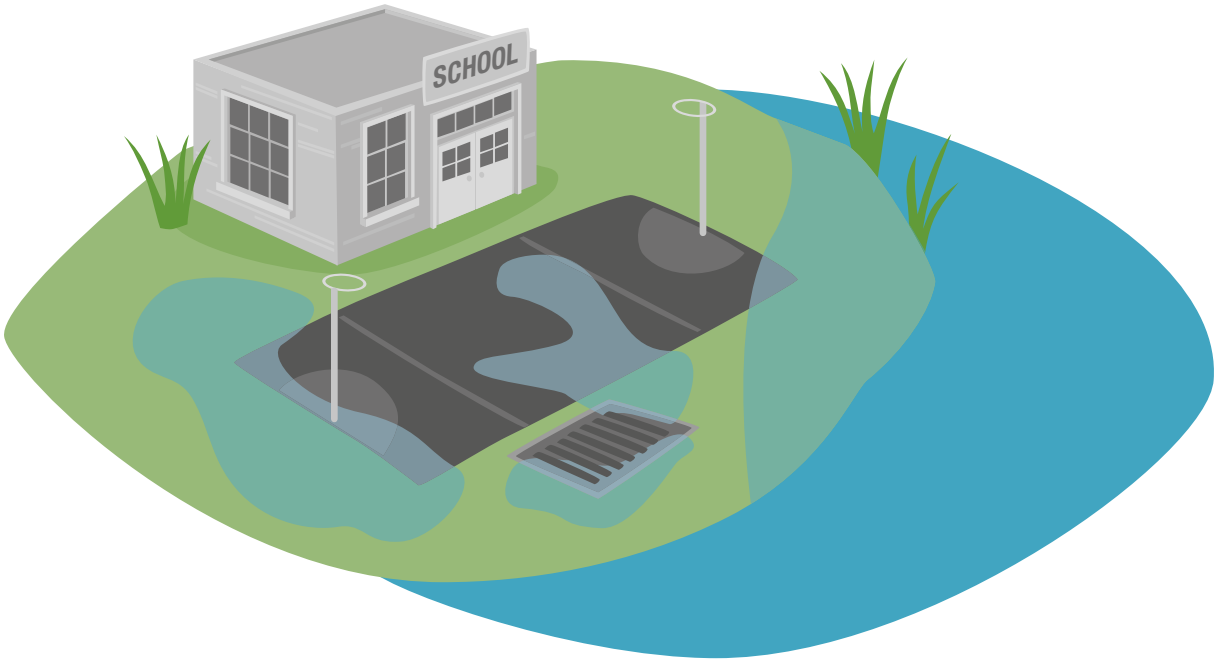
Flooding: many New Zealanders live on floodplains

Damaging flood events will occur more often and will affect rural and urban areas differently. At and near the coast, floods will interact with rising sea levels and storm surges. Increasing frequency and severity of high intensity rainfall events will increase these risks.

What climate trends will affect surface flooding events?

Floods are triggered by periods of prolonged or intense rainfall, which can also cause sediment and debris to wash into rivers, or saturate sloping ground, causing landslides. The key driver of surface flooding is extreme rainfall[48] but an important factor is saturation of the ground by preceding rain, which will make run-off and river flooding more likely. In urban settings intense rain storms create overland flow beyond the capacity of storm water systems thus creating widespread impacts to property and assets.

48 Councils are required to provide up-to-date information on properties within their districts either using the LIM or the district plan. Such information includes characteristics of the land including potential erosion, avulsion, falling debris, subsidence, slippage, alluvion, or inundation (Local Government Official Information and Meetings Act 1987- s44A(2)(a)).



What is already happening?

Flooding is the most frequent natural disaster in New Zealand and the second most costly one after earthquakes. About two-thirds of New Zealand's population lives in areas prone to flooding[49]. There is already observational evidence of an increase in the number of days with high intensity rainfall events in some western parts of South Island over the period 1930 to 2004. Some recent flooding events have been partly attributed to climate change, e.g. the very intense rainfall in Golden Bay in 2011[50]. However, research has found that flood statistics do not show an increase in floods through time so far, across New Zealand as a whole, but that increased flood losses are due to increased development in flood prone areas[51]. New Zealand has a relatively short river level record which means that even though there is a legislated expectation that buildings should not be exposed to flooding for more than in a 1-in-50 year event, it is difficult to project the likelihood of such rare and extreme flood events.

What might the future hold?

In a high carbon world, we can expect increased extreme precipitation events (both the frequency and amount of rainfall) in many regions[52]. Increases in extreme rainfall are likely, especially in places where average rainfall is expected to increase[53]. Wetter weather can saturate the ground, changing the underlying conditions so that floods occur more often. There may be changes to the intensity and occurrence of tropical cyclones, some of which transform into intense extra-tropical lows that bring heavy rainfall to New Zealand. Events which currently have return periods of 1-in-100 years are likely to become considerably more frequent. For example, Figure 10 shows estimated changes in return periods of floods in the Hutt River. The current flood risk management plan for the Hutt River aims to increase existing flood protection levels to the central city area over the next 30 years to a design flood of 2300 m^3/s[54].

49 Rouse H.L. (2012). Flood risk management research in New Zealand: Where are we, and where are we going? GNS Science Report, 2012/04.

50 See footnote 49.

51 Smart G.M. & McKerchar A.I. (2010). More flood disasters in New Zealand. Journal of Hydrology (NZ) 49(2): 69–78.

52 Gluckman P.D. (2013) New Zealand's changing climate and oceans: The impact of human activity and implications for the future. An assessment of the current state of scientific knowledge. Publication of the Prime Minister's Science Advisory Committee, Wellington, New Zealand.

53 See footnote 52.

54 Wellington Regional Council (2001). Hutt River Floodplain Management Plan: For the Hutt River and its Environment. Wellington: Wellington Regional Council.

For this flood volume, the current estimated Annual Exceedance Probability of a 1-in-440 year event would increase to around a 1-in-100 year event by the end of the century in a low carbon world, and closer to a 1-in-50 year event in a high carbon world[55].

Another direct effect of climate change on potential flooding is through sea-level rise, which will increase base levels for coastal river reaches. As outlined in the coastal section above, coastal flooding is also more likely to occur in the future, which, combined with river flooding, will increase the size and frequency of floods at coastal river mouths.

What are the implications?

The incidence of a major flood occurs, on average, every eight months[56] and comes at a significant cost. For example, the estimated costs of the damaging 2004 floods were $380 million 2006 dollars[57, 58]. The impacts are economic, social and cultural, affecting communities living in floodplain areas and the councils that service them. For example, local government manages 'more than $100 billion of community assets'[59]. In addition, there are environmental effects such as soil and channel erosion and modification of in-stream habitats for aquatic life.

The implications will, however, vary widely across different regions, communities, organisations and groups. In upper catchment areas, where flooding-induced soil erosion occurs, there are significant secondary risks to land-based primary sector productivity. In steep catchments, floods can also erode and carry sediment and debris adversely impacting structures (such as bridge piles) and land assets downstream. The most common risk, however, is inundation of low-lying areas in the lower catchment. Water inundation can damage buildings and property, especially when it ponds for several days, flooding arable or pasture areas; in urban areas infrastructure such as housing, transport, energy, storm-water and wastewater systems, telecommunications, and public facilities can be disrupted and the combination of effects can pose significant challenges to emergency services, including risks to life and health. There are also flow-on effects of resulting disruption to economic activity and access to domestic and international markets, when arterial roads are blocked for significant periods of time, for example, the Manawatu Gorge, Arthurs Pass, and the Kaikoura coast road which have all in recent times been closed following storm events.

It is highly likely that changing flood risks will exacerbate many existing vulnerabilities of different regions, communities, organisations and groups across New Zealand[60]. Floods often pose a risk for long-lived infrastructure such as established urban areas, public buildings and roads, features of the built landscape that have proven difficult to upgrade retrospectively due to statutory and practice limitations and private interests in land[61]. As the climate changes, other pressures such as population growth and pressure for land use intensification will come into play, creating expectations of ongoing protection and increasing the risk profile because of locked-in assets, commonly known as the 'levee effect'[62]. To manage such risks and their changes over time, traditional engineering solutions such as stop-banks and revetments, and static planning measures such as land-use zoning, will need to be re-examined and more flexible measures that can respond to change will need to be designed. Furthermore, strong social-cultural networks and designing ways of tapping into them through adaptive governance arrangements[63] will be vital for achieving sustainable solutions and on-going risk management.

55 Lawrence J., Reisinger A., Mullan B. and Jackson B. (2013) Exploring climate change uncertainties to support adaptive management of changing flood-risk. Environmental Science & Policy 33, 133–142.

56 Ministry for the Environment (2009). Preparing for coastal change: A guide for local government in New Zealand.

57 Department of the Prime Minister and Cabinet New Zealand (2007). National Hazardscape Report. Wellington: Officials' Committee for Domestic and External Security Coordination.

58 Insurance Council of New Zealand (2012). Cost of Disaster Events. Claims History, from http://www.icnz.org.nz/current/weather/index.php.

59 New Zealand Office of the Auditor-General (2014). Water and Roads: Funding and management challenges. Wellington, New Zealand.

60 King D.N., Penny G. and Severne C. (2010). The climate change matrix facing Māori society. In: Climate change adaptation in New Zealand: Future scenarios and some sectoral perspectives. Nottage R.A.C., Wratt D.S., Bornman J.F. and Jones K. (Eds). New Zealand Climate Change Centre. Pp 100–111.

61 Lawrence J., Sullivan F., Lash A., Ide G., Cameron C., and McGlinchey L. (2013). Adapting to changing climate risk by local government in New Zealand: institutional practice barriers and enablers. Local Environment, 1–23. doi: 10.1080/13549839.2013.839643.

62 Tobin G. A. (1995). The levee love affair: A stormy relationship Journal of the American Water Resources Association, 31(3), 359–367.

63 Glavovic B. C. & Smith G. E. (2014). Adapting to Climate Change: Lessons from natural hazards planning. Dordrecht: Springer.

Key knowledge gaps

- Improved elevation information about river beds, floodplains and urban areas to inform flood inundation modelling.
- Improved 'damage' curves to calculate effects of inundation.
- Further understanding required of how Matauranga Māori informs flood management and catchment planning.
- Joint probabilistic methods to improve understanding of combined fluvial and coastal flooding.
- Improved operational flood forecasting to help manage flood events.

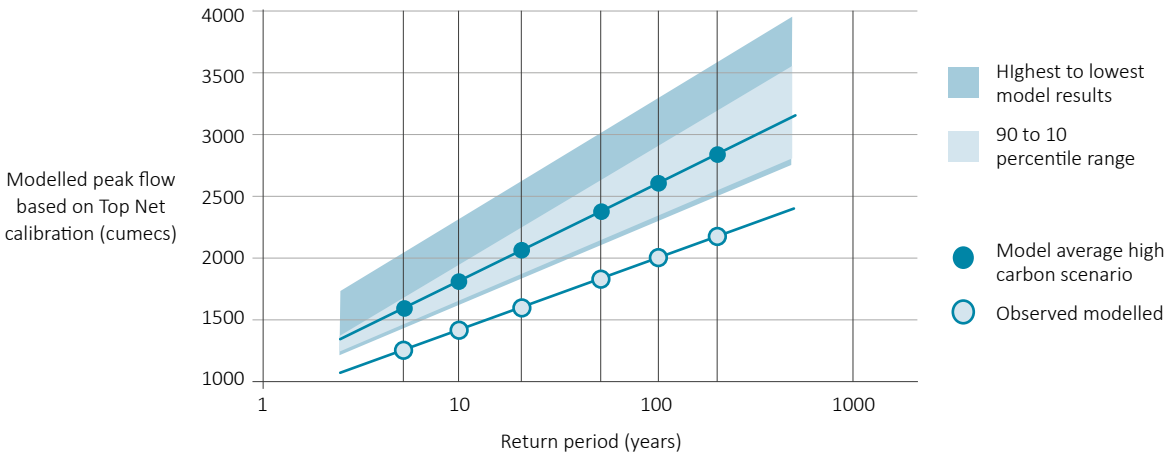
Learn more

For more information on inland surface flooding, see:

- For guidance to help local government to manage coastal climate change risks, see the Ministry for the Environment's *Tools for estimating the effects of climate change on flood flow: A guidance manual for local government in New Zealand*, and *Preparing for future flooding: a guide for local government in New Zealand*. http://www.mfe.govt.nz/publications/rma/tools-estimating-effects-climate-change-flood-flow-guidance-manual-local-government.
- New Zealand has a flood management standard to ensure best practice when considering flood risk: NZS 9401:2008 Managing flood risk - A Process Standard.
- For general guidance on floodplain management see *Floodplain Management Planning Guidelines: current thinking and practice in New Zealand. (2001)* Opus Consulting in conjunction with the Sustainable Management Fund, Ministry for the Environment, Wellington.
- For information on trends in sustained rain events in New Zealand, see Statistics New Zealand's Environmental indicators Te Taiao Aotearoa web pages: http://www.stats.govt.nz/browse_for_stats/environment/environmental-reporting-series/environmental-indicators/Home/Atmosphere-and-climate/three-day-rain.aspx.

Figure 10: 100-year changes in flood frequency for the Hutt River, for a high-carbon future.

The blue line and outlined circles show estimated peak river flows for a range of return periods in the present climate.
The blue line and filled circles show estimated values for the late 21st century.



Source: Lawrence et al. 2013[64].

64 Lawrence J., Reisinger A., Mullan B., & Jackson B. (2013). Exploring climate change uncertainties to support adaptive management of changing flood-risk. Environmental Science & Policy, 33(0), 133–142. doi: http://dx.doi.org/10.1016/j.envsci.2013.05.008.

