Ministry for the
Environment
Manatū Mō Te Taiao

National Climate Change Risk Assessment for New Zealand

Arotakenga Tūraru mō te Huringa Āhuarangi o Āotearoa

Technical report

Pūrongo Whaihanga

New Zealand Government

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Disclaimer

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1 Introduction

The first *National Climate Change Risk Assessment for New Zealand: Arotakenga Tūraru mō te Huringa Āhuarangi o Āotearoa* (NCCRA) was carried out from September 2019 to May 2020, and focused on the risks to New Zealand from hazards caused, exacerbated or influenced by the physical impacts of climate change. The risk assessment team also considered the potential for positive consequences (opportunities) arising from a changing climate.

The purpose of the assessment was to build an understanding of the risks and opportunities from long-term trends in the climate (ongoing, gradual change) and changes in extreme weather, to support the development of a national adaptation plan (NAP).

1.1 Purpose and format of this report

The outputs of the NCCRA have been presented in three reports, as table 1 outlines. The primary audience for this report is central government, but a broad range of partners, stakeholders and communities is also likely to be interested.

Table 1: Overview of NCCRA reports

Report	Report purpose
Main report (Ministry for the Environment, 2020a)	Provides a high-level summary of risk assessment findings, with a focus on the 10 most significant risks.
Technical report (this report)	Provides further detail on assessment findings, including risks, opportunities and gaps in each domain, and qualitative descriptions of exposure, vulnerability, consequence, adaptation and strength of evidence. This report provides the evidence base for the assessment findings, and will be an ongoing resource for the NAP. It is intended as a companion to the main report.
Method report (Ministry for the Environment, 2020b)	Outlines the approach to the risk assessment and engagement methodology, including results of the engagement process.

The technical report provides a baseline and evidence base, and reflects the current knowledge of climate change risks in New Zealand. It presents the detailed assessment findings of the NCCRA, including all priority risks, opportunities and knowledge gaps. It also includes comprehensive references of all literature reviewed. Table 2 outlines the sections in the body of this technical report.

Table 2: Technical report overview

Section	Description of content
Report	
1. Introduction	• Overview of value domains • Introduction to cross-cutting concepts used in this technical report.
2. Climate change in New Zealand	Description of climate variables and hazards affecting New Zealand.
3. Natural environment domain	• Domain description • Māori perspective on the domain and risks
4. Human domain	

Section	Description of content
5. Economy domain 6. Built environment domain	• Snapshot of key issues and themes in each domain • Summary of climate change risks and opportunities in each domain • Further detail on climate change risks identified, including: – summary of each risk – exposure – vulnerability (sensitivity and adaptive capacity) – interacting risks – confidence – adaptation urgency profile • Opportunities • Gaps.
7. Governance domain	Same content as sections 3–6, with the addition of further detail on climate change risks identified, including: • summary of each risk • detailed description of each risk, including interactions with risks identified in other domains (replaces exposure, vulnerability and interacting risks) • consequence • confidence • adaptation urgency profile.
References	Full references for citations in this report.

1.2 Overview of the value domains and cross-cutting concepts

This first NCCRA is based on *Arotakenga Huringa Āhuarangi: A Framework for the National Climate Change Risk Assessment for Aotearoa New Zealand* (the NCCRA framework) (Ministry for the Environment, 2019a). Developed by an expert panel, the framework sets out the methods to be used for the NCCRA. It takes a values-based approach, and weaves in te ao Māori and engagement principles, providing a comprehensive knowledge and skill base for understanding climate change risks.

The process combines scientific, technical and expert information with mātauranga Māori, local knowledge, and experience (Ministry for the Environment, 2019a). The NCCRA was developed in three stages by a diverse, multidisciplinary team of academics and consultants.

The following sections explain key terms and concepts used in this report.

1.2.1 Value domains

The NCCRA framework outlines five value domains for assessing risks and opportunities (table 3). These domains represent groups of values, assets and systems that may be at risk from climate change-related hazards, or have the propensity to be beneficially affected.

The value domains are a mix of those used in the New Zealand Treasury's Living Standards Framework (New Zealand Treasury, 2018) and the *National Disaster Resilience Strategy* (Ministry of Civil Defence and Emergency Management, 2019). They are interconnected, are applicable at the individual, community and national levels, and include tangible and intangible values. Table 3 describes each of the domains.

Table 3: Value domains used for assessing risks and opportunities

Value domain	Description
Human	People's skills, knowledge, and physical and mental health (human), the norms, rules and institutions of society (social), and the knowledge, heritage, beliefs, arts, morals, laws and customs that infuse society (cultural).
Natural environment	All aspects of the natural environment that support the full range of New Zealand's indigenous species, he kura taiao – living treasures, and the ecosystems they form in terrestrial, freshwater and marine environments.
Economy	The set and arrangement of inter-related production, distribution, trade and consumption practices that allocate scarce resources.
Built environment	The set and configuration of physical infrastructure, transport and buildings.
Governance	The governing architecture and processes of interaction and decision-making in and between governments, and economic and social institutions. Institutions are the rules and norms held by social actors that shape interactions and decision-making, and the agents that act within the institutional frameworks.

Each value domain consists of a series of 'elements at risk', as table 4 outlines.

Table 4: Elements at risk in each value domain

Value domain	Elements at risk
Human	Community wellbeing, social cohesion and social welfare (urban communities, rural communities, coastal communities), health, education, sports, recreation, cultural heritage (archaeological sites, museums, arts, theatre), ahurea Māori, tikanga Māori – Māori culture, values and principles, cultural taonga.
Natural environment	New Zealand's indigenous species, including he kura taiao – living treasures, terrestrial ecosystems, freshwater ecosystems, coastal, estuarine and marine ecosystems, biosecurity.
Economy	Primary industries (forestry, agriculture, horticulture, viticulture and fisheries, aquaculture and marine farming), land use, tourism, technology and business, whakatipu rawa – Māori enterprise, insurance and banking, fiscal and financial systems.
Built environment	Built infrastructure across a range of sectors including housing, public amenity, water, wastewater, stormwater, energy, transport, communications, waste and coastal defences.
Governance	Treaty partnerships, all governing and institutional systems, all population groups, including vulnerable groups in society, all infrastructure, communities, natural ecosystems and their adaptive capacity.

1.2.2 Interdependencies, cascading and direct and indirect impacts

The NCCRA provides a national overview of how New Zealand may be affected by various hazards and threats caused, exacerbated or influenced by climate change, and the risks and opportunities this brings. It does not, however, consider cascading impacts, interdependencies and future socio-economic projections.

There has been little research about how climate change impacts cascade across human systems, and even less into how this should be considered in a climate change risk assessment. These areas will need more research.

The domains used for the NCCRA, and the elements at risk in each, are highly interconnected and interdependent. Because of the interdependencies between the domains, the risk assessment team examined both direct and indirect risks.

Most direct risks can be found in the natural environment, economy, human and built environment domains, where specific elements at risk are directly exposed to climate hazards.

The economy, human and governance domains also include indirect risks because of their reliance on, or interaction with, elements at risk in other domains that are directly exposed to climate change hazards.

This assessment addresses the significance of cascading impacts by:

- assessing the effect of governance risks on risks in other domains; in particular, the impact of governance risks on the ability of governments, organisations and individuals to adapt to risks in the other value domains. See section 1.2.3 for more information
- providing a case study on the effect of cascading impacts, in section 6 of the main report
- including a qualitative description of interdependencies between risks in each risk profile ('interacting risks' subsection in each of sections 3 to 7).

1.2.3 Governance domain

Governance-related climate change risks are distinct from the risks in the other domains because they are indirect and cut across all the domains, and emerge from other domain risks. They also reduce society's ability to address risks in the other domains by reducing adaptive capacity (Lawrence et al, 2018). While cross-cutting and indirect risks were identified in other domains, the risk assessment team considered governance risks to be significant barriers or enablers to climate action, and relevant to all domains. Because of this, the team assessed the elements at risk from the governance domain differently. Adaptive capacity was used to understand how governance risks affect the risks in other domains, and vice versa, and to prioritise those governance risks with the greatest effect.