Freshwater resources: New Zealanders rely on the availability of freshwater

Increased pressure on water resources is almost certain in future. Decreasing annual average rainfall in eastern and northern regions of both main islands, plus higher temperatures, are projected to increase the frequency and intensity of droughts and the risk of wild fire. At the same time, urban expansion and increased demand for water from agriculture will result in increased competition for freshwater resources.

What climate trends will affect the availability of freshwater resources?

Freshwater is a key driver for New Zealand's economy, including urban water supply, energy generation, pasture and crop production, viticulture, horticulture and tourism. Freshwater also is critical to our national and cultural identity, and our unique ecosystems.

Annual average rainfall is expected to decrease in the northeast of the South Island and north and east of the North Island, and increase in many other parts of New Zealand[65]. The areas where decreasing rainfall is expected tend to be already dry. Rising average temperatures will compound drying trends by increasing evapotranspiration, resulting in reduced soil moisture and increasing water demand even where rainfall remains the same. This is projected to increase the frequency and intensity of droughts in already dry regions and increase the risk of wild fire. Increased competition is expected over how to use freshwater resources for economic, social and environmental purposes.

In some areas, particularly the east of the South Island, changes in river run-off will depend significantly on whether rivers have their headwaters in the Southern Alps (which would see increased supply from increased precipitation and increased snow melt, resulting in an average increase by 5–10% by 2040) or to the east of the Southern Alps main divide. In the latter case, reductions in summer run-off (when demand for agricultural irrigation is greatest) are expected along with increases in winter from increased snow melt, at least over the next several decades[66].

65 Reisinger A., Kitching R.L., Chiew F., Hughes L., Newton P.C.D., Schuster S.S., Tait A., & Whetton P. (2014). Australasia. In: Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part B: Regional Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Barros V.R., Field C.B., Dokken D.J., Mastrandrea M.D., Mach K.J., Bilir T.E., Chatterjee M., Ebi K.L., Estrada Y.O., Genova R.C., Girma B., Kissel E.S., Levy A.N., MacCracken S., Mastrandrea P.R., & White L.L. (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA,. https://ipcc-wg2.gov/AR5/report/- Chapter 25, Australasia.

66 Ministry for Primary Industries (2013). Four degrees of global warming: Effects on the New Zealand primary sector. MPI Technical Information Paper 2013/49.

What is already happening?

The use of freshwater is a highly contested issue in New Zealand, in terms of both quantity and quality. There is competition over use of water for safe urban supply, storage dams and irrigation, hydropower schemes, native ecosystem maintenance, and cultural and recreational purposes. Negative impacts on water quality of nitrate leaching associated with livestock farming, and increased sediment loading where trees are harvested for timber or to make way for new land uses, are also cause for concern. Rainfall run-off into many New Zealand rivers reflects natural variations in precipitation patterns such as El Niño/La Niña and the Interdecadal Pacific Oscillation, with significant increases and decreases of average flows[67]. Due to strong natural variability and changing land use patterns, it has not yet been possible to clearly attribute any changes in river run-off to a changing climate. However, well-known links between precipitation and river run-off imply that future changes in rainfall patterns will clearly affect freshwater availability in New Zealand's major rivers.

What might the future hold?

Many of the factors that already contribute to tensions over the use of freshwater will be affected by a changing climate. Rising temperatures and reduced annual average rainfall will contribute to growth in demand for water for agriculture, along with increasing reliance on irrigation for agricultural production and rising interest in enhanced water storage to buffer agricultural production against the impacts of droughts and dry summers. The frequency and severity of major droughts is expected to increase in many parts of New Zealand, including some that are not currently known to be drought prone (Figure 11). This will increase the pressure to develop additional water storage options, which has implications for minimum environmental flows (i.e. water left in the river to protect ecosystem health) and water allocation during dry periods and downstream effects from nitrate leaching from livestock production. There are also indications that irrigation regimes can affect soil carbon storage[68].

The effects of changing hydrological regimes on drinking water availability are likely to seriously affect those places and populations where reticulated supply systems are poorly developed (or non-existent), and where there are inadequate resources to import water or pay for private treatment facilities. Understanding these socio-economic contexts, and their changes over time, will be critical to reducing future risks. The effect of the changing climate on the use of water by plants and vegetation is still uncertain, particularly because it is not yet clear to what extent rising CO_2 concentrations will have on plants' ability to use available water. Studies indicate that plants tend to lose less water through their leaves when CO_2 concentrations are higher, but the magnitude of this effect is highly uncertain and may depend on other factors in addition to CO_2, such as the age and species composition of plant communities, soils, and general climate conditions. At one extreme, increased water use efficiency could compensate for much but not all of the increased evaporation losses and decreased rainfall in some regions, while at the other extreme, the effect from increased CO_2 concentrations may be very small.

67 McKerchar A.I. & Henderson R.D. (2003). Shifts in flood and low-flow regimes in New Zealand due to interdecadal climate variations. Hydrological Sciences Journal 48(4): 637-654.

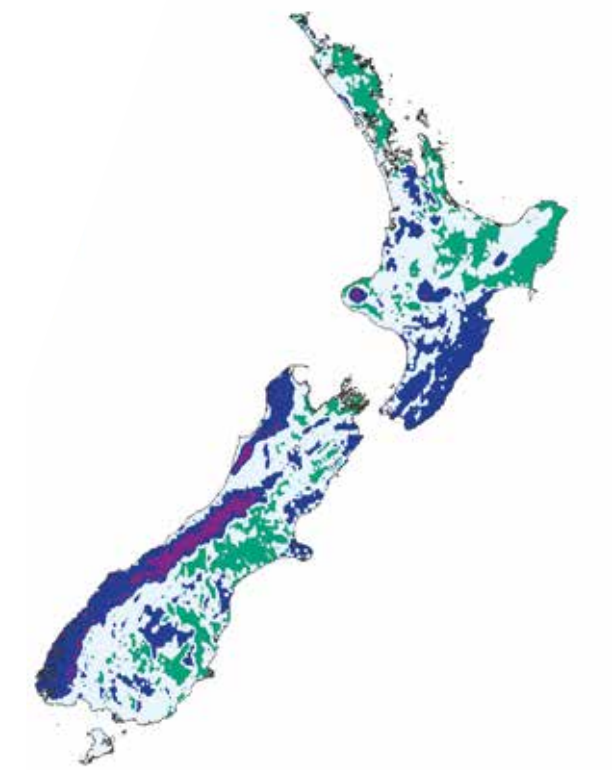
68 New Zealand Agricultural Greenhouse Gas Research Centre (NZAGRC) (2015). Fact Sheet: Soil Carbon. http://www.nzagrc.org.nz/user/file/881/Factsheet3_Soil%20Carbon.pdf.

Figure 11: Projected changes in drought frequency across New Zealand under a climate change scenario midway between low- and high-carbon futures.

The maps show the average percentage of time that a location is in drought, historically (right map) and projected for 2040 (left map). The frequency of droughts is projected to double in some regions such as Canterbury and parts of Otago, which currently are (on average) in drought less than 10% of a year, but this could rise to more than 20% of a year by the 2040.

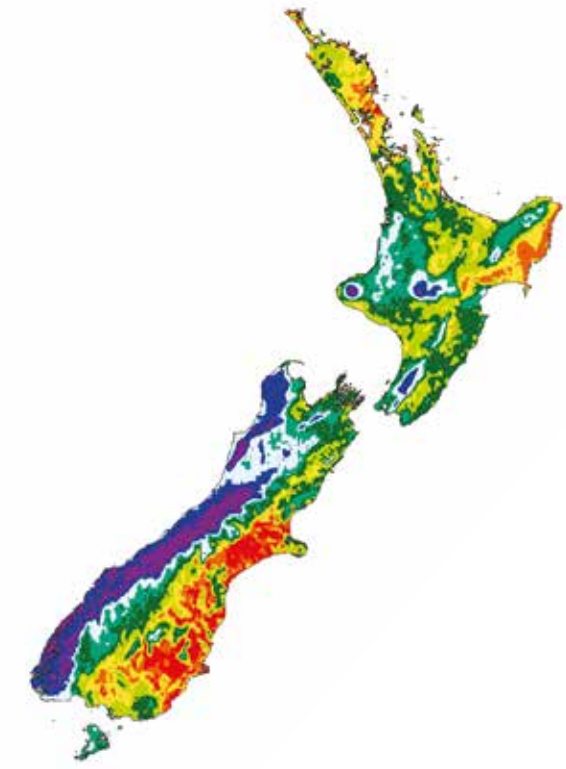
New Zealand historical drought frequency

or 1980–1990

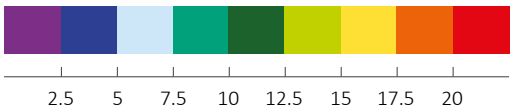


New Zealand median drought frequency

or 2030–2050



% of time



Note: The changes are based on a mid-range scenario of climate change and global greenhouse gas emissions.

Source: Clark et al. 2011[69].

69 Clark A., Mullan A.B., and Porteous A. (2011). Scenarios of regional drought under climate change. NIWA Client Report WLG2010-32 for Ministry of Agriculture and Forestry. 135 pp.

What are the implications?

The most significant challenges for freshwater management in New Zealand under a changing climate are likely to come from the co-evolving changes in demand for water and land-uses that use water and increase pressure on water quality. New Zealand society will need to balance competing demands for economic gains, to sustain other societal and cultural goals and values, and to maintain its freshwater ecosystems (including at-risk native freshwater fauna[70]). There is also a strong overlap in drought risk areas with rural Māori populations, and communities which are dependent on non-reticulated systems for their fresh water[71]. Any widespread creation of new forests to store carbon could have significant co-benefits by reducing soil erosion and providing forest habitats, at least temporarily in the case of plantation forest, but this could result in additional water use, sediment supply at harvest and consequent reductions in freshwater availability and quality for other uses.

Agriculture, as one of New Zealand's biggest export earners, is critically dependent on freshwater for irrigation or reliable rainfall. A large number of studies have explored the implications and response options for agriculture to a changing climate, which include not only freshwater issues but also changes in pasture and crop productivity from rising temperature and CO_2, reduction of winter chilling for some fruits, and changing pests, diseases, and efficacy of biological pest control agents. Some of those changes can pose severe challenges for some regions and production systems, and may require transformational changes in land and farm management. At a national scale though, existing studies indicate only moderate productivity changes of a few percent.

However, it is unclear to what extent this reflects an inherent resilience of New Zealand's agriculture system or simply the fact that existing studies have insufficiently explored the full range of potential future changes resulting from simultaneous changes in climate (including variability and seasonality), CO_2, pests and diseases along with the changing social fabric of rural communities, societal attitudes to water and landscape management, and changing global markets.

Urban water supply comes with a different set of implications. Water supply and demand management will be needed, but societal and cultural values regarding water recycling and pricing, for example, make the management of alternative water supply and distribution for use in human settlements highly challenging. Experience from Australia suggests that large reductions in water consumption per capita are possible in urban areas given the right incentives (of the order of 40–50%[72]).

70 Department of Conservation (2014). Conservation status of New Zealand freshwater fish, 2013. http://www.doc.govt.nz/Documents/science-and-technical/nztcs7entire.pdf.

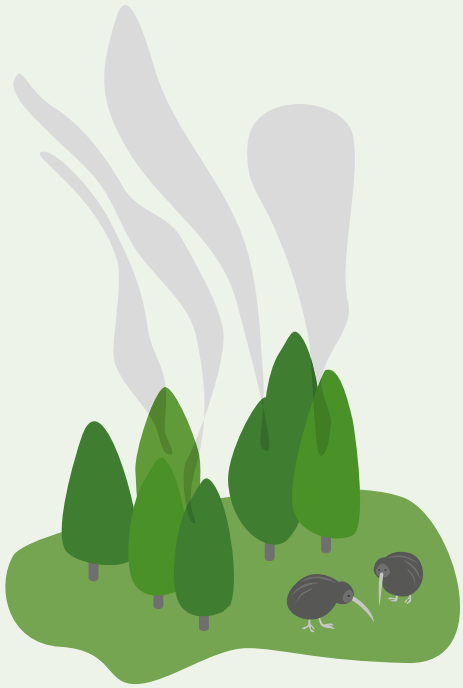
71 King D., Penny G. & Severne C. (2010). The climate change matrix facing Māori society. In: Climate change adaptation in New Zealand: Future scenarios and some sectoral perspectives. Nottage R.A.C., Wratt D.S., Bornman J.F. & Jones K. (eds). New Zealand Climate Change Centre, Wellington, pp 100–111.

72 Reisinger A., Kitching R.L., Chiew F., Hughes L., Newton P.C.D., Schuster S.S., Tait A., & Whetton P. (2014). Australasia. In: Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part B: Regional Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Barros V.R., Field C.B., Dokken D.J., Mastrandrea M.D., Mach K.J., Bilir T.E., Chatterjee M., Ebi K.L., Estrada Y.O., Genova R.C., Girma B., Kissel E.S., Levy A.N., MacCracken S., Mastrandrea P.R., & White L.L. (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA. https://ipcc-wg2.gov/AR5/report/- Chapter 25, Australasia.

Fire Risk

Changes in temperature, rainfall, windiness, and humidity have an impact on wild fire risk, with implications for infrastructure, recreation, forest fire resource planning, and the protection of important ecosystems and species. Changing fire danger comes as a result of the changing climate (rainfall and temperature) and its effects upon soil moisture and fuel (e.g. the amount of litter on the forest floor and how dry this becomes).

Climate change is expected to increase seasonal fire severity (Figure 12) and the number of days with very high and extreme fire weather, with greater changes in the east and north of the country. Fire season length will be extended in many already high-risk areas and higher CO_2 may enhance fuel loads by increasing vegetation productivity in some regions[73]. Climate change and fire will affect vegetation and biodiversity in many ways.



Most New Zealand native ecosystems have limited exposure, but also limited adaptation to fire. It is likely that increased fire incidence will increase risk, especially in parts of New Zealand where urban margins expand into rural areas, and increased exposure to fire smoke could in some situations exacerbate respiratory conditions such as asthma. It will also increase economic risks to plantation forestry and other productive land uses. Forest regeneration following wildfires also reduces water yields and reduced vegetation cover increases erosion risk and has implications for water quality. While improved understanding of climate drivers of fire risk is assisting fire managers and communities in New Zealand, changes in management to date show limited evidence of being driven by climate change[74].

73 Watt M.S., Kirschbaum M.U.F., Meason D., Jovner A., Pearce H.G., Moore J.R., Nicholson I., Bulman L., Rolando C., Palmer D.J., Harrison D., Hock B.K., Tait A., Ausseil A.E., and Schuler J. (2012). Future forest systems. Scion, Rotorua. Scion Client Report (MAF SLMACC) No. 19141. 155 p.

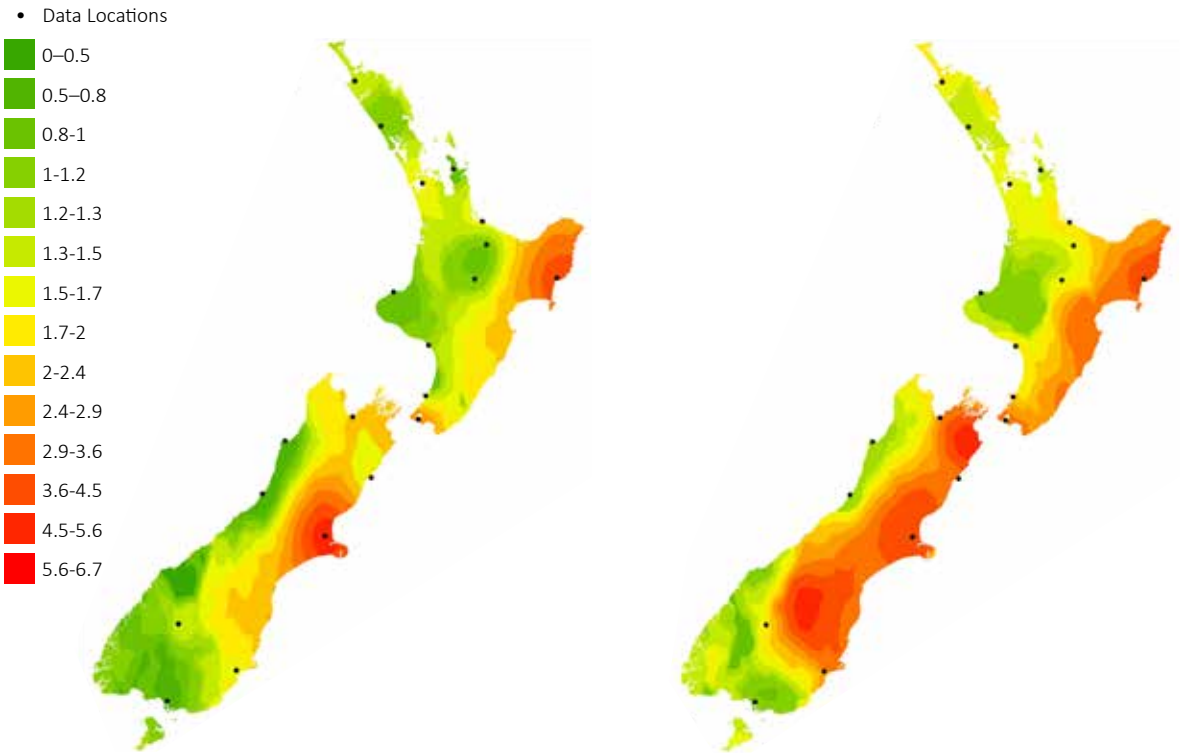
74 Reisinger A., Kitching R.L., Chiew F., Hughes L., Newton P.C.D., Schuster S.S., Tait A., & Whetton P. (2014). Australasia. In: Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part B: Regional Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Barros V.R., Field C.B., Dokken D.J., Mastrandrea M.D., Mach K.J., Bilir T.E., Chatterjee M., Ebi K.L., Estrada Y.O., Genova R.C., Girma B., Kissel E.S., Levy A.N., MacCracken S., Mastrandrea P.R., & White L.L. (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA,. https://ipcc-wg2.gov/AR5/report/- Chapter 25, Australasia.

Figure 12: Changes in seasonal fire severity for a medium emissions scenario, midway between low- and high-carbon futures.

Actual (1980–1999) VH+E Forest Fire Danger (fire season months)

Projected VH+E Forest Fire Danger (fire season months)

2090: 16 Model Average



Source: Pearce et al. 2011[75].

75 Pearce H.G., Kerr J., Clark A., Mullan B., Ackerley D., Carey-Smith T., and Yang E. (2011). Improved Estimates of the Effect of Climate Change on NZ Fire Danger. MAF Technical Paper No. 2011/13, Ministry of Agriculture and Forestry, Wellington, New Zealand, 84 pp.

Key knowledge gaps

- Scenario analysis that takes climate variability and extremes into account, especially for the high carbon world; changes in natural climate patterns (El Niño etc) that alter occurrence of extremes.
- Integrated understanding for the agriculture sector of interactions between climate and water availability, and implications of climate change for pests and diseases.
- The effect of CO_2 levels on how well plants are able to use water.
- Integrated land-use models to assist climate-smart landscape planning, to inform economically, socially and environmentally useful choices between different agricultural production systems, forestry, horticulture, and other forms of land-use, taking climate variability and change, changes in water availability and demand (and how this is allocated to users), and carbon prices into account. Link with nitrate leaching and water quality objectives.
- Build climate change scenarios (including carbon prices) into existing activities such as the Land and Water Forum and the National Science Challenge 'Our land and water'.
- Further understanding required of how Matauranga Māori informs assessments of the changing 'state' of freshwater resources.

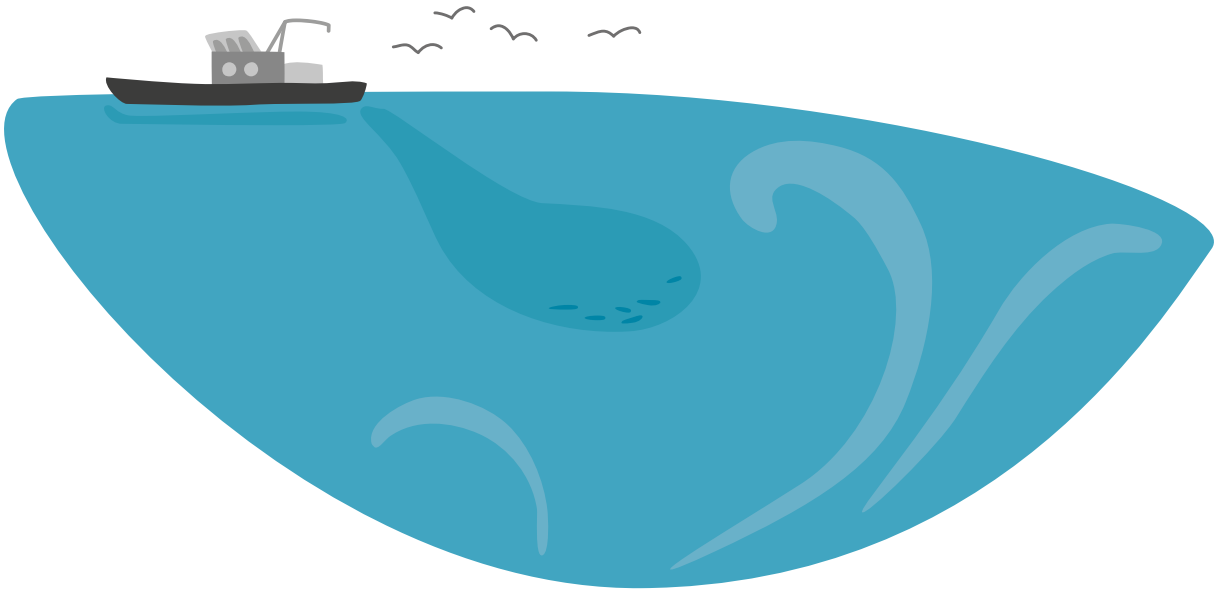
Learn more

For more information on freshwater resources in the context of climate change:

- NIWA's Climate change freshwater impacts assessments. https://www.niwa.co.nz/freshwater-and-estuaries/our-services/climate-change-freshwater-impacts-assessments.
- The National Policy Statement for Freshwater Management 2014 (NPS-FM 2014). http://www.mfe.govt.nz/sites/default/files/media/Fresh%20water/nps-freshwater-management-jul-14.pdf.
- Ministry for the Environment web page on *Climate change impacts in New Zealand*. http://www.mfe.govt.nz/climate-change/how-climate-change-affects-nz/climate-change-impacts.
- Ministry for Primary Industries Research Reports on the Impacts of and Adapting to Climate Change. http://archive.mpi.govt.nz/environment-natural-resources/climate-change/research-and-funded-projects/research-and-funded-projects-table
- Scion and NIWA's *Impact of Climate Variability on Fire Danger* report. http://www.fire.org.nz/Research/Published-Reports/Documents/fc485a9561a60d31ba1317c67e075e05.pdf.
- For information on trends in soil moisture and drought in New Zealand, see Statistics New Zealand's *Environmental indicators Te Taiao Aotearoa* web pages: http://www.stats.govt.nz/browse_for_stats/environment/environmental-reporting-series/environmental-indicators/Home/Atmosphere-and-climate/soil-moisture-drought.aspx.

The ocean: New Zealand is surrounded by sea

Changes in ocean temperature, chemistry, and currents due to climate change will have impacts on New Zealand's marine life, fishing, aquaculture and recreation use.



What climate trends will affect the oceans around New Zealand?

The waters around New Zealand are warming as the overlying atmosphere warms, and changes in thermal stratification in the near-surface ocean are expected to lead to decreases in nutrients such as nitrate and phosphate in the surface ocean, where most marine organisms live[76].

Changes in ocean chemistry may also impact on many marine species. As the amount of CO_2 in the atmosphere increases, some of the CO_2 is absorbed by the earth's oceans. Once CO_2 enters the oceans, it reacts chemically with water to form acid, so lowering the pH. Changes in chemistry and temperature are expected to have a particularly strong effect on calcifiers, organisms that form carbonate shells (e.g. mussels, pāua, corals), and trends in temperature and nutrient patterns may lead to southward migration of many fish that normally live at lower latitudes into the waters around New Zealand[77].

76 Rickard G., Behrens E. and Chiswell S. (2015). CMIP5 Earth System Models with Biogeochemistry: An Assessment for the New Zealand Exclusive Economic Zone, submitted.

77 Molinos G.J, Halpern B.S., Schoeman D.S., Brown C.J., Kiessling W., Moore P.J., Pandolfi J.M., Poloczanska E.S., Richardson A.J. and Burrows M.T. (2015). Climate velocity and the future global redistribution of marine biodiversity, Nature Climate Change, doi:10.1038/nclimate2769

What is already happening?

Observations from a global network of floats show that the surface layer of the oceans (the top 700 m) warmed by 0.18°C between 1955 and 2010[78]. Regional transects through the Tasman Sea have shown warming throughout the upper 800 m of the water column in the 1990s, and the Western Tasman sea is warming at a rate four times the global average due to changes in the East Australian Current[79]. A fifteen-year time series of regular measurements off the coast of Dunedin shows that ocean acidification is already occurring in the waters around New Zealand, which is consistent with similar measurements from other sites around the world[80], and with increases in atmospheric CO_2 (Figure 13.)

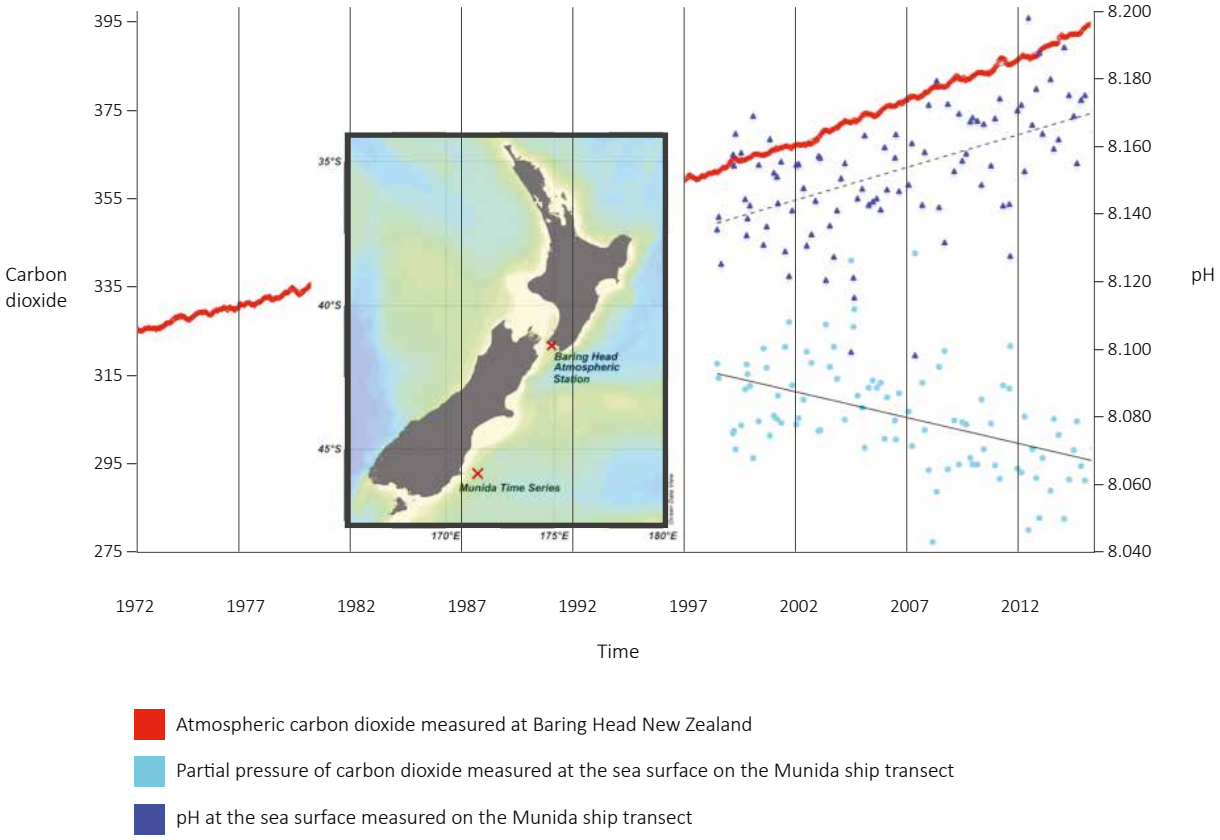
78 Levitus S., Antonov J. I., Boyer T. P., Baranova O. K., Garcia H. E., Locarnini R. A., Mishonov A. V., Reagan J. R., Seidov D., Yarosh E. S. & Zweng M. M. (2012). World ocean heat content and thermosteric sea level change (0–2000 m), 1955–2010, Geophys. Res. Lett., 39, L10603, DOI:10.1029/2012GL051106.