The method report provides further detail about how the risks were assessed across domains.

1.2.4 Te ao Māori and climate change risk

The NCCRA must balance the analytical nature of a risk assessment with diverse Māori views and values. Risk assessments are reductive analytical exercises that rely on simplifying complex systems (the natural environment, society, economy) into discrete parts and potential future events, and assessing and prioritising these potential events (risks).

There are clear connections and dependencies between the risks from each assessed domain. For Māori consulted during this risk assessment, exploring these interdependencies provided a more detailed understanding of how climate change will affect the wellbeing of Aotearoa New Zealand. However, the framework shows that the current climate change risk assessment methodologies do not offer a rigorous method for factoring interdependencies into national risk assessments, and addressing this issue is beyond the scope of this first NCCRA.

The NCCRA recognised Māori perspectives in the following ways.

1. **Interconnectedness of domains:** The NCCRA recognises the interconnectedness and interdependencies between domains, and describes these for each domain (in sections 3 to 7). This is discussed further in the key concept case study 1: Interdependencies and cascading effects in the main report. Interdependencies between domains and risks have not affected the risk ratings, however, except for the ratings of governance risks (see section 1.2.3).

2. **Ngā Mātāpono*:*** The NCCRA is underpinned by the guiding principles of the framework (Ministry for the Environment, 2019a), which have informed the overall approach for engagement and the risk assessment. The method report provides more detail about how the principles were applied.
3. **Māori perspective on each domain:** Sections 3 to 7 of this report include an overview that identifies relevant Māori concepts and values for each domain.
4. **Risks of particular relevance to Māori:** While all the risks identified are relevant to Māori, the NCCRA also identifies risks that are particularly relevant to Māori interests, values and practices. These risks are listed in section 1.2.51.2.5 and described in detail in sections 3 to 7.

1.2.5 Risks of particular relevance to Māori

The following risks in each domain have been identified as being of particular significance to Māori.

These first risks potentially impact Māori interests, kawa (protocols) and tikanga (correct procedures, lore, practices) and diverse expressions of mana (authority, dignity, control, governance, power) and kaitiakitanga (intergenerational sustainability):

- H5 – Risks to Māori social, cultural, spiritual and economic wellbeing from loss and degradation of lands and waters, as well as cultural assets such as marae, due to ongoing sea-level rise, changes in rainfall and drought
- H6 – Risks to Māori social, cultural, spiritual and economic wellbeing from loss of species and biodiversity due to greater climate variability and ongoing sea-level rise
- H8 – Risks to Māori and European cultural heritage sites due to ongoing sea-level rise, extreme weather events and increasing fire weather
- G4 – Risk of a breach of Treaty obligations from a failure to engage adequately with and protect current and future generations of Māori from the impacts of climate change.

As well as the above risks, some other risks will have a disproportionate impact on Māori or certain Māori groups. These include:

- H1 – Risks to social cohesion and community wellbeing from displacement of individuals, families and communities due to climate change impacts
- H2 – Risks of exacerbating existing inequities and creating new and additional inequities due to differential distribution of climate change impacts
- H4 – Risks of conflict, disruption and loss of trust in government from changing patterns in the value of assets and competition for access to scarce resources primarily due to extreme weather events and ongoing sea-level rise
- H7 – Risks to mental health, identity, autonomy and sense of belonging and wellbeing from trauma due to ongoing sea-level rise, extreme weather events and drought
- B1 – Risk to potable water supplies (availability and quality) due to changes in rainfall, temperature, drought, extreme weather events and ongoing sea-level rise
- B2 – Risks to buildings due to extreme weather events, drought, increased fire weather and ongoing sea-level rise
- B4 – Risk to wastewater and stormwater systems (and levels of service) due to extreme weather events and ongoing sea-level rise

- B6 – Risks to linear transport networks due to changes in temperature, extreme weather events and ongoing sea-level rise
- G6 – Risks to the ability of the emergency management system to respond to an increasing frequency and scale of compounding and cascading climate change impacts in New Zealand and the Pacific region
- G8 – Risk to the ability of democratic institutions to follow due democratic decision-making processes under pressure from an increasing frequency and scale of compounding and cascading climate change impacts.

The opportunities identified are relevant to Māori business, particularly as they relate to:

- the primary sector (EO1), which is a strong focus for the Māori economy
- whakatipu rawa (Māori enterprise) (EO2)
- mahinga kai (food provisioning).

The health and financial opportunities presented by warmer winters are particularly significant to vulnerable populations such as low-income families, in which Māori are disproportionately represented (HO1, BO1). For detailed descriptions of these risks and opportunities, see sections 3 to 7.

1.3 Key concepts

For this climate change risk assessment, risks are framed through the concepts of hazard, exposure and vulnerability, with the overlap defining the risk (IPCC, 2014a). Risk is a function of:

- climate change hazards (which can be physical events or trends, such as sea-level rise or seasonal climate changes)
- the degree to which things we value (people, assets) are exposed to the hazard
- the vulnerability of those valued things to its effects.

Vulnerability is influenced by socio-economic and cultural processes (including adaptation and mitigation actions, and governance), which can affect the consequences (and therefore the risk) resulting from exposure to a hazard. Risks in each domain are explored using these concepts, except for the governance domain as described in section 1.2.3.

Criteria and guidance for the assessment were developed at the start of each stage, and guided the assessment of risks in relation to exposure, vulnerability and consequence. Appendix C of the method report (Ministry for the Environment, 2020b) lists these criteria. A brief overview is given below.

1.3.1 Exposure

The Intergovernmental Panel on Climate Change (IPCC) defines exposure as:

> "the presence of people, livelihoods, species or ecosystems, environmental functions, services, and resources, infrastructure, or economic, social, or cultural assets in places and settings that could be adversely affected by a change in external stresses."
> (IPCC, 2007b, p 5)

In the context of climate change, these external stresses are usually specific climate and other biophysical variables (IPCC, 2007b). New Zealand's Ministry of Civil Defence and Emergency Management describes exposure as:

> "the number, density or value of people, property, services, or other things we value (taonga) that are present within an area subject to one or more hazards (ie, within a hazard zone), and that may experience potential loss or harm." (Ministry of Civil Defence and Emergency Management, 2019)

1.3.2 Vulnerability

The IPCC defines vulnerability as:

> "the propensity or predisposition to be adversely affected. Vulnerability encompasses a variety of concepts and elements including sensitivity or susceptibility to harm and lack of capacity to cope and adapt." (IPCC, 2014b, p 5)

This report focuses on the sensitivity and adaptive capacity components of vulnerability. Sensitivity is the degree to which something exposed could be affected by a climate hazard and may relate to physical attributes, like the building material of a house, or social, economic and cultural attributes such as age or socio-economic circumstances (Ministry for the Environment, 2019a). Various natural environments will also respond differently because they have a range of sensitivities to climate change drivers, with some reaching a tipping point or irreversibility sooner than others. Adaptive capacity refers to "the resources available for adaptation to climate change and variable or other related stresses, as well as the ability of a state to use these resources effectively in pursuit of adaptation" (Ministry for the Environment 2017c, p 98).

As discussed in section 1.2.3, governance risks often reduce the ability of actors to address risks from other domains by reducing adaptive capacity. Given this influence, it is important to acknowledge and explore the impacts of the priority governance risks on other domains and vice versa. Each risk related to other domains described in this report includes some discussion on the impact of governance risks on the adaptive capacity of that risk.

1.3.3 Consequence

New Zealand's Ministry of Civil Defence and Emergency Management describes consequence as the outcome of an event that may result from a hazard. It can be expressed quantitatively (for example, units of damage or loss, disruption period, monetary value of impacts or environmental effect), semi-quantitatively by category (for example, high, medium or low level of impact) or qualitatively (a description of the impacts) (adapted from Ministry of Civil Defence and Emergency Management, 2019).

Consequence is also often defined as the outcome of an event affecting objectives (ISO/IEC 27000:2014 and ISO 31000: 2009) (Ministry for the Environment, 2019a). In this report, a consequence rating is provided in each risk profile for three timeframes – now, 2050 and 2100 – with some discussion on how the risk is expected to change over time.