79 Ridgway K. R. (2007). Long-term trend and decadal variability of the southward penetration of the East Australian Current. Geophysical Research Letters 34, L13613.

80 Bates N., Astor Y., Church M., Currie K., Dore J., Gonaález-Dávila M., Lorenzoni L., Muller-Karger F., Olafsson J. and Santa-Casiano M. (2014). A Time-Series View of Changing Ocean Chemistry Due to Ocean Uptake of Anthropogenic CO_2 and Ocean Acidification. Oceanography, 27, (1), 126-141, doi:10.5670/oceanog.2014.

Figure 13: Changes in Carbon Dioxide and Ocean pH in New Zealand.

Observed atmospheric CO_2 leads to increased sea surface CO_2 (dark blue) and decreasing sea surface pH (light blue). In the inset map, colours indicate depth, shallower in the tan to light green regions and deeper in the blue regions.



Source: Brailsford et al. 2012[81].

81 Brailsford G. W., Stephens B. B., Gomez A. J., Riedel K., Mikaloff Fletcher S. E., Nichol S. E. and Manning M. R. (2012). Long-term continuous atmospheric CO_2 measurements at Baring Head, New Zealand, Atmos. Meas. Tech., 5, 3109-3117, doi:10.5194/amt-5-3109-2012.

The variability and rate of change in pH will differ in coastal waters as these are also influenced by terrestrial factors and run-off. In order to monitor the rate of acidification in New Zealand's coastline, 14 new coastal observing stations have recently been established, forming the New Zealand Ocean Acidification Observing Network (NZOA-ON).

At present, there is not sufficient data to determine if or how climate change has impacted marine life in the New Zealand region. However, ocean acidification has played a key role the collapse of oyster spat production at commercial hatcheries in the Pacific Northwest of the United States which experiences seasonal upwelling of deep, nutrient rich but acidic waters to the surface[82]. During the oyster larval stage, elevated acidity and reduced carbonate concentrations can cause mortality and slow growth of Pacific oysters[83].Upwelling events in 2007 and 2008 caused a near collapse of commercial oyster spat and, as a result, the industry and government have worked together to develop an adaptation strategy to address the problem. A network of pH sensors have been deployed to identify upwelling conditions, and the oyster hatcheries now use this data to identify safe times to intake water[84].

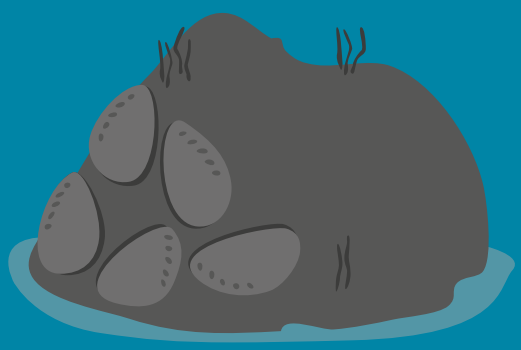
82 Feely R.A., Sabin E. C.L., Hernandez-Ayon J.M., Ianson D. and Hales B. (2008). Evidence for upwelling of corrosive "acidified" water onto the continental shelf. Science 320:1,490–1,492, http://dx.doi.org/10.1126/science.1155676.

83 Barton A., Hales B., Waldbusser G., Langdon C., and Feely R. (2012). The Pacific oyster, Crassostrea gigas, shows negative correlation to naturally elevated carbon dioxide levels: Implications for near-term ocean acidification impacts. Limnology and Oceanography 57, 698-710, doi:10.4319/lo.2012.57.3.0698.

84 Barton A., Waldbusser G.G., Feely R.A., Weisberg S.B., Newton J.A., Hales B., Cudd S., Eudeline B., Langdon C.J., Jefferds I., King T., Suhrbier A., and McLaughlin K. (2015). Impacts of coastal acidification on the Pacific Northwest shellfish industry and adaptation strategies implemented in response. Oceanography 28(2):146–159, http://dx.doi.org/10.5670/oceanog.2015.38.

Case Study: Pāua

Experimental work on the impacts of acidification in New Zealand waters on juvenile pāua has shown that pāua grow more slowly under acidic conditions and their shells show clear signs of being dissolved[85]. Similar effects were found for growth and shell surfaces of flat oysters. This is consistent with observed negative effects of ocean acidification on the function and metabolism of Antarctic bivalves[86, 87].



85 Cunningham S. C. (2013). The effects of ocean acidification on juvenile Haliotis iris (Thesis, Master of Science). University of Otago.

86 Bylenga C.H., Cummings V.J., and Ryan K.G. (2015). Fertilisation and larval development in an Antarctic bivalve, Laternula elliptica, under reduced pH and elevated temperatures Marine Ecology Progress Series, 536, 187-201, doi:10.3354/meps11436.

87 Cummings V. Hewitt J., Van Rooyen A., Currie. K., Beard S, Thrush S., Norkko J., Barr N., Heath P., Halliday N.J., Sedcole R., Gomez A., McGraw C., and Metcalf V. (2011). Ocean Acidification at High Latitudes: Potential Effects on Functioning of the Antarctic Bivalve Laternula elliptica, PLoS ONE 6(1): e16069. doi:10.1371/journal.pone.0016069.

What might the future hold?

In a high carbon world, the average pH in the waters around New Zealand is expected to decrease by 0.3 pH units (from 8.1 to 7.8) between 2005 and 2080–2100. Because pH units are on a logarithmic scale, this corresponds to a doubling of the concentration of hydrogen ions (H+) in the ocean. In a low carbon world, the pH is expected to decrease only by about 0.06 pH units by the middle of this century (a 15% increase in hydrogen ions compared with current levels), then gradually increase again through the remainder of the century. This result is one of the most robust features of the models used to predict climate change[88].

Climate change will also affect sea temperatures and currents (see Figure 14). Climate models suggest that the greatest sea surface warming for our region will occur in the waters to the west of New Zealand, which are projected to warm by over 3 degrees in a high carbon world or around 1 degree in a low carbon world. Waters to the east of New Zealand are likely to warm a little less, while waters to the south of New Zealand will warm more slowly[89].

What are the implications?

New Zealand has an Exclusive Economic Zone (EEZ) of 4 million square kilometres – the fourth largest in the world, with important fishing and shellfish aquaculture industries and natural marine biodiversity. Ocean warming, acidification, sedimentation and other anthropogenic stressors pose a risk to many ecologically and economically important species in the New Zealand region, including commercial and customary fisheries and deepwater coral reefs that form habitat for many marine species. Some species that presently live in lower latitude regions may migrate into New Zealand waters in response to rising temperatures and changing ecological community structures[90]. Models suggest primary production in coastal waters may be particularly vulnerable, due to additional stresses from terrestrial process, but some organisms in these waters may be less sensitive to changes as they are adapted to a wider range of natural variability. Māori ownership, management and utilisation of commercial and non-commercial fisheries in New Zealand is significant (approx. 40% of the national fisheries quota). The capacity of this sector to manage climate-related risks in the future will likely depend on the flexibility of the industry to modify their practices and investments, while simultaneously taking advantage of new opportunities. The ability of the natural marine ecosystems to adapt is largely unknown.

88 Rodgers K. B., Lin J., and Frölicher T.L. (2015). Emergence of multiple ocean ecosystem drivers in a large ensemble suite with an Earth System Model, Biogeosciences, 12, 3301–3320.

89 Rickard G., Behrens E. and Chiswell S. (2015). CMIP5 Earth System Models with Biogeochemistry: An Assessment for the New Zealand Exclusive Economic Zone, submitted.

90 Molinos G.J, Halpern B.S., Schoeman D.S., Brown C.J., Kiessling W., Moore P.J., Pandolfi J.M., Poloczanska E.S., Richardson A.J. and Burrows M.T. (2015). Climate velocity and the future global redistribution of marine biodiversity, Nature Climate Change, doi:10.1038/nclimate2769.

Lowering the pH of the water below a threshold creates conditions in which calcium carbonate, which makes up the exoskeleton of many marine organisms, will naturally dissolve. Therefore, species that form an external calcium carbonate shell, such as cold-water corals, pāua, kina, mussels, oysters, and some types of plankton, are particularly sensitive to ocean acidification. There is clear evidence that reductions in pH impair formation of larval shells in bivalve mollusc species[91], although no studies are specific to New Zealand species at present.

A new Ministry of Business, Innovation and Employment (MBIE) research project has been initiated to address these knowledge gaps and investigate potential effects on coastal ecosystems with a particular focus on greenshell mussels, pāua and snapper. International research suggests that fish may also be affected by ocean acidification[92], and new work is underway to characterise impacts on fish in the New Zealand region[93].

Case Study: Cold-water corals

A preliminary modelling study of future coral habitat regions suggests that while suitable habitat regions will shrink for many coral species in the New Zealand region in a high carbon world, the Chatham Rise is likely to remain a suitable coral habitat[94]. This region could therefore provide an opportunity to maintain some marine biodiversity in a high carbon world.

Cold-water corals support important ecosystems in regions such as the Chatham Rise. Most corals in the New Zealand region live in deep ocean regions that are saturated in aragonite, a form of calcium carbonate that they use to form their external skeletons. At present, the waters of the Southwest Pacific are generally saturated in aragonite to an average depth of about 1000 m. However, in a high carbon world, only the top 200 m of the Southwest Pacific will be saturated with respect to aragonite by the end of the century. Only a quarter or less of known coral habitats occur in this depth range[95].

91 Kroeker K. J., Kordas R. L., Crim R., Hendriks I. E., Ramajo L., Singh G. S., Duarte C. M. and Gattuso J.-P. (2013). Impacts of ocean acidification on marine organisms: quantifying sensitivities and interaction with warming. Glob Change Biol, 19: 1884–1896. doi:10.1111/gcb.12179; Waldbusser G.G., Voigt E.P., Bergschneider H., Green M.A., and Newell R.I.E. (2011). Biocalcification in the Eastern oyster (Crassotrea virginica) in relation to long-term trends in Chesapeake Bay pH. Estuaries and Coasts, 34, 221–231.

92 Munday P., Cheal A.J., Dixson D.L., Rummer J.L., and Fabricius K.E. (2014). Behavioural impairment in reef fishes caused by ocean acidification at CO_2 seeps, Nature Climate Change 4, 487–492 (2014) doi:10.1038/nclimate2195.

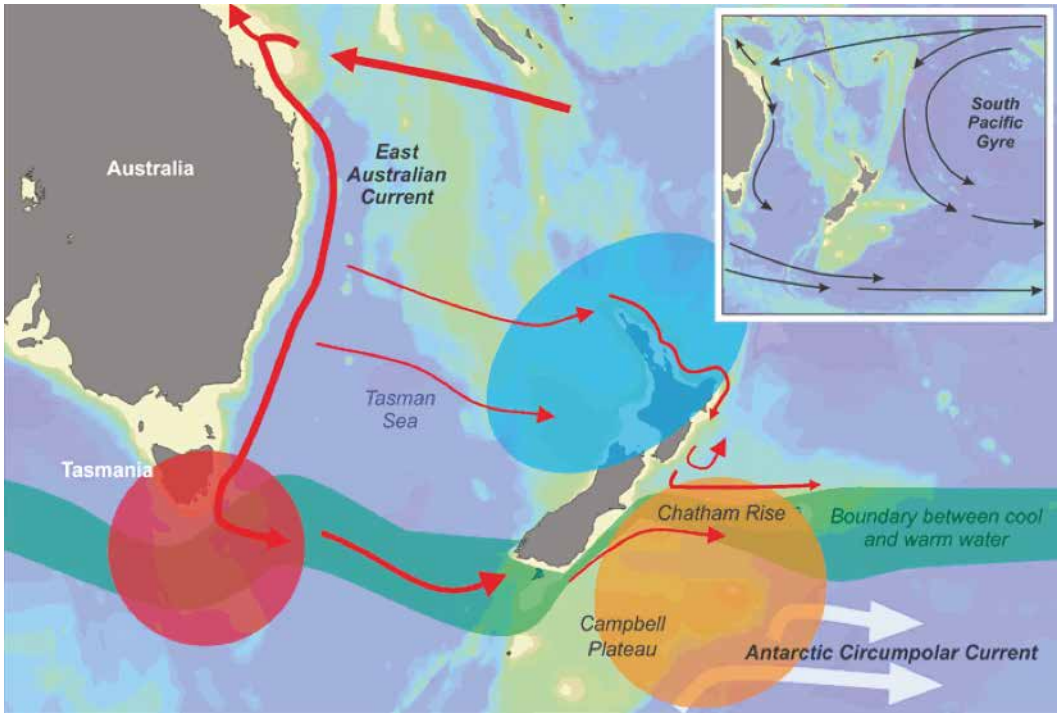
93 Renwick J.A., Hurst R.J., and Kidson J.W. (1998). Climatic influences on the recruitment of southern gemfish (Rexea solandri, Gempylidae) in New Zealand waters. International Journal of Climatology 18: 1655–1667; Beentjes M.P. & Renwick J.A. (2001). The relationship between red cod, Pseudophycis bachus, recruitment and environmental variables in New Zealand. Environmental Biology of Fishes 61: 315–328.; Dunn M., Hurst R., Renwick J., Francis C., Devine J., and McKenzie A. (2009). Fish abundance and climate trends in New Zealand. New Zealand Aquatic Environment and Biodiverstiy. Report No. 31.NIWA, Wellington.

94 Anderson O., Mikaloff Fletcher S.E., and Bostock H. (2015). Development of models for predicting future distributions of protected coral species in the New Zealand region. Client report for Marine Species and Threats, Department of Conservation, November 2015.

95 Resplandy L., Bopp L., Orr J. C. and Dunne J. P. (2013). Role of Mode and Intermediate waters in ocean acidification : analysis of CMIP5 models (2013). Geophysical Research Letters. doi: 10.1002/grl.50414; Cao L., Han Z., Meidi Z., and Shuangjing W. (2014), Response of ocean acidification to a gradual increase and decrease of atmospheric CO_2, Environmental Research Letters, 9(2014) 024012 doi:10.1088/1748-9326/9/2/024012.

Figure 14: Changing sea temperatures around New Zealand over the next 100 years.

Increased energy in the south Pacific Gyre (ocean current) will bring more warm equatorial seawater through the Tasman Sea and around New Zealand coast over the next 100 years. This will result in sea temperatures off the New Zealand coast, especially the South Island's east coast, rising by about 2°C over the next century. For the underlying map, colours indicate depth, shallower in the tan to light green regions and deeper in the blue regions.



Much warmer than today Warmer than today Cooler than today

Source: Cortese et al. 2013[96].

96 Cortese G., Dunbar G.B., Carter L., Scott G.H., Bostock H., Bowen M., Crundwell M.P., Hayward B.W., Howard W., Martinez J.I., Moy A., Neil H., Sabaa A. and Sturm A. (2013). Southwest Pacific Ocean response to a warmer world : insights from Marine Isotope Stage 5e. Paleoceanography, 28(3): 585-598; doi: 10.1002/palo.20052.

Key knowledge gaps

- How will changes in global ocean circulation interact with the complex sea bed around New Zealand, and what will that mean for temperature, nutrient supply, and biological productivity?
- How will marine organisms and ecosystems respond to the combined effects of multiple stressors (ocean acidification, nutrient supply, and temperature)?
- Little is known about how interactions within whole ecosystems and food webs will change, or whether organisms have the capacity to adapt to climate change.
- Impacts of human induced changes in temperature, nutrients, and ocean acidification in coastal zones on ocean flora and fauna are even more uncertain, due to the additional influence of runoff and the higher spatial and temporal variability in these regions. What range of conditions are organisms in these areas already adapted to, and how will they respond to future change?
- Options for mitigation and adaptation of the effects of climate change on marine ecosystems are limited to local actions, but research to date has been limited.
- Little consolidated knowledge of changes in the productivity of warm and cold water marine species that supply important commercial and non-commercial fisheries (i.e. Māori customary resources).

Learn more

For more information on ocean trends in the context of climate change:

- Recent Ocean Acidification research in New Zealand: http://www.otago.ac.nz/oceanacidification/index.html.
- Ocean acidification impacts: http://www.bioacid.de; http://www.niwa.co.nz/news/ocean-acidification-what-does-it-mean-for-shellfish.
- Ocean acidification and oyster hatcheries in the Pacific Northwest: http://www.sciencemag.org/content/337/6091/146.full?sid=ab745b18-873c-4c38-8e60-dd864bf649f7.
- Educational resources: http://sciencelearn.org.nz/Contexts/Life-in-the-Sea/Sci-Media/Video/Ocean-acidification; https://www.youtube.com/watch?v=cAwZ7VCYn44.
- For information on changes in ocean acidification around New Zealand, see Statistics New Zealand's *Environmental indicators Te Taiao Aotearoa* web pages: http://www.stats.govt.nz/browse_for_stats/environment/environmental-reporting-series/environmental-indicators/Home/Marine/ocean-acidification.aspx.

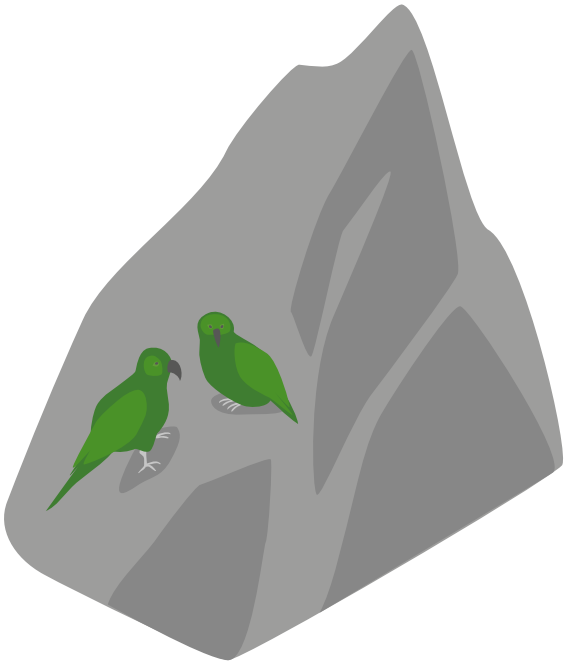
Ecosystem change: New Zealand has unique ecosystems

Over half of New Zealand's more then 50,000 species are found nowhere else in the world; over three quarters of the vascular plants, raising to 93% for alpine plants, and over 80% for the more than 20,000 invertebrates[97].

Existing environmental stresses will interact with, and in many cases be exacerbated by, shifts in mean climatic conditions and associated change in the frequency or intensity of extreme events, especially fire, drought, and floods[98].

97 Costello M.J., Coll M., Danovaro R., Halpin P., Ojaveer H. & Miloslavich P. (2010). A census of marine biodiversity knowledge, resources, and future challenges. PL0S ONE 5(8): 1–15; Gordon D.P. (2013). New Zealand's genetic diversity. In. Dymond J.R. (ed). Ecosystem Services in New Zealand – conditions and trends. Lincoln, New Zealand, Manaaki Whenua Press; New Zealand Inventory of Biodiversity, Volume one Kingdom Animalia, Radiata, Lophotrochozoa, Deuterostomia (2009). Ed Gordon D.P. Canterbury University Press; New Zealand Inventory of Biodiversity, Volume Two Kingdom Animalia, Chaetognatha, Ecdysozoa, Ichnofossils (2010). Ed Gordon D.P. Canterbury University Press; New Zealand Inventory of Biodiversity (2012). Volume Three, Kingdoms Bacteria, Protozoa, Chromista, Plantae, Fungi. Ed Gordon D.P. Canterbury University Press; Halloy S.R.P & Mark A.F. (2003). Climate-Change Effects on Alpine Plant Biodiversity: A New Zealand Perspective on Quantifying the Threat. Arctic, Antarctic, and Alpine Research, 35(2):248-254.

98 Reisinger A., Kitching R.L., Chiew F., Hughes L., Newton P.C.D., Schuster S.S., Tait A., & Whetton P. (2014). Australasia. In: Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part B: Regional Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Barros V.R., Field C.B., Dokken D.J., Mastrandrea M.D., Mach K.J., Bilir T.E., Chatterjee M., Ebi K.L., Estrada Y.O., Genova R.C., Girma B., Kissel E.S., Levy A.N., MacCracken S., Mastrandrea P.R., & White L.L. (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA,. https://ipcc-wg2.gov/AR5/report/- Chapter 25, Australasia.



What climate trends will affect New Zealand's ecosystems?

Climate, especially temperature and moisture availability, is the major determinant of which species are located where across the globe. Some ecosystems, like those in alpine and sub-alpine areas, will be more affected by increasing winter temperatures, snow cover and accumulation[99]. The inland basins, braided rivers and lakes of the eastern South Island will be more affected by the increase in time spent in drought (Figure 15).

In the short to medium term, the key drivers of ecosystem change will likely be the indirect effects of climate change[100]. The indirect effects of climate change on native ecosystems through introduced species and human agency include:

- Increased range and abundance of animal pests.
- New diseases and pathogens.
- Increased range and abundance of weeds.
- Increased fire risk.
- Increased water abstraction.
- Land use change.
- Increased renewable energy (hydroelectricity, biomass, wind and marine energy systems).
- Changing coastal development.

Alpine and sub-alpine ecosystems are likely to be affected by increasing temperature, in particular warmer winters, which globally are associated with rising treelines, although evidence suggests that treeline rise is variable and likely to be a delayed response[101]. The suitable habitat for alpine species will be reduced and fragmented as the suitable climate space moves upslope[102].

99 McGlone M. & Walker S. (2011). Potential effects of climate change on New Zealand's terrestrial biodiversity and policy recommendations for mitigation, adaptation and research. Science Conservation 2011.

100 McGlone M., Walker S., Hay R. and Christie J. (2010). Climate change, natural systems and their conservation in New Zealand. In: Climate change adaptation in New Zealand: Future scenarios and some sectoral perspectives. Nottage R.A.C., Wratt D.S., Bornman J.F. & Jones K. (eds). New Zealand Climate Change Centre, Wellington, pp 82–99.

101 Harsch M.A., Hulme P.E., McGlone M.S. and Duncan R.P (2009). Are treelines advancing? A global meta-analysis of treeline response to climate warming. Ecology Letters, 12(10): p. 1040–1049.

102 Halloy S.R.P. & Mark A.F. (2003). Climate-Change Effects on Alpine Plant Biodiversity: A New Zealand Perspective on Quantifying the Threat. Arctic, Antarctic, and Alpine Research, 35(2):248-254.

Figure 15: Schematic of the effects of climate change on ecosystems.

Inland basins, braided rivers and lake ecosystems are likely to be affected by the combination of increasing temperature, more frequent drought and more extreme hot days[103].

Forest ecosystems are likely to be affected by indirect interactions with introduced predators, herbivores and weed species.

Coastal ecosystems will be affected by rising sea levels combined with high rain events[104].

What is already happening?

Globally, species have shifted their distributions to higher elevations and latitudes during shifting in response to changing climate conditions[105]. There is also strong evidence that treelines are shifting upslope, particularly in less abrupt treelines in locations with strong winter warming[106].

In New Zealand, the direct effects of climate change on native ecosystems have been difficult to establish. This has been a result of:

- The paucity of baseline and historical data make detecting a change difficult.
- New Zealand's oceanic setting and existing highly variable climate regime may mean that average climate values are not well correlated with the extreme values that drive population size and range limits[107].
- Changes in distribution and abundance are more difficult to detect in rare, geographically restricted species, especially under a mask of widespread species decline driven by introduced predators, herbivores competitors and weeds, habitat loss and fragmentation[108].

The Department of Conservation has developed guidance to help to plan for the risks posed by climate change to our native ecosystems and biodiversity[109]. Frameworks have been further developed to help assess the relative threats and benefits climate change might hold for individual species[110].

103 Piggott J.J., Salis R.K., Matthaei C.D., Lear G., and Townsend C.R. (2015) Climate warming and agricultural stressors interact to determine stream periphyton community composition Global Change Biology (2015) 21, 206–222, doi: 10.1111/gcb.12661.

104 Lundquist C.J., Ramsay D., Bell R.G., Swales A., and Kerr S. (2011). Predicted impacts of climate change on New Zealand's biodiversity. Pacific Conservation Biology 17: 179–191.

105 Chen I.C., Hill J.K., Ohlemüller R., Roy D. B. and Thomas C.D. (2011). Rapid Range Shifts of Species Associated with High Levels of Climate Warming. Science, 333(6045): p. 1024-1026; Chen I.C., Shiub H-J, Benedickc S., Holloway J.D., Cheye V.K., Barlowf H.S., Hilla J.K. and Thomasa C.D. (2009). Elevation increases in moth assemblages over 42 years on a tropical mountain. Proceedings of the National Academy of Sciences of the United States of America. 106(5): p. 1479-1483; Hickling R., Roy D.B, Hill J. K., Fox R. and Thomas C. D. (2006). The distributions of a wide range of taxonomic groups are expanding polewards. Global Change Biology. 12(3): p. 450-455; Hill J.K., Griffiths H.M., and Thomas C.D. (2011). Climate Change and Evolutionary Adaptations at Species' Range Margins. Annual Review of Entomology. 56: p. 143-159; Parmesan C. (2003). Invasions as a consequence of climate-mediated range shifts. Ecological Society of America Annual Meeting Abstracts. 88: p. 261; Thomas C.D. (2010). Climate, climate change and range boundaries. Diversity and Distributions. 16(3): p. 488-495.