1.3.4 Adaptation decision urgency

The NCCRA risk assessment team presented the analysis findings by the urgency of the required adaptation.

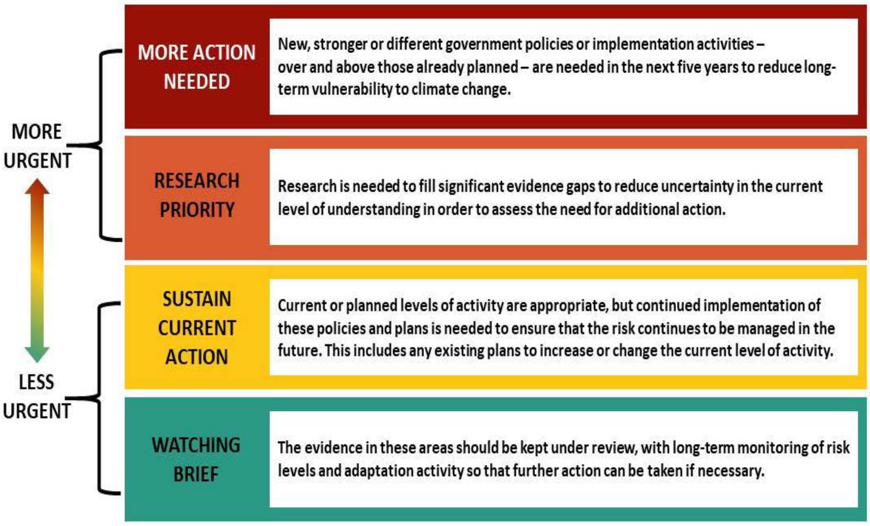
Urgency is defined as “a measure of the degree to which further action is needed in the next five years to reduce a risk or realise an opportunity from climate change” (Committee on Climate Change, 2016, p 5).

The NCCRA framework adopted the urgency categories from the 2017 UK Climate Change Risk Assessment (UK CCRA 2) (Committee on Climate Change, 2016) (see figure 1) and adapted them to the New Zealand context. The 2017 UK Climate Change Risk Assessment designed these categories to be mutually exclusive, so that each risk falls into a single category; because of this approach, the UK assessment has only one urgency category assigned to each risk. Applying this approach in the New Zealand context for the risks examined in stage 2 was impractical; given New Zealand is still in the early stages of planning for climate change, a more nuanced application of the urgency categories was adopted.

The NCCRA developed an ‘urgency profile’ for each risk. This profile considers the applicability of each of the urgency categories to each risk, then uses a weighted sum of the profile to calculate an overall urgency rating. The more urgent categories were weighted higher than the less urgent categories to calculate the overall urgency rating (figure 1 indicates the relative urgency of the categories). As such, each risk has an overview of the types of actions required, using the urgency categories, and is then assigned an overall rating to inform adaptation decision-making.

Figure 1: Adaptation urgency in the NCCRA

Urgency categories in the NCCRA framework (Committee on Climate Change, 2017):



MORE ACTION NEEDED	New, stronger or different government policies or implementation activities – over and above those already planned – are needed in the next five years to reduce long-term vulnerability to climate change.
RESEARCH PRIORITY	Research is needed to fill significant evidence gaps to reduce uncertainty in the current level of understanding in order to assess the need for additional action.
SUSTAIN CURRENT ACTION	Current or planned levels of activity are appropriate, but continued implementation of these policies and plans is needed to ensure that the risk continues to be managed in the future. This includes any existing plans to increase or change the current level of activity.
WATCHING BRIEF	The evidence in these areas should be kept under review, with long-term monitoring of risk levels and adaptation activity so that further action can be taken if necessary.

Application in the NCCRA:

Each risk was given a rating out of 100, according to the need for each of these types of action (four ratings in total).

The four ratings (weighted based on the associated level of urgency for that type of action) were then combined to provide a total rating for action urgency.

The overall urgency ratings are useful for comparing relative action urgency between risks in each domain. The ratings are less useful for comparing the relative urgency between risks in different domains.

2 Climate change in New Zealand

2.1 Overview

New Zealand is already experiencing the impacts of a changing climate and, due to past emissions, these impacts will continue far into the future. Global surface temperatures have warmed on average by about 1 degree Celsius since the late 19th century. In New Zealand, a warming of 1 degree was recorded between 1909 and 2018. The five warmest years, based on monthly mean temperatures, were 2016 (+0.84 degrees), 2018 and 1998 (tied on +0.80 degrees), 1999 (+0.74 degrees) and 2013 (+0.72 degrees), relative to the 1981–2010 average temperature (NIWA, 2019b).

The oceans have already warmed, and snow and ice have diminished (IPCC, 2013). Although regional climate trends and gravitational effects mean that sea level does not rise uniformly around the globe, between 1961 and 2018 a mean rate of sea-level rise of 2.44 millimetres per year was recorded across four long-term monitoring sites. This rate is more than double the mean rate of the previous 60 years (from the start of records in 1900 to 1960), which was 1.22 millimetres per year (Ministry for the Environment, 2017a).

This section provides an overview of climate change projections for New Zealand. Risks identified in the National Climate Change Risk Assessment for Aotearoa New Zealand (NCCRA) are likely to be sensitive to the degree of climate change.

Box 1: Key points from *Snapshot: Climate Projections for New Zealand* (Ministry for the Environment, 2016)

NIWA has developed climate projections for New Zealand, based on the broader global projections provided in the *IPCC Assessment Report 5*. NIWA's projections suggest New Zealand is likely to experience:

- higher temperatures, with an increase of about 1.0 degree Celsius by 2040 and about 3.0 degrees Celsius by 2090 under a high-emissions scenario (RCP8.5), in relation to the 1995 baseline. Slight gradients from north to south and from east to west are likely, with the greatest warming experienced in the northeast
- a change in daily precipitation extremes (very wet days), with an increase in western regions and the south of the South Island, and a decrease in extremes in the east of the North Island
- an increase in very extreme precipitation events (that is, those with a greater than two-year average recurrence interval) by a projected 5 per cent for five-day duration events, and 14 per cent for one-hour duration events, per degree of warming. Regional variability is uncertain; however, there will possibly be larger increases in the very north and the very south of the country
- an increase in the number of hot days and decrease in the number of frost and snow days
- increased frequency of dry days for much of the North Island, and for some parts of the South Island
- increased northeasterly airflow in summer and stronger westerlies in winter, particularly in the south
- increased frequency and intensity of droughts over time, particularly under a high-emissions scenario (RCP8.5). The strongest increases are over the northern and eastern North Island and along the eastern side of the Southern Alps

- an increase in storm intensity, small-scale wind extremes, and thunderstorms
- stronger ex-tropical cyclones that cause more damage through heavy rain, strong winds and storm surge.

2.2 Global context

It is accepted internationally that the climate is changing due to increasing quantities of greenhouse gases in the atmosphere. These changes have been observed in both global and regional climates, and warming due to human activity is recognised as unequivocal (IPCC, 2019). The warming of the atmosphere, Earth's surface and the oceans is driving rising sea levels and changes in rainfall and temperature patterns. Reducing greenhouse gas emissions can slow this trend, but climate change cannot be prevented entirely, due to historical emissions and the lag effects on atmospheric (and subsequently ocean) warming of these long-lived gases.

The climate modelling community has developed four pathways that explore a range of credible futures, based on possible scenarios for future greenhouse gas concentrations in the atmosphere (box 2). The Intergovernmental Panel on Climate Change (IPCC) has published extensive climate model simulations, which give an understanding of what future changes are likely across a range of climate variables for each of these emissions scenarios globally. NIWA has refined these global projections to give a higher spatial resolution for New Zealand, based on the *IPCC Assessment Report 5*, which enables localised risk assessments to be undertaken. An updated set of global projections, Assessment Report 6, is due to be released by the IPCC in 2021.

Box 2: Climate change scenarios used in the NCCRA

The projections and assessments outlined in this report are based largely on climate model projections using representative concentration pathways (RCPs). RCPs are scenarios of possible future emissions trajectories that encompass a range of possible climate policies. They include time series data of emissions and concentrations of greenhouse gases, aerosols and chemically active gases, as well as for land use and land cover. RCPs provide only one set of many possible scenarios that would lead to different levels of global warming (IPCC, 2019).