106 Harsch M.A., Hulme P.E., McGlone M.S. and Duncan R.P (2009). Are treelines advancing? A global meta-analysis of treeline response to climate warming. Ecology Letters, 12(10): p. 1040–1049.

107 McGlone M., Walker S., Hay R. and Christie J. (2010). Climate change, natural systems and their conservation in New Zealand. In: Climate change adaptation in New Zealand: Future scenarios and some sectoral perspectives. Nottage R.A.C., Wratt D.S., Bornman J.F. and Jones K. (eds). New Zealand Climate Change Centre, Wellington, pp 82–99.

108 McGlone M. & Walker S. (2011). Potential effects of climate change on New Zealand's terrestrial biodiversity and policy recommendations for mitigation, adaptation and research. Science Conservation 2011.

109 Christie J.E. (2014). Adapting to a changing climate A proposed framework for the conservation of terrestrial native biodiversity in New Zealand. Department of Conservation.

110 Thomas C. D., Hill J. K., Anderson B. J., Bailey S., Beale C. M., Bradbury R. B., Bulman C. R., Crick H. Q. P., Eigenbrod F., Griffiths H. M., Kunin W. E., Oliver T. H., Walmsley C. A., Watts K., Worsfold N. T. and Yardley T. (2011). A framework for assessing threats and benefits to species responding to climate change. Methods in Ecology and Evolution. 2(2): p. 125–142.

What might the future hold?

In a high carbon world, conditions will likely change faster, giving species less time to move or adapt to changes in climate. In a low carbon world, ecosystem changes will happen more slowly and more species will be able to keep pace with the changing climate conditions, so that species interactions can stay intact and fewer species will become extinct[111].

Changing temperatures will impact on the range of pests and pathogens that could threaten New Zealand's managed ecosystems, and resulting changes in land use in response to changing growing conditions are likely to be expensive[112]. New Zealand may also become more habitable to disease vectors such as mosquitoes, which will impact on New Zealand's susceptibility to human diseases like dengue fever[113].

Snow accumulation is expected to decline by 32–79% at 1000 m and 6–51% at 2000 m[114], associated with the snow line moving upwards. The number of alpine and sub-alpine species likely to become extinct in the long run can be estimated from species-area relationships to provide scenarios of climate-change effects as vegetation zones migrate. If the present mean temperature of 0.9°C higher than in 1900 is maintained, 40–70 species of native plants could become at risk[115].

In parts of New Zealand, higher temperatures and more frequent drought will likely result in less freshwater resource (decreased rainfall and snowmelt) producing more frequent and more severe low river flows. New Zealand's lakes tend to be cold and nutrient poor and when increased temperatures combine with added nutrient inputs from the surrounding production landscape, this will likely cause cyanobacterial blooms[116].

Changes in temperature and rainfall will also have an impact on annual fire risks (see Fire Risk box), with implications for recreation, forest fire resource planning, and the protection of important ecosystems and species.

The well-being of such natural systems is of paramount importance to whānau/hāpu/iwi and Māori business, particularly given the fundamental role of the natural environment in Māori values and the continuing rural and urban utilisation of public land, waterways and coastal resources for hunting, fishing, recreation and the collection of cultural resources.

111 Thomas C.D., Anderson B.J., Moilanen A., Eigenbrod F., Heinemeyer A., Quaife T., Roy D.B., Gillings S., Armsworth P.R. and Gaston K.J. (2013). Reconciling biodiversity and carbon conservation. Ecology Letters. 16: p. 39–47.

112 Royal Society of New Zealand (2014). Challenges for Pest Management in New Zealand. http://www.royalsociety.org.nz/pestmanagement/.

113 Tompkins D., Brock A., Jones G., McBride G., Tait A., Benschop J., Marshall J., French N., Harper S., Parshotam A., Ye W., Anderson A., MacLeod C. and Slaney D. (2012). Modelling the Impacts of Climate Change On Infectious Diseases in New Zealand. Health Analysis & Information For Action (HAIFA). ESR. http://haifa.esr.cri.nz/assets/Modelling-the-Health-Impacts-of-Climate-Change-Report.pdf.

114 Reisinger A., Kitching R.L., Chiew F., Hughes L., Newton P.C.D., Schuster S.S., Tait A., & Whetton P. (2014). Australasia. In: Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part B: Regional Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Barros V.R., Field C.B., Dokken D.J., Mastrandrea M.D., Mach K.J., Bilir T.E., Chatterjee M., Ebi K.L., Estrada Y.O., Genova R.C., Girma B., Kissel E.S., Levy A.N., MacCracken S., Mastrandrea P.R., & White L.L. (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA,. https://ipcc-wg2.gov/AR5/report/ – Chapter 25. Australasia.

115 Halloy S.R.P. & Mark A.F. (2003). Climate-Change Effects on Alpine Plant Biodiversity: A New Zealand Perspective on Quantifying the Threat. Arctic Antarctic and Alpine Research, 35(2): p. 248-254.; Dullinger S., Gattringer A., Thuiller W., Moser D., Zimmermann N.E., Guisan A., Willner W., Plutzar C., Leitner M., Mang T., Caccianiga M., Dirnböck T., Ertl S., Fischer A., Lenoir J., Svenning J-C, Psomas A., Schmatz D.R., Silc U., Vittoz P. and Hülber K. (2012). Extinction debt of high-mountain plants under twenty-first-century climate change. Nature Clim. Change. 2(8): p. 619–622.

116 Rigosi A., Hanson P., Hamilton D.P., Hipsey M., Rusak J. A., Bois J., Sparber K., Chorus I., Watkinson A.J., Qin B., Kim B., and Brookes J.D. (2015). Determining the probability of cyanobacterial blooms : the application of Bayesian networks in multiple lake systems. Ecological Applications, 2015. 25: p. 186–199.

What are the implications?

At an individual, household and community level, ecosystem change from climate change will affect New Zealanders' use of the environment for well-being, recreation, supplementing household food supplies and self-reliance, the collection of cultural resources and the transfer of tikanga and kawa, and diverse constructions of personal identity. Councils will likely face increased costs because some pest species (e.g. introduced weeds, wilding pines) will almost certainly increase in abundance and spread. At an economic level much of New Zealand's trade[117], tourism[118], branding and international reputation rely on New Zealand's environment[119].

For New Zealand's flora and fauna, more mobile species may keep pace with the rate of climate change[120], and, as species distributions change, the interactions they experience will change. As a consequence, biotic communities will become reshuffled[121] and species which rely on relationships with others (e.g. pollinators, host plants, prey species, nesting sites) may become negatively affected.

Most of New Zealand's vital ecosystems are maintained not by a single species but by a suite of interacting species. It is the unique community composition and community interactions that determine ecosystem functions and hence the services that ecosystems provide[122]. New Zealand's native plants and animals already face pressure from habitat loss and fragmentation, introduced mammalian predators and herbivores and invasive plants. Climate change will increase the stress on many of these already stressed systems.

Key knowledge gaps

- How to integrate the best available science into institutionalised planning and decision-making processes in the most effective way.
- How climate responsive Ecosystem Based Management (EBM) is enabled and enhanced.
- Further understanding required of how Matauranga Māori informs ecological base-lines, assessment and well-being.

Learn more

For more information on understanding and managing ecosystems under climate change:

- McGlone, M. and S. Walker, *Potential effects of climate change on New Zealand's terrestrial biodiversity and policy recommendations for mitigation, adaptation and research*, in *Science Conservation* 2011. http://www.doc.govt.nz/Documents/science-and-technical/sfc312entire.pdf.
- For information on changes in New Zealand's biodiversity, see Statistics New Zealand's *Environmental indicators Te Taiao Aotearoa* web pages: http://www.stats.govt.nz/browse_for_stats/environment/environmental-reporting-series/environmental-indicators/Home/Biodiversity.aspx.

117 The Treasury (2012). N.Z.G. Economic and Financial Overview 2012. 2015-08-21.

118 Statistics New Zealand (2014). Tourism Satellite Account: 2014. 2015-08-21.

119 Chetty K., Devadas V. and Fleming J. (2015). The framing of climate change in New Zealand newspapers from June 2009 to June 2010. Journal of the Royal Society of New Zealand. 45(1): p. 1–20.

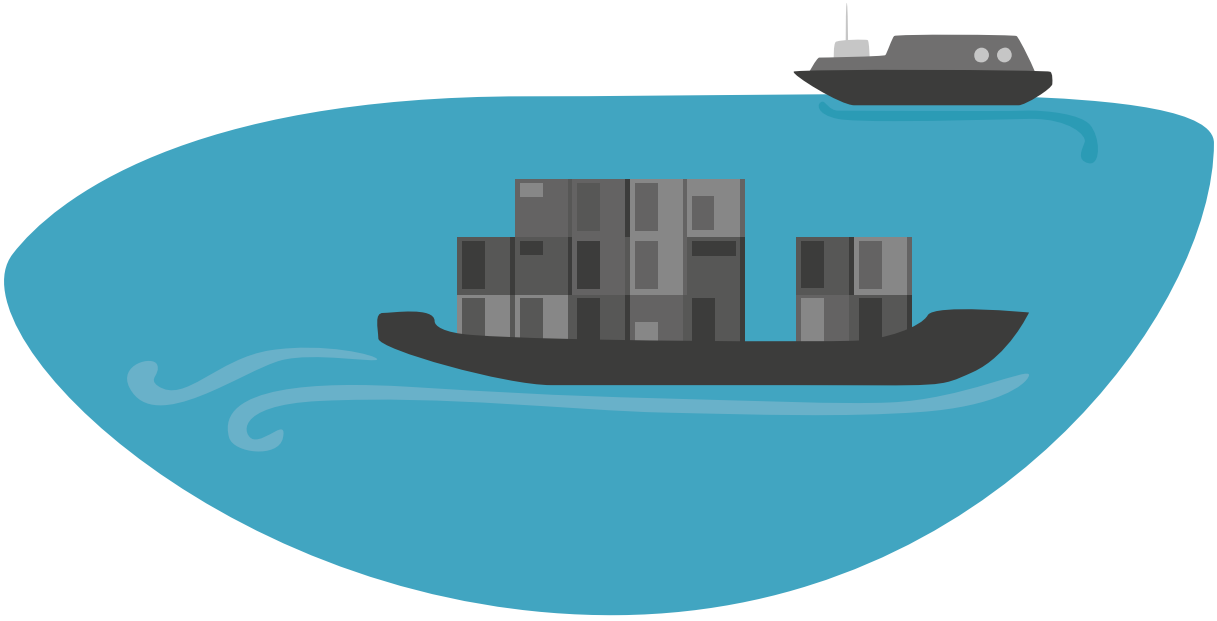
120 Araujo M.B. & Luoto M. (2007). The importance of biotic interactions for modelling species distributions under climate change. Global Ecology and Biogeography. 16(6): p. 743–753; Tscharntke T. & Tylianakis J. (2010). Conserving complexity: Global change and community-scale interactions. Biological Conservation. 143(10): p. 2249-2250; Anderson B.J., Arroyo B.E., Collingham Y.C., Etheridge B., Fernandez-De-Simon J., Gillings S., Gregory R.D., Leckie F.M., Sim I.M.W., Thomas C.D., Travis J.M.J. and Redpath S.M.(2009). Using distribution models to test alternative hypotheses about a species' environmental limits and recovery prospects. Biological Conservation. 142(3): p. 488-499; Araújo M. B., Rozenfeld A., Rahbek C. and Marquet P. A. (2011). Using species co-occurrence networks to assess the impacts of climate change. Ecography. 34(6): p. 897-908.

121 Williams J.W. & Jackson S.T. (2007). Novel climates, no-analog communities, and ecological surprises. Frontiers in Ecology and the Environment. 5(9): p. 475-482; Harley C.D.G. (2011). Climate Change, Keystone Predation, and Biodiversity Loss. Science. 334(6059): p. 1124-1127; Tylianakis J. M., Didham R. K., Bascompte J. and Wardle D. A (2008). Global change and species interactions in terrestrial ecosystems. Ecology Letters. 11(12): p. 1351–1363.

122 Wardle D.A., Bardgett R.D., Callaway R.M., and Van der Putten W.H. (2011). Terrestrial Ecosystem Responses to Species Gains and Losses. Science. 332(6035): p. 1273-1277; Maestre F.T., Bowker M.A., Escolar C., Puche M.D., Soliveres S., Maltez-Mouro S., García-Palacios P., Castillo-Monroy A.P., Martínez I. and Escudero A. (2010). Do biotic interactions modulate ecosystem functioning along stress gradients? Insights from semi-arid plant and biological soil crust communities. Philosophical Transactions of the Royal Society of London, Series B: Biological Sciences. 365(1549): p. 2057-2070; Anderson B. J., Armsworth P. R., Eigenbrod F., Thomas C. D., Gillings S., Heinemeyer A., Roy D. B. and Gaston K. J (2009). Spatial covariance between biodiversity and other ecosystem service priorities. Journal of Applied Ecology. 46(4): p. 888–896.

International impacts: New Zealand is affected by impacts and responses to climate change occurring overseas

The ways in which other countries are affected by and will respond to climate change, plus commitments New Zealand makes to international climate treaties, will influence New Zealand's international trade relationships, migration patterns and specific domestic responses.



What climate trends will have international impacts for New Zealand?

For a strongly internationally-connected country such as New Zealand, climate change impacts far from our shores are likely to be felt here. Four key risks of relevance to New Zealand and its international connections[123] are:

- All aspects of food security are potentially affected by climate change, including food access, utilization, and price stability.
- Climate change over the 21st century is projected to increase displacement of people.
- Climate change can indirectly increase risks of violent conflicts in the form of civil war and inter-group violence by amplifying well-documented drivers of these conflicts such as poverty and economic shocks.
- The impacts of climate change on the critical infrastructure and territorial integrity of many states are expected to influence national security policies.

Climate change impacts are also projected to slow down economic growth, but global economic impacts from climate change are difficult to estimate[124]. In addition, long-haul tourism is a key element of New Zealand's export revenue, and this could be affected by perceptions of climate change and the acceptability of long-haul travel, costs of fossil fuels essential for air travel, and desirability of alternative destinations.

The combination of reduced food security, increased displacement and migration (notably from the Pacific Islands and possibly Australia) and the potential for political instability and national security issues imply that patterns of international trade, demand for services, and international tourism, could change substantially in future as a consequence of climate change. Increasing climate-driven disasters and disease patterns will alter the demand for aid to support post-disaster recovery as well as longer term development goals. This could also influence the role that defence forces play in the region to support stability, development and managed migration.

123 IPCC (2014). Summary for policymakers. In: Climate Change 2014: Impact, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Field C.B., Barros V.R., Dokken D.J., Mach K.J., Mastrandrea M.D., Bilir T.E., Chatterjee M., Ebi K.L., Estrada Y.O., Genova R.C., Girma B., Kissel E.S., Levy A.N., MacCracken S., Mastrandrea P.R., and White L.L. (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, pp.1–32.

124 See footnote 123.

What is already happening?

There is evidence of climate change impacts on crops and food production in many parts of the world[125] (Figure 16). Agricultural commodity prices are extremely sensitive to quantities available for purchase at any one time: in January 2011, after floods in Australia and storms in the United States, meat processors in those countries were forced to close and the New Zealand commodity price index hit record highs as a result of an unprecedented 10 per cent rise in the price of bull beef[126]. But the global connections are not only one-way: given New Zealand's dominant position in the global milk trade, the 2012/13 drought in New Zealand resulted in a rise of global dairy prices, which in turn to some extent buffered the losses to dairy farmers in New Zealand[127].

What might the future hold?

If, as projected, the world's population reaches about nine billion by 2050, the UN Food and Agriculture Organisation (FAO) estimates global food production will need to increase by some 70 per cent. Meanwhile, in emerging economies such as India and China, rising wealth is driving a burgeoning market for higherprotein food. Between 1980 and 2002, FAO statistics show annual meat consumption tripled in the developing world, from 47 to 137 million tonnes, and this is projected to rise further to more than 200 million tonnes by 2030, and more than 300 million tonnes by 2050[128]. Changes in crop yields will vary by region and over time, with yield decreases strongly outweighing increases from around 2030 (Figure 17).

In a high carbon world, many people are likely to be displaced due to rising sea levels, flooding, and drought. While it is very difficult to predict how this might affect migration patterns, it could lead to increased demand for opportunities to migrate to New Zealand. In addition, many of the Pacific Islands, with whom we share cultural and political ties, will find it difficult to adapt to rising sea levels. New Zealand would be a natural source of support for providing post-disaster recovery assistance, preparation and strengthening of infrastructure, and to support decision-making around the longer-term future of the most affected communities.

As noted above, climate change can indirectly increase risks of violent conflicts in the form of civil war and inter-group violence, and is expected to have an effect on national security polices around the world. This, in turn, can be expected to exert pressure on New Zealand to assist in efforts to maintain regional stability.

125 IPCC (2014). Summary for policymakers. In: Climate Change 2014: Impact, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Field C.B., Barros V.R., Dokken D.J., Mach K.J., Mastrandrea M.D., Bilir T.E., Chatterjee M., Ebi K.L., Estrada Y.O., Genova R.C., Girma B., Kissel E.S., Levy A.N., MacCracken S., Mastrandrea P.R., and White L.L. (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, Table SPM.A1

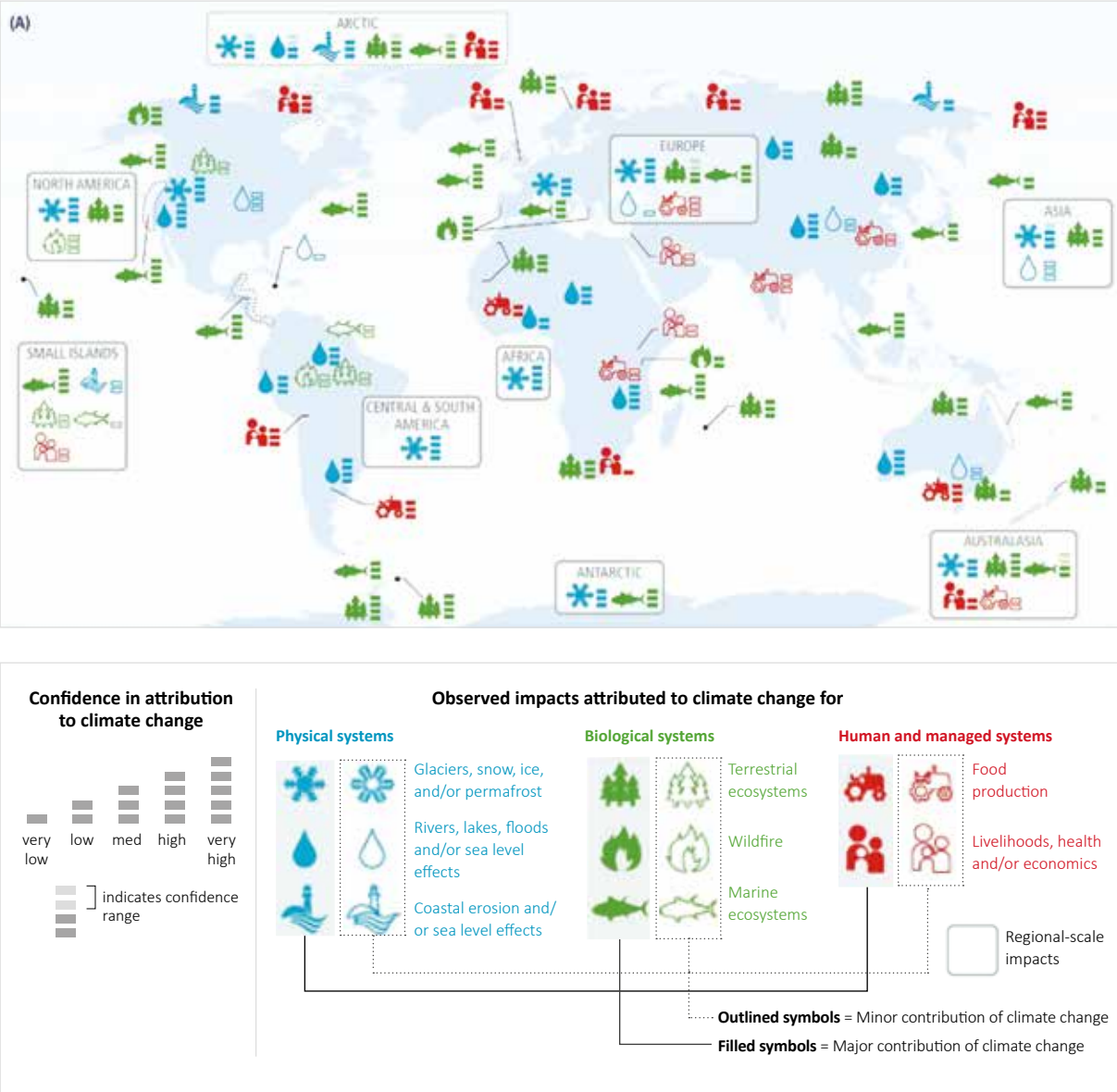
126 New Zealand Agricultural Greenhouse Gas Research Centre (NZAGRC) (2012). Impacts of Global Climate Change on New Zealand Agriculture. Factsheet 2. November 2012. http://www.nzagrc.org.nz/fact-sheets.html

127 Reisinger A., Kitching R.L., Chiew F., Hughes L., Newton P.C.D., Schuster S.S., Tait A., & Whetton P. (2014). Australasia. In: Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part B: Regional Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Barros V.R., Field C.B., Dokken D.J., Mastrandrea M.D., Mach K.J., Bilir T.E., Chatterjee M., Ebi K.L., Estrada Y.O., Genova R.C., Girma B., Kissel E.S., Levy A.N., MacCracken S., Mastrandrea P.R., & White L.L. (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA,

128 Alexandratos and Bruinsma (2012). World Agriculture Towards 2030/2050, ESA Working Paper No. 12-03, FAO, Rome, Italy.

Figure 16: Global patterns of impacts in recent decades attributed to climate change.

Impacts are shown at a range of geographic scales. Symbols indicate categories of attributed impacts, the relative contribution of climate change (major or minor) to the observed impact, and confidence in attribution.

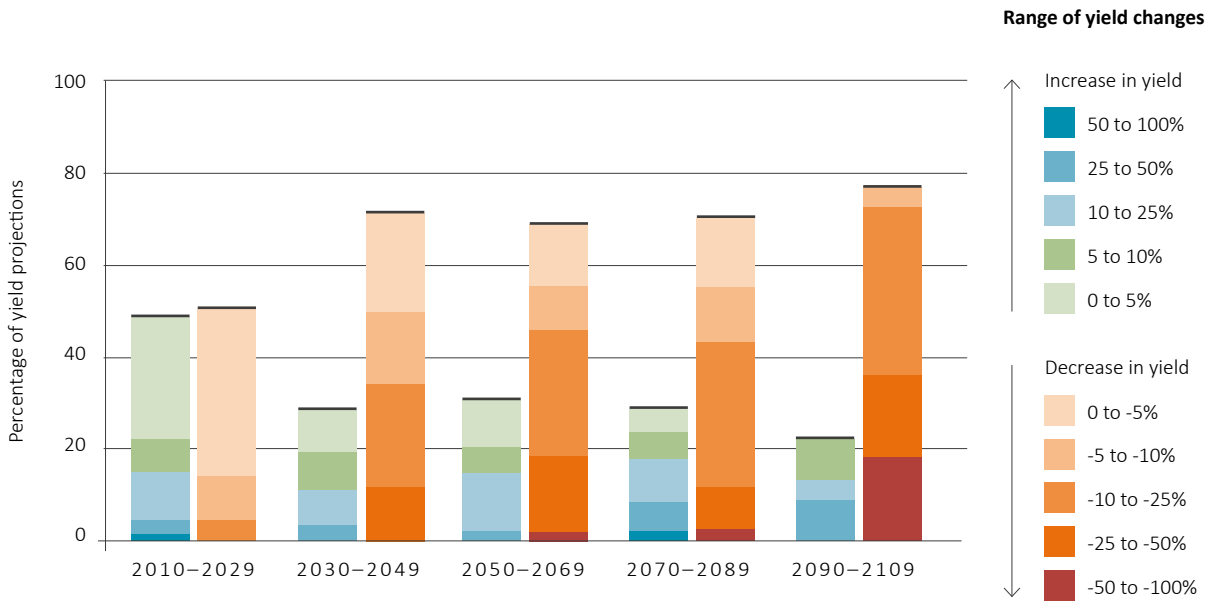


Source: IPCC[129].

129 IPCC (2014). Summary for policymakers. In: Climate Change 2014: Impact, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Field C.B., Barros V.R., Dokken D.J., Mach K.J., Mastrandrea M.D., Bilir T.E., Chatterjee M., Ebi K.L., Estrada Y.O., Genova R.C., Girma B., Kissel E.S., Levy A.N., MacCracken S., Mastrandrea P.R., and White L.L. (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, Table SPM.2.

Figure 17: Summary over a large number of studies of projected changes in major crop yields relative to the late 20th century, due to climate change over the 21st century, including projections for different emission scenarios, for tropical and temperate regions, and for adaptation and no-adaptation cases combined.

Most studies cover scenarios where global mean temperatures increase by less than 4°C by 2100. Blue represents yield increases and orange represents yield decreases. Data for each timeframe sum to 100%. Different studies have focused on different locations, and therefore studies indicate both yield losses and increases at any given time. However, the number of studies projecting yield losses increases with time the more the world warms, while the number of studies projecting yield increases becomes smaller.



Source: IPCC[130].

130 IPCC (2014). Summary for policymakers. In: Climate Change 2014: Impact, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Field C.B., Barros V.R., Dokken D.J., Mach K.J., Mastrandrea M.D., Bilir T.E., Chatterjee M., Ebi K.L., Estrada Y.O., Genova R.C., Girma B., Kissel E.S., Levy A.N., MacCracken S., Mastrandrea P.R., and White L.L. (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, Table SPM.7.

What are the implications?

The net implications of climate change for New Zealand are more complex than purely domestic physical impacts or domestic climate policies. New Zealand faces a number of issues – international climate and trade policies, global production dynamics, unanticipated effects of climate policies overseas and seemingly unrelated economic initiatives, shifts in consumer perception and preferences, and our international reputation.

Crucially, not all of these issues are negative, and some are already delivering gains to New Zealand. For example, increasing global commodity prices due to negative effects of climate change on food production globally could benefit New Zealand farmers[131], but making use of such price rises also relies on New Zealand's ability to trade in global markets. A world increasingly challenged by climate change, and with strong differences in impacts between low-latitude developing countries and temperate developed countries, will not necessarily provide the market conditions that would allow New Zealand farmers to capture those benefits. Quantifying the net effect of future international impacts of, and responses to, climate change is challenging, but current estimates are that benefits to New Zealand from the global response to climate change could go a long way to offsetting, or even overpowering, negative domestic effects[132]. However, existing model-based studies of such international connections are often simplistic and assume that only some variables change but not others.

Careful consideration of these complex dynamics will reveal the best strategy for New Zealand, and how best to protect and enhance our environmental reputation (Figure 18)[133].