As under the NCCRA framework, for the initial risk screening (stage 1) the risk assessment team used projections for RCP8.5, to help identify and prioritise the most significant climate-related risks. These were then analysed further during the detailed risk assessment. Using RCP8.5 allows a greater breadth of impacts to be appraised and compared, because it presents a single high scenario of global emissions continuing at the present rate. RCP8.5 is a high greenhouse gas emissions scenario that is likely to occur if climate change policies are not implemented, leading to continued and sustained growth in atmospheric greenhouse gas concentrations (IPCC, 2019). It should not be seen as a 'worst-case' scenario, as more extreme climate changes are possible. The team also used RCP4.5 for the detailed risk assessment (stage 2), to consider the climate change risks for other trajectories if greater mitigation of greenhouse gas emissions is carried out.

Figure 2: **Global average surface temperature change from 2006 to 2100, as determined by multi-model simulations relative to 1986–2005**

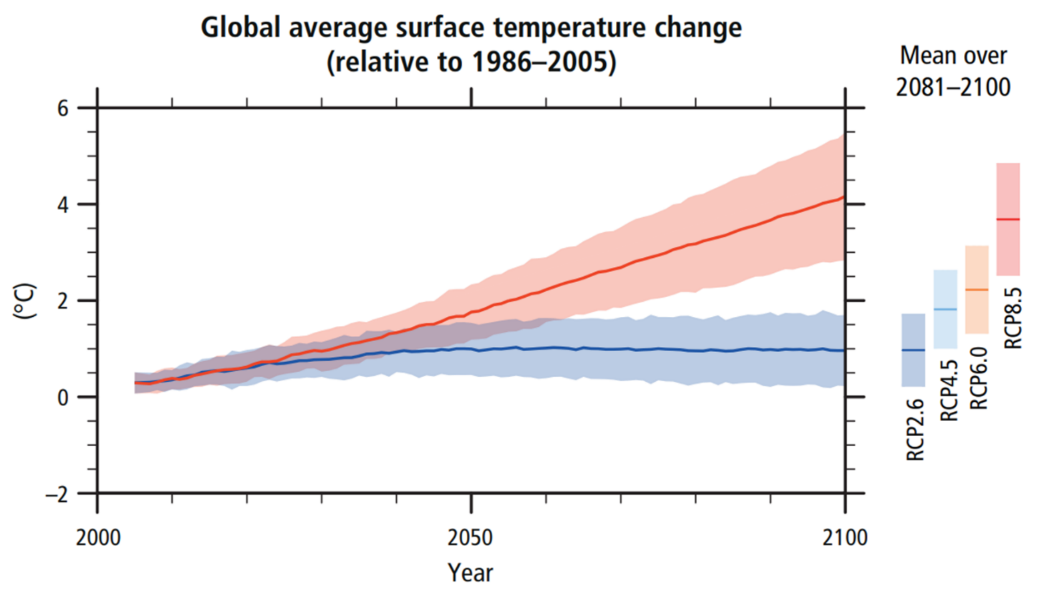
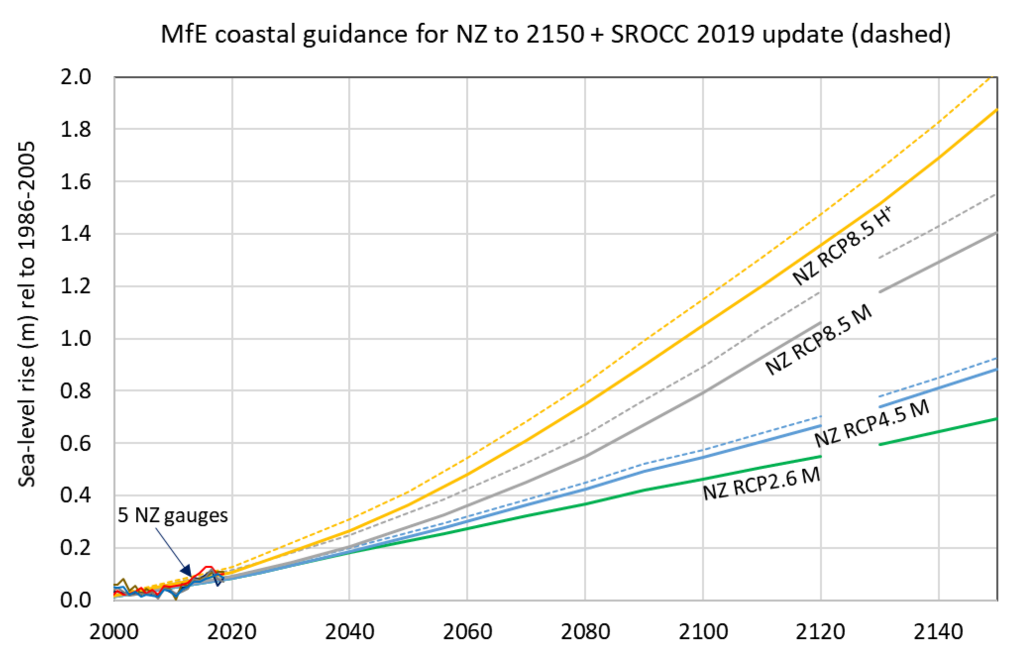


Figure 2 shows time series of projections and a measure of uncertainty (shading) for scenarios RCP2.6 (blue) and RCP8.5 (red). The mean and associated uncertainties averaged over 2081–2100 are given for all RCP scenarios as coloured vertical bars at the right-hand side of each panel (IPCC, 2019).

Figure 3: **Four sea-level rise (SLR) projections for New Zealand until 2150 from the Ministry for the Environment coastal guidance (Ministry for the Environment, 2017b) and the annual mean sea level series to 2018 from five tide gauges in New Zealand (Stats NZ, 2019a)**



The dashed lines in figure 3 show the increases in SLR for these New Zealand scenarios from the IPCC's 2019 *Special Report on the Ocean and Cryosphere in a Changing Climate* (SROCC).

2.3 Climate projections

Natural variations have always played a part in New Zealand's climate and will continue to do so; but climate change is expected to shift the range and the pattern of this variability. New Zealand is observing gradual changes, such as in sea-level rise and higher average temperatures, and more frequent and severe extreme weather events such as heatwaves and coastal flooding and changing seasonality (Ministry for the Environment, 2018). Climate change poses significant additional risks to New Zealand's communities and environment (both natural and built), and will require adaptive responses that increase resilience to its impacts.

NIWA developed the New Zealand climate change projections used in this report by downscaling higher-resolution global climate models released in the IPCC's *Fifth Assessment Report* (IPCC, 2013). These statistically and dynamically downscaled data help local decision-makers and researchers better understand current and potential changes in New Zealand's climate. The results of these models are published in *Climate Change Projections for New Zealand* (Ministry for the Environment, 2018) and *Our Future Climate New Zealand* (NIWA, 2016a). Sea-level rise projections for New Zealand that can be used in planning, assessments and design are available in the Ministry's coastal guidance (Ministry for the Environment, 2017b), as figure 3 shows. A recent IPCC report (IPCC, 2019) indicates further projected increases for the higher scenarios (for example, for New Zealand by 2100, an extra 0.10 metres for RCP8.5 and 0.03 metres for RCP4.5, as figure 3 shows).

Downscaling techniques include up to 41 different global climate models for 'statistical' methods, and 24 simulations for 'dynamical' methods (six global models run through a regional climate model for the four RCPs). Due to the complexities of New Zealand's climate systems, the confidence of projected changes is communicated by assessing model agreement; that is, there is a higher confidence in the direction of change when a greater number of models produce similar outputs. Most figures in this chapter were produced by calculating the changes from each model separately and then averaging them – to produce what is called the 'ensemble-mean'. The ensemble-mean of the models agrees better with observed historical changes than any single model by itself.

While these projections provide plausible futures under climate change, there is inherent uncertainty in any projection of future climate change. This is due to:

- limitations in understanding of climate processes and how they are represented in climate models
- uncertainty in natural climate variability
- future social and economic changes
- the process of downscaling to more detailed spatial and temporal scales, which increases the envelope of uncertainty (Wilby and Dessai, 2010).

Box 3: Consistency in time periods and RCPs

The climate projections for 2031–50 are described as the medium term, or 2040, representing the average for the 20-year period. The climate projections for 2081–2100 are described as the long term, or 2090, representing the average of that 20-year period. Unless otherwise specified, all projections in this chapter refer to a baseline time period of 1996–2005, and represent projections under an RCP8.5 emissions scenario.

2.4 Climate projections and hazards

Error! Reference source not found. shows a summary of projected changes to New Zealand's climate. Unless otherwise specified, all projections are based on RCP8.5, and have a baseline time period of 1996–2005.

Table 5: Summary of climate change projections for New Zealand (Ministry for the Environment, 2018)

Climate variable	Description of change	Change in 2040	Change in 2090
Temperature			
Mean temperature	Overall increase, with greatest changes at higher elevations. Warming greatest in summer and autumn, and least in winter and spring.	+1.0°C	+3.0°C
Minimum and maximum temperatures	Overall increase, with greatest changes at higher elevations, particularly for maximum temperature.	Not available	Daily range increases by up to 2°C
Number of cold nights (<0°C)	Overall decrease in number of cold nights.	Average 50% decrease	Average 90% decrease
Number of hot days (>25°C)	Increase in number of hot days, particularly in already warm regions.	Average 100% increase	Average 300% increase
Rainfall			
Average rainfall	Regional and seasonal variation, generally an annual pattern of increases in west and south and decreases in north and east.	Substantial variation around the country, increasing in magnitude with increasing emissions.	
Number of dry days	More dry days throughout the North Island and in inland South Island.	Not available	Up to 10 or more dry days per year (about 5% increase).
Extreme rainfall events	Increase everywhere.	The 1-in-10-year event up 11% for 1-hour duration, up 5% for 5-day duration.	The 1-in-10-year event up 34% for 1-hour duration, up 15% for 5-day duration.
Snow	Large decreases confined to high-altitude or southern regions of the South Island.	Not available	Snow days per year reduce by 30 days or more.
Drought	Increase in severity and frequency, especially in already dry areas.	Not available	About 50 mm increase per year on average, in July–June potential evapotranspiration deficit (PED).[1]
Other variables			
Pressure and wind	Varies with season, on average more northeast airflow in summer. Strengthened westerlies in winter.	Generally, the changes in pressure are only a few hectopascals, but the spatial pattern matters for mean wind changes.	
Extreme wind speeds	General increase. Most robust increases occur in the southern half of North Island, and throughout the South Island.	Up about 10% in parts of the country.	

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[1] PED is the measure for lack of soil moisture, a major source of plant stress.

Climate variable	Description of change	Change in 2040	Change in 2090
Storms	Likely poleward shift of mid-latitude cyclones and possibly also a small reduction in frequency.	Specific projections are not available for storms in New Zealand.	
Solar radiation	Varies around the country and with season. West Coast shows the largest changes by 2090: summer increase (about 5%) and winter decrease (5%).	Seasonal changes generally lie between –5 and +5%.	
Relative humidity	Overall decreasing, with largest decreases in South Island in spring and summer.	Not available	About 5%, especially in the South Island.

Note: Where numbers are provided, they are the mean change for the country, averaged over all 41 models for the 20 years centred on 2040 or 2090.

2.5 Temperature

2.5.1 Average temperature

Table 6: Average temperature

Average temperatures

Description

Estimation of surface temperatures, which influence water and coastal-sea temperatures.

Projections

The pattern of annual average warming is expected to be largely uniform across the country, with slight gradients from north to south and from east to west. The North Island is expected to experience slightly greater warming than the South Island. Warming is generally projected to be highest in summer and autumn, and lowest in winter and spring.

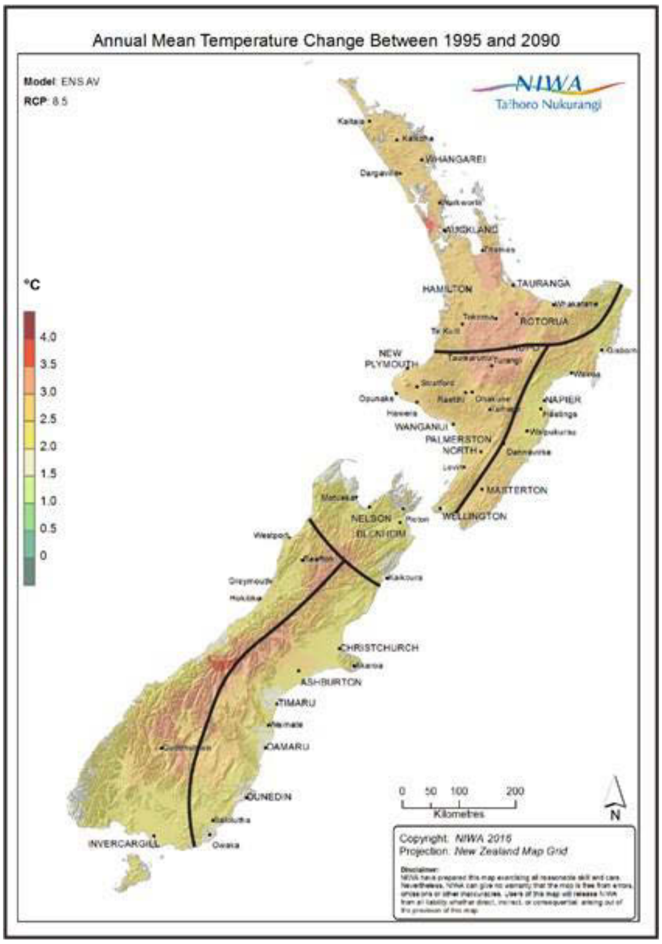
By 2040 mean temperatures in New Zealand are projected to increase by about 1.0 degree Celsius from the 1995 baseline, and by 2090 by about 3.0 degrees. This warming trend is consistent across the majority of New Zealand, with an increased rate of warming projected towards the north and for higher-altitude areas on the South Island.

Table 7: Mean projected change (and 5–95% confidence interval range) in annual mean temperature for 2040 and 2090 under RCP8.5

	2040	2090
Annual mean temperature	1.0 (0.5–1.7)	3.0 (2.0–4.6)

Map

Figure 4: Change in annual mean temperatures 1995–2090 under RCP8.5 (NIWA, 2016a)



For more information on the direction of change for each zone, see appendix B *Higher mean temperatures: air and water*.

2.5.2 Heatwaves and number of hot days

Table 8: Heatwaves and number of hot days

Number of hot days

Description

The number of days over 25 degrees Celsius.

Projections

As average temperatures rise, the number of days with a maximum temperature of over 25 degrees is also projected to rise. On average fewer than 15 hot days historically occur each year along the western coast of the South Island, while the North Island and inland areas of the South Island historically experience up to about 27 hot days per year.

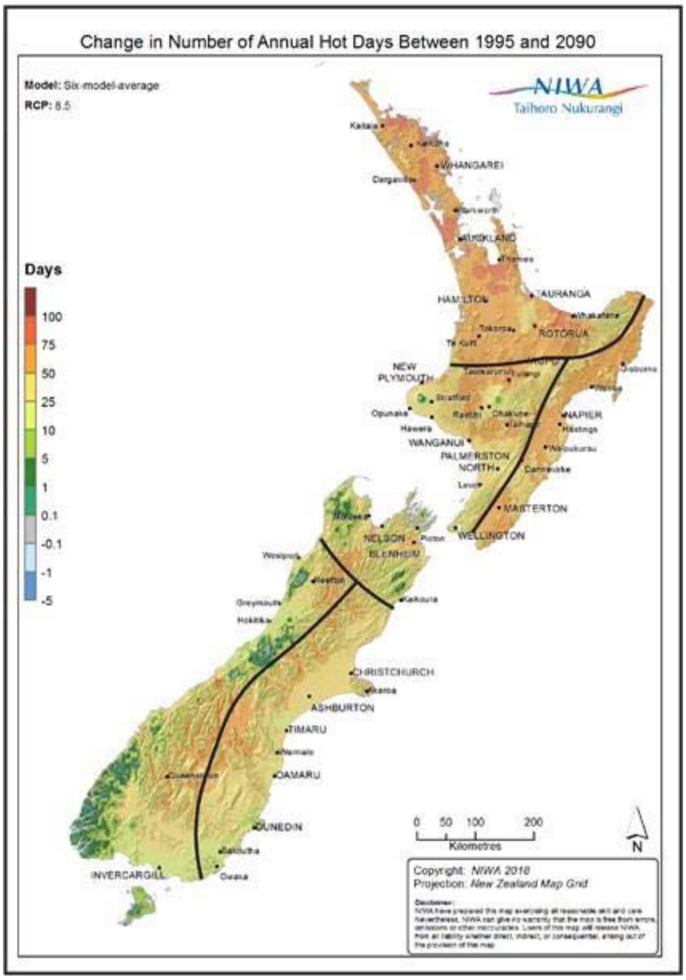
Figure 5 illustrates that, generally, the number of hot days in New Zealand is expected to increase towards the northern and inland parts of the country.

In 2040, the average projected increase in the number of hot days is 71 per cent (34–135 per cent increase) for all regions. In 2090, the projected increase is 286 per cent (128–634 per cent increase).

For more information on the direction of change for each zone, see appendix B *Heatwaves: increasing persistence, frequency and magnitude*.

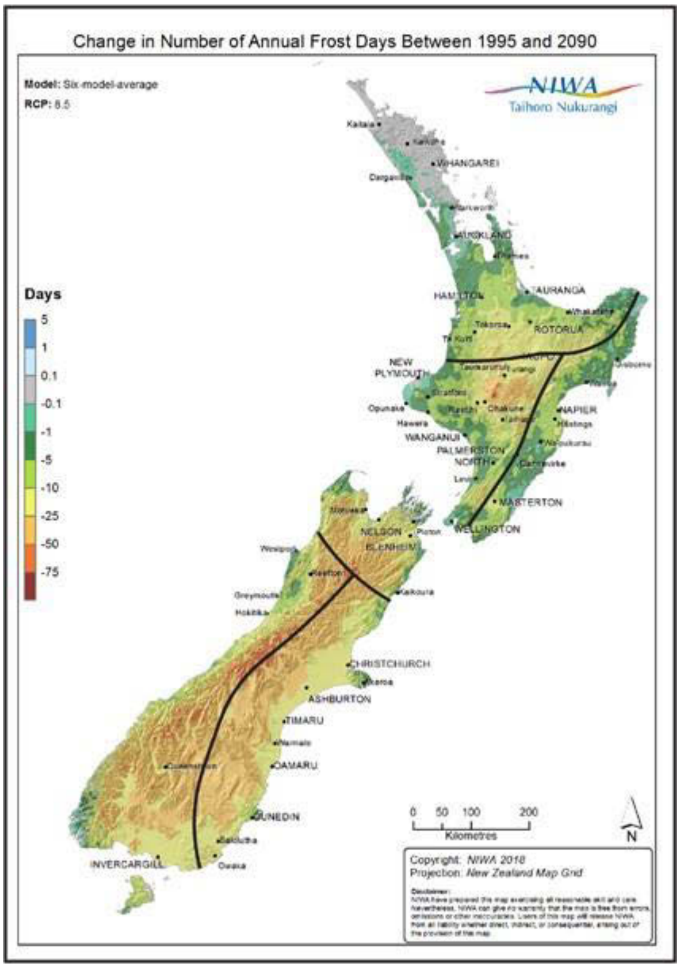
Map

Figure 5: Change in number of hot days 1995–2090 under RCP8.5 (NIWA, 2016a)



2.5.3 Cold (frosty) nights

Table 9: Cold (frosty) nights[2]

<table>
<tr><th colspan="2">Cold (frosty) nights</th></tr>
<tr><th>Description</th><th>Map</th></tr>
<tr><td>The number of days when minimum temperatures drop below 0 degrees Celsius (usually occurring overnight).
Projections
As average temperatures rise, the number of cold days is projected to decrease in frequency across the country. Average reductions are projected to vary from 49 per cent in 2040, through to 86 per cent in 2090, across all regions (figure 6).
The number of cold days is projected to show much larger decreases in regions that already exhibit cooler temperatures, such as those at higher altitudes in both the North and South Islands.
For more information on the direction of change for each zone, see appendix B <i>Reducing frost, snow and ice cover</i>.</td><td>Figure 6 Change in number of cold days 1995–2090 under RCP8.5 (NIWA, 2016a)

 </td></tr>
</table>

2.5.4 Wildfire

Table 10: Wildfire

Wildfire
Description
Wildfire risk is measured by the fire weather index (FWI) and daily severity rating (DSR) on daily time scales, and seasonally as the seasonal severity rating (SSR). Higher FWI and DSR values indicate a more intense fire development, and higher SSR numbers indicate a greater seasonal risk. Wildfire is an extreme climatological event and can be ignited by non-climate sources such as arson, machinery usage or power line faults.
Projections
On average, all climatological measures of wildfire risk will increase across New Zealand to the end of the century. The four main drivers of wildfire are all expected to change to promote an increase in wildfire risk: • increased temperature

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[2] Cold (frosty) nights is a climate hazard described as the days when minimum temperatures drop below 0°C, which usually occurs overnight.

- decreased relative humidity
- increased wind speed
- decreased rainfall.

These variables are used to calculate the dryness and availability of the land surface fire fuel, and the spread and ferocity of the fire given these weather conditions. Temperature and relative humidity are the best indicators of climatological wildfire risk, while wind speed and precipitation stoke or quench the risk on the daily time scale.

The SSR is highest in the east coast of the North Island (Gisborne, Hawke's Bay and Wellington), inland areas of Otago and south Canterbury (central Otago, Queenstown-Lakes and Mackenzie), and northern parts of Marlborough. The SSR is lowest at elevations greater than about 800 metres, as well as the entire West Coast region, and Southland and coastal Otago.

The fire season length is the number of days exceeding a particular DSR. Regionally, the fire risk is projected to increase by about 10 per cent per decade for all measures, including season length. The cities and towns with the highest risk include Lower Hutt, Blenheim, Wellington and Hastings. These locations have a 'moderately vigorous surface fire' season length currently of 14–20 days, which will increase by 10–15 per cent by the middle of this century.

For more information on the direction of change for each zone, see appendix B *Increasing fire-weather conditions: harsher, prolonged season*.

2.6 Precipitation

2.6.1 Average precipitation

Table 11: Average precipitation

Average precipitation	
Description	**Map**
Changes to seasonal average liquid (for example, rainfall) and solid (for example, snowfall) precipitation.	
Projections	

Precipitation projections are highly variable by region and season. The Ministry for the Environment (2016) notes that the overall pattern demonstrates a reduction in the north and east of the North Island, and increases almost everywhere else, especially on the South Island West Coast. In summer, it is likely that conditions will be wetter in the east of both islands, with drier conditions in the west and central North Island. The largest rainfall changes by the end of the century (2090) will be for particular seasons rather than annually.

Figure 8 shows that in summer, precipitation is generally expected to either decrease (by around 15 per cent) or show little change for most of the country, except for the west coast of the South Island, and parts of Canterbury (around 25 per cent increase).

In winter, precipitation changes show a pattern of increases in the west and south (up to 40 per cent) and decreases in the east and north of the country (around 15 per cent).

For more information on the direction of change for each zone, see appendix B *Change in mean annual rainfall*.

Figure 7: Change in annual mean rainfall 1995–2090 under RCP8.5 (NIWA, 2016a)

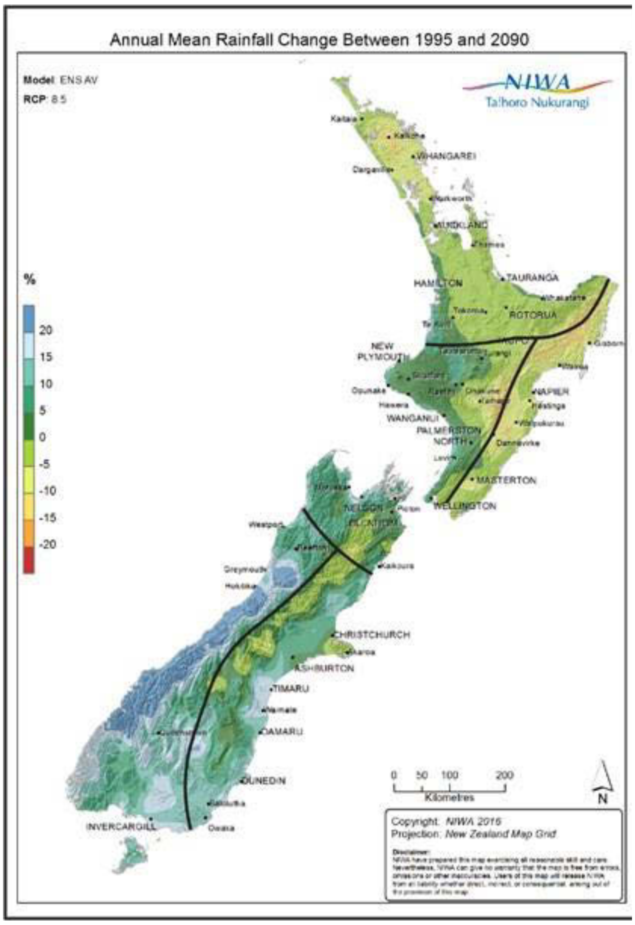
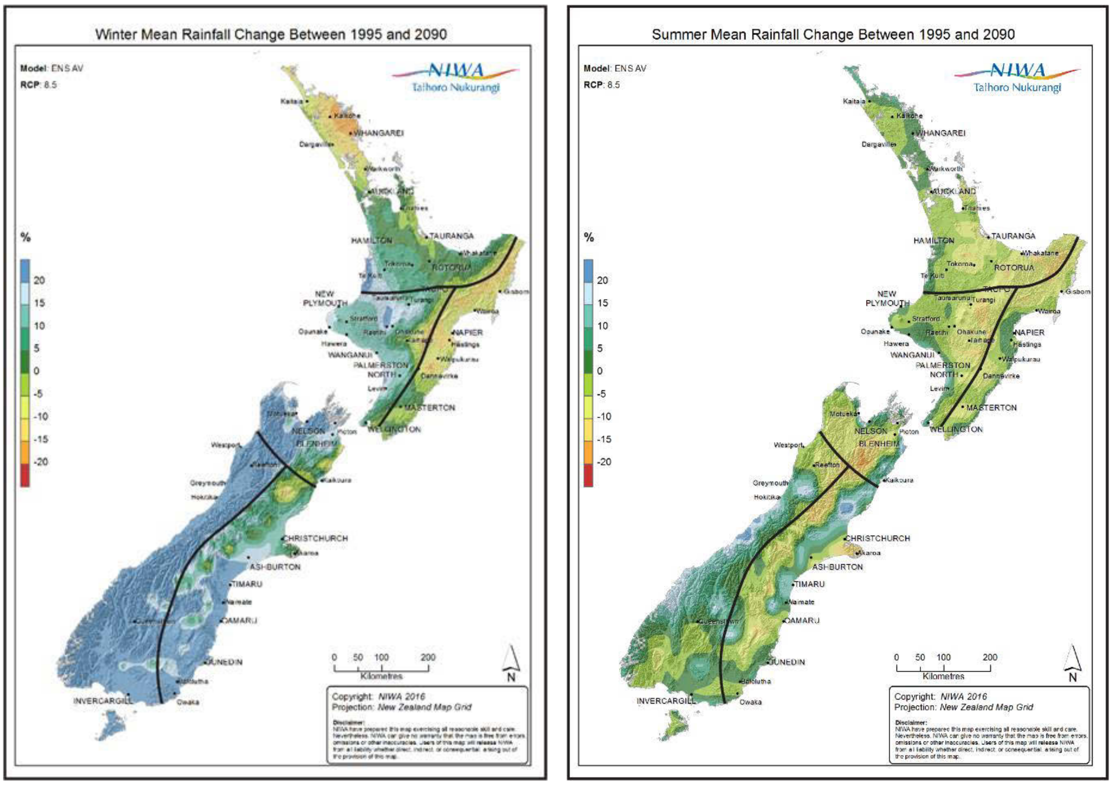


Figure 8: Projected changes in precipitation (%) for summer (Dec, Jan, Feb) (left) and winter (Jun, Jul, Aug) (right) for 2081–90 under RCP8.5 (NIWA, 2016a)



2.6.2 Wet days and heavy rainfall

Table 12: Wet days and heavy rainfall

Wet days and heavy rainfall

Description

Measured by the number of days with rainfall over 25 millimetres.

Heavy rainfall is the 99th percentile of the daily rainfall distribution from 1986–2005, representing, on average, the three wettest days each year. Heavy rainfall events are influenced by rainfall and by temperature, because a warmer atmosphere can hold more moisture.

Projections

Large increases are expected in extreme rainfall everywhere in the country for rare events, as shown in figure 9 and figure 10. Northland is the place most likely to see the biggest increases in extreme rainfall, due to a projected increase in ex-tropical cyclones (which are excluded from the rainfall projections used for this assessment). Other areas, such as Otago and Southland, are projected to experience increases of over 20 per cent more wet days, and a 30 per cent increase in the intensity of 99th percentile rainfall events.

For more information on the direction of change for each zone, see appendix B *Increasing hail severity or frequency*; *Increased storminess and extreme winds/rainfall*.

Maps

Figure 9: Change in number of wet days (>25 mm daily rainfall) 1995–2090 under RCP8.5 (NIWA, 2016a)

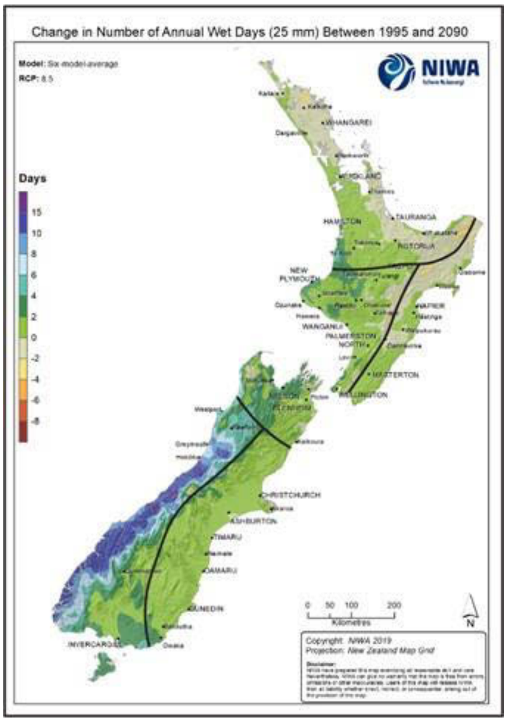
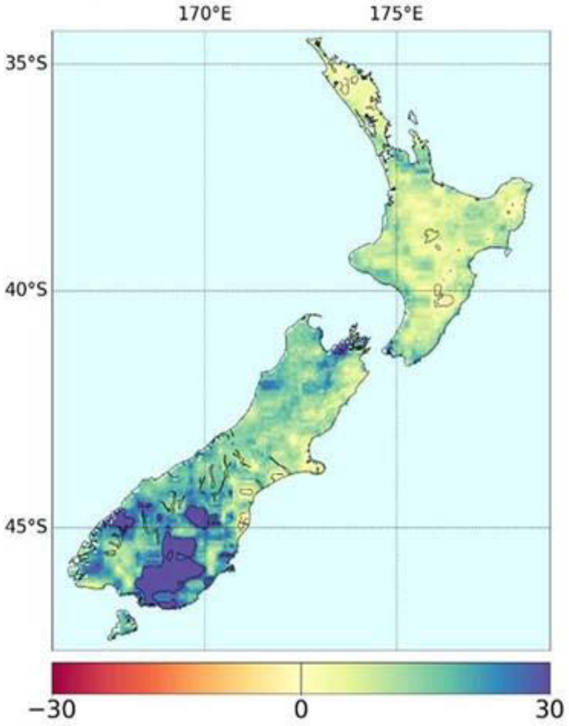


Figure 10: Projected changes in extreme precipitation (99th percentile event) (%) 1995–2090 under RCP8.5 (Ministry for the Environment, 2018)



2.6.3 Snow days

Table 13: Snow days

Snow days

Description

The number of precipitation days where the mean temperature is below the freezing point.

Projections

The number of snow days each year is expected to decrease across New Zealand, with the largest reduction in the coldest regions, which have a large number of snow days in the present climate. For example, in the South Island high country and inland basins a reduction in the snow season of 30 days or more is typical for the end-of-century results.

Less snow storage over winter will also decrease seasonal snowmelt and river flow. However, the potential change in total snow amounts (volume) needs further analysis. In general, the model simulations show a reduction in total snow amount, along with a reduction in snow days. It is possible snow amount could increase with rising temperatures in special circumstances; a warmer atmosphere can hold more moisture, and on a day where the temperatures are higher but still below freezing, there is the potential for heavier snowfalls. No analysis of snow extremes has been carried out at this point.

For more information on the direction of change for each zone, see appendix B *Reducing frost, snow and ice cover.*

2.7 Drought

Table 14: Drought

Drought

Description

Drought is projected using the potential evapotranspiration deficit (PED) – the cumulative sum of the difference between potential evapotranspiration and precipitation over 12 months.

Projections

PED changes are largely based on, and consistent with, the temperature and precipitation change patterns in the regional climate model. Changes in other climate variables (solar radiation, relative humidity, and wind) also influence calculated PED changes, but to a lesser degree.

Projected future changes in PED are well understood for most of New Zealand and these are considerable, especially in the drought-prone northern and eastern coasts of the North and South Islands. By 2090, a consistent increase in PED of 50 millimetres or more each year is expected on average in July–June (that is, a 50-millimetre deficit in rainfall) for much of the North Island. The strongest changes are expected over the northern and eastern regions, and in the northeastern and central South Island east of the main divide, indicating long-term drying of these regions.

For more information on the direction of change for each zone, see appendix B *More and longer dry spells and drought*.

2.8 Wind

Table 15: Wind

Strong winds	
Description	**Map**
Strong winds are those that exceed the 99th percentile, determined by ranking daily values over the projection period.	**Figure 11: Projected changes in strongest daily average wind speed per year (99th**
Projections	
The largest increases in 99th percentile daily wind speed are projected for coastal Canterbury and central Otago, with increases of over 10 per cent by the end of the century. Figure 11 suggests little change, or even a decrease, in	

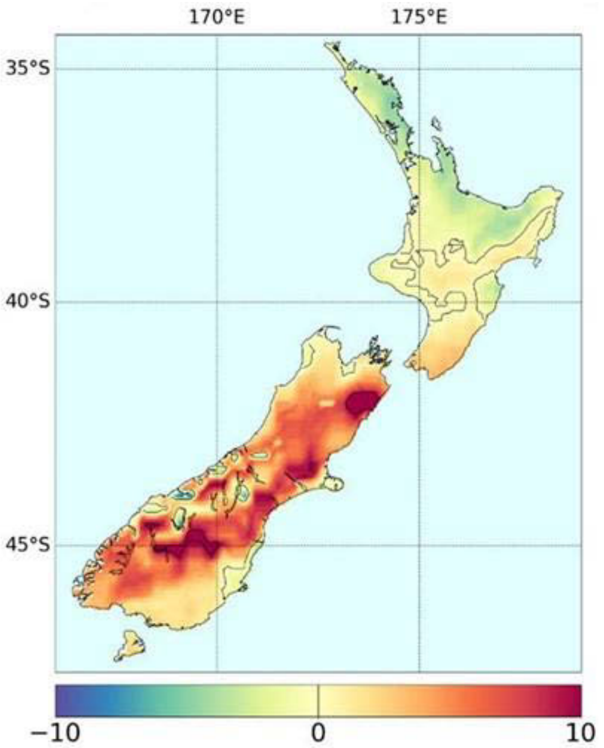
extreme daily winds in Northland and Bay of Plenty.

This may be an underestimate, and NIWA (2016b) notes that it is possible the geographic area of the regional climate model is too small to properly detect the effect of ex-tropical cyclones entering the New Zealand region. In global models, tropical cyclones projections are underestimated because of the low model resolution, and the small scale of these intense circulations (NIWA, 2016b).

Analysis of changes in extreme hourly winds (for example, 1 per cent annual exceedance probability (AEP)), including tornadoes, is not available.

For more information on the direction of change for each zone, see appendix B *Increased storminess and extreme winds/rainfall*.

percentile speeds), 1995–2090, under RCP8.5



2.9 Solar radiation

Table 16: Solar radiation

Solar radiation	
Description	**Map**
Solar radiation is dependent on astronomical factors, rainfall and cloudiness.	
Projections	

Solar radiation is typically three to four times higher in summer than in winter. The highest solar radiation levels are recorded in the Nelson–Marlborough and central Otago regions in summer, and in the northern North Island and Nelson–Marlborough regions in winter.

Climate modelling projects solar radiation to increase by up to 10 per cent on the west coast of the South Island in summer, and smaller increases elsewhere, with the notable exception of coastal Canterbury where sunshine is predicted to decrease on average compared with a 1995 baseline. The reduced summer sunshine levels in coastal Canterbury are consistent with increased rainfall in that region. The winter changes are almost the reverse of the summer ones, with an approximate 5 per cent decrease in solar radiation in western parts of the North Island, and decrease of 10 per cent or more in the western and southern South Island. The eastern North Island is projected to have an increase in winter sunshine levels, as shown in figure 12 and figure 13.

Figure 122: Change in annual mean surface radiation 1995–2090 under RCP8.5 (NIWA, 2016a)

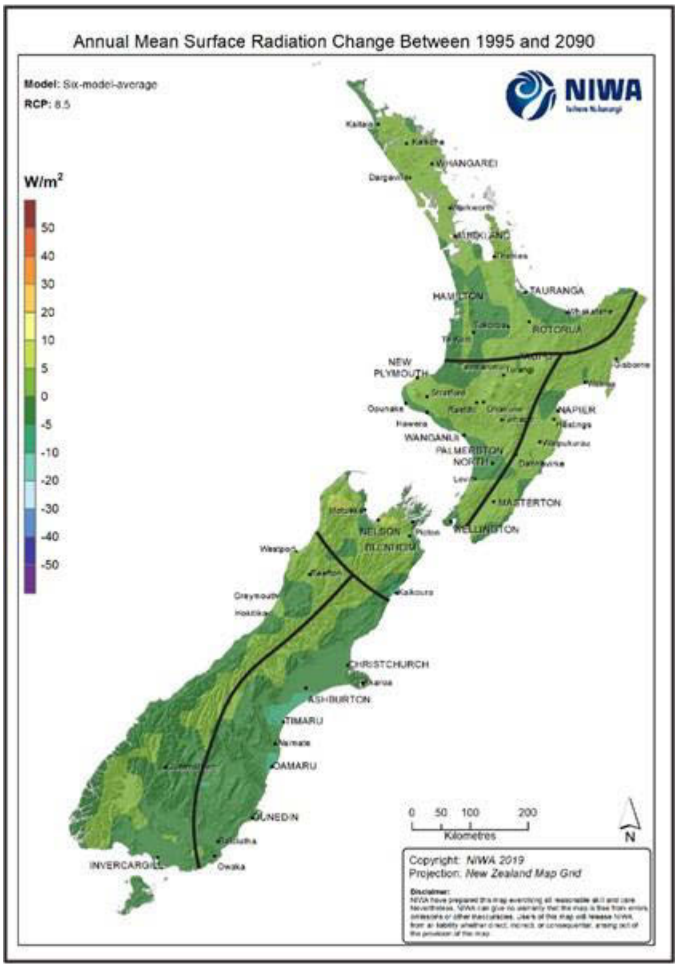