In a severely resource-constrained and divided world people may not care about, nor afford the luxury of shared environmental goals and put little premium on such values. In an increasingly highly populated world, with climate change exacerbating existing vulnerabilities, regional crises and financial instability could have negative consequences for New Zealand.

In a world where social responsibility is a key driver of both public and private investment, it is likely that food production and consumption, as well as utility planning systems, will undergo much re-configuration as communities and industries develop the agility required to respond to and plan for climate change.

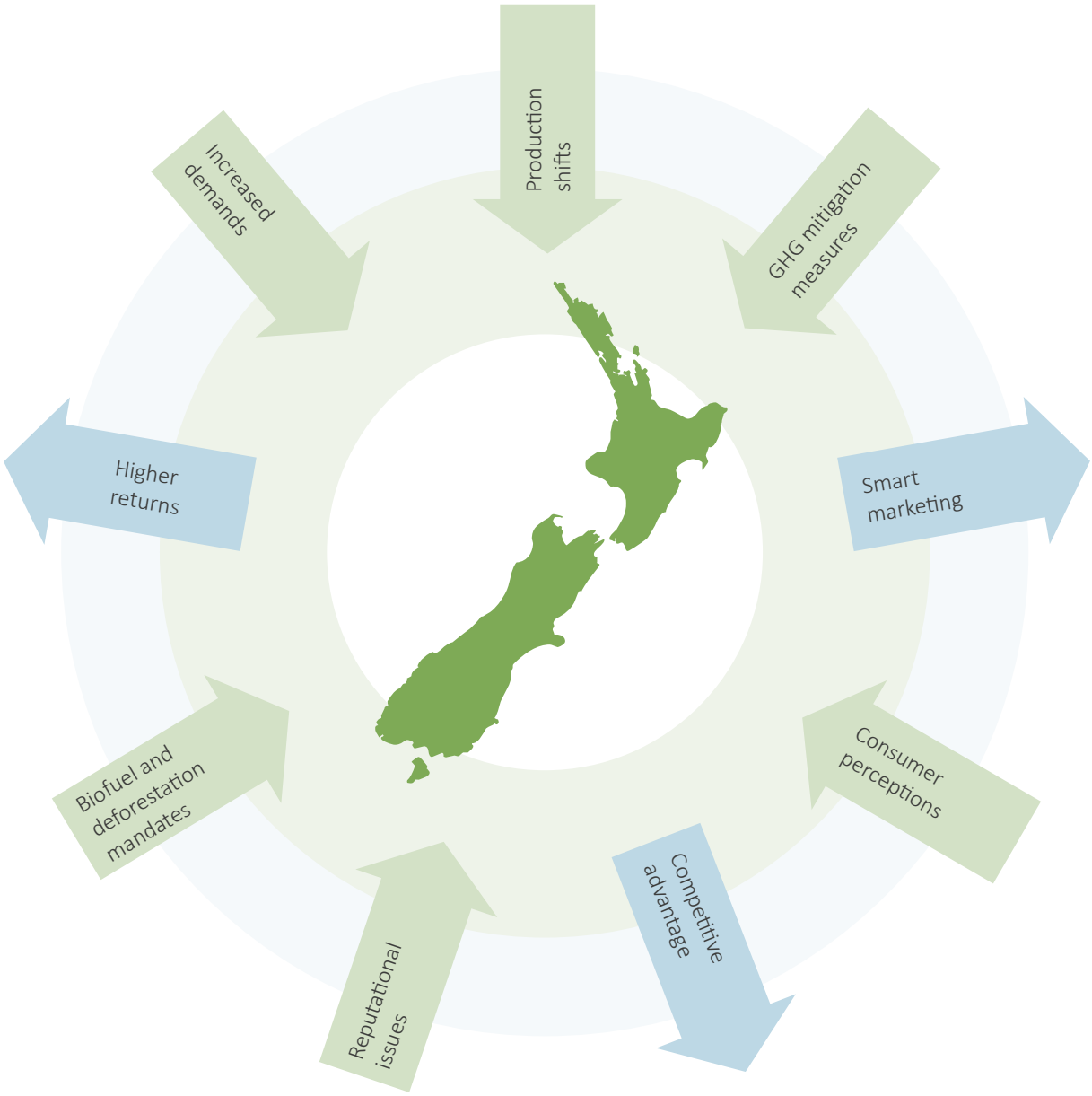
131 Reisinger A., Kitching R.L., Chiew F., Hughes L., Newton P.C.D., Schuster S.S., Tait A., & Whetton P. (2014). Australasia. In: Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part B: Regional Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Barros V.R., Field C.B., Dokken D.J., Mastrandrea M.D., Mach K.J., Bilir T.E., Chatterjee M., Ebi K.L., Estrada Y.O., Genova R.C., Girma B., Kissel E.S., Levy A.N., MacCracken S., Mastrandrea P.R., & White L.L. (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, pp. 1371-1438. https://ipcc-wg2.gov/AR5/report/- Chapter 25, Australasia, 9.2.

132 See footnote 131.

133 New Zealand Agricultural Greenhouse Gas Research Centre (NZAGRC) (2012) Impacts of Global Climate Change on New Zealand Agriculture. Factsheet 2. November 2012. http://www.nzagrc.org.nz/fact-sheets.html.

Figure 18: Climate change is expected to affect New Zealand agriculture in multiple ways, both through direct and indirect impacts.

While indirect impacts are often harder to quantify, preliminary indications are that they could be at least as important as direct impacts from climate change and response measures within New Zealand – and some of the international flow-on effects could be strongly positive[134].



134 New Zealand Agricultural Greenhouse Gas Research Centre (NZAGRC) (2012). Impacts of Global Climate Change on New Zealand Agriculture. Factsheet 2. November 2012. http://www.nzagrc.org.nz/fact-sheets.html.

Key knowledge gaps

- The influence scenario planning has on the formation of new markets and New Zealand's positioning in the blue economy[135].
- Integrated modelling of domestic and international trends in product demand and production capacities, with a focus on the implications of climate change and climate policies on key competitors and destination countries for New Zealand products.
- Better understanding of changes in consumer perceptions and their implications for the creation or loss of niche markets.
- Integrated assessment of development and climate goals in regions with which New Zealand has important economic or cultural ties, and the opportunities for New Zealand to engage positively in these trends.
- Increased understanding of economic, demographic and societal trends in New Zealand, the extent to which they are shaped by global processes or determined by national directions and priorities, and the extent to which they shape vulnerabilities and adaptation options to climate change.

Learn more

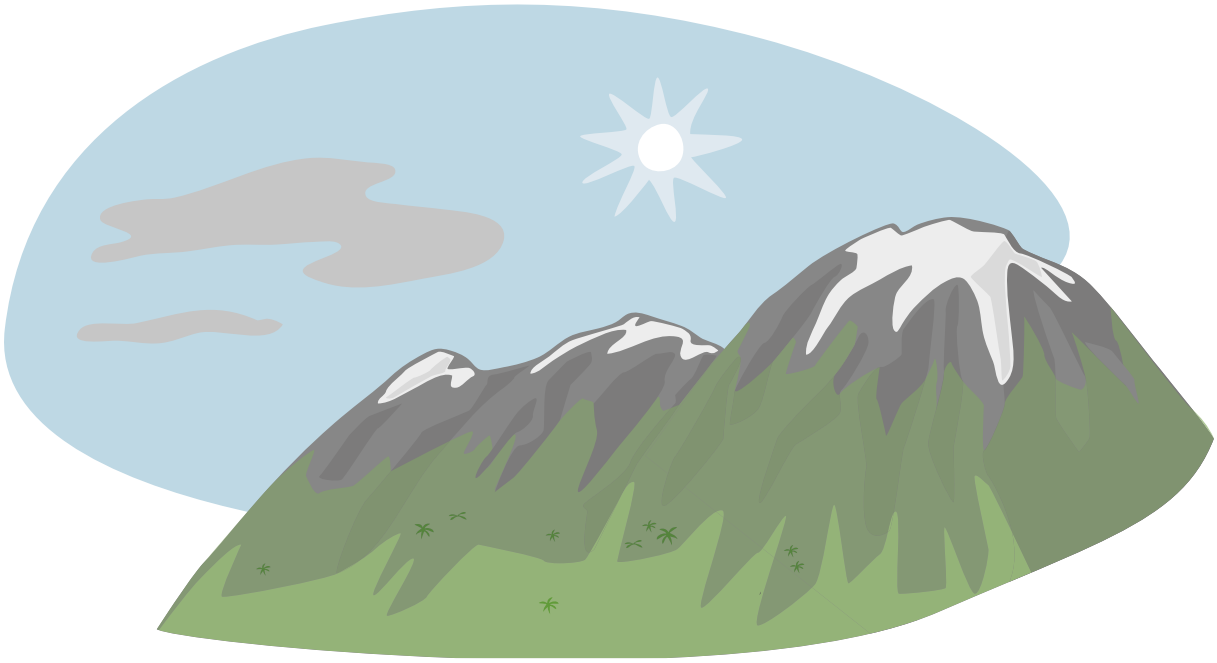
For more information on international impacts in the context of climate change:

- *The roads ahead: Narratives for shared socioeconomic pathways describing world futures in the 21st century*. Global Environmental Change (2015), http://dx.doi.org/10.1016/j.gloenvcha.2015.01.004.
- IPCC, 2014: *Climate Change 2014: Impacts, Adaptation, and Vulnerability*. Chapters 12, 24, 25 and 29. https://ipcc-wg2.gov/AR5/report/full-report/.
- For information on the economic performance of New Zealand's agriculture industry see Statistics New Zealand's *Environmental indicators Te Taiao Aotearoa* web pages: http://www.stats.govt.nz/browse_for_stats/environment/environmental-reporting-series/environmental-indicators/Home/Land/value-primary-industries/economic-performance-agriculture.aspx.

135 Blue Economy: a sustainable ocean economy that is a result of economic activity being in balance with the long-term capacity of ocean ecosystems, which thus support this activity and remain resilient and healthy. A Blue Economy should have a set of economic practices that work with the dynamics of marine ecosystems to create economic and social values, sustain or enhance the resourcefulness of those environments, and generate short and long-term benefits for investors, communities and marine ecosystems. http://www.sustainableseaschallenge.co.nz/sites/default/files/Sustainable%20Seas%20Research%20Plan%20-%2030%20September%202015.pdf.

Conclusion

This report has described in general terms the changes in climate that are expected globally and nationally during the 21st century, before focusing on six key areas of risk for New Zealand: coastal margins; flooding from rivers; availability of and competition for freshwater; changes to our surrounding oceans; threats to unique ecosystems; and flow-on effects from climate change impacts and responses overseas.



Some of the key points that emerge from consideration of climate change for New Zealand are:

- Change is under way and some impacts and implications are already becoming tangible. Climate change will almost certainly accelerate this century (unless drastic action is taken to reduce global emissions of greenhouse gases). Even small changes in average conditions can be associated with large changes in the frequency of occurrence of extreme events.
- Human systems, and infrastructure, may not cope with rapid change or extreme events, particularly given that many systems are designed on the basis that there is no long term change in external environment. For example, sea levels globally have been relatively static for several thousand years and the development of coastal infrastructure reflects that.
- In terms of the modern climate (atmosphere, oceans, snow and ice, sea level), the past is no longer a guide to the future. Planning for the future requires a dynamic approach that allows flexible responses to changing risks and societal expectations, uncertainties and the potential for surprises.
- A changing climate creates new and amplifies existing climate-related risks for New Zealand. Risks are a combination of the occurrence of adverse events and exposure and vulnerability to those events. Risks can be reduced, even in the face of an increasing frequency of adverse events, by reducing exposure and vulnerability to them.
- Some climate change events may have a low probability but drastic consequences if they occur and therefore represent significant risks. Uncertainty does not mean that we cannot take meaningful and necessary action to manage and reduce clearly identified changing risks from climate change.
- It is critical to communicate clearly the changing nature of risks and the need for responsive systems to address them. People and communities that are affected must be involved in the discussion.
- New Zealand is very connected internationally, so climate changes in other parts of the globe will have impacts on New Zealand. New Zealand cannot chart its response to climate change based on impacts in New Zealand alone.

Even though the science of climate change and the increasing risks it poses are based on very robust evidence, responses to climate change remain a highly contested area. In many instances, apparent debate about scientific evidence masks a much deeper underlying contest amongst conflicting values and societal priorities. This poses particular challenges in New Zealand's devolved decision-making system.

Risk is often portrayed and understood as the product of probability and consequence, but climate change outcomes especially over the long term exhibit deep uncertainty – not least because the New Zealand impacted by climate change decades from now will be fundamentally different from today's in some respects, yet similar in others and influenced by decisions made today. Effective management of key risks from climate change will benefit from a coordinated approach that helps decision-makers reconcile near-term and local special interests with longer-term community and national benefits, and that helps bridge gaps across the interface of science, policy and practice.

This report has sought to provide a clear summary of the scientific evidence and projections of climate change and to identify key risks these changes pose to New Zealand, including as a result of wider societal changes and environmental pressures. It was not within the Panel's mandate to identify opportunities or responsibilities for addressing the key risks, but it is hoped that the information conveyed in this report can act as a basis for such a wider national discussion.

Further information

This paper was authored by a Royal Society of New Zealand panel chaired by Dr James Renwick. The Panel members were: Dr Barbara Anderson, Dr Alison Greenaway, Mr Darren Ngaru King, Dr Sara Mikaloff-Fletcher, Dr Andy Reisinger, and Dr Helen Rouse. The Royal Society of New Zealand would like to thank the following experts for the valuable input in commenting on and reviewing the paper: Professor Bruce Glavovic, Dr Paul Newton, and Professor Jean Palutikof.

For further information

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or go to the Royal Society of New Zealand web page:
www.royalsociety.org.nz/climate-change-implications-for-new-zealand

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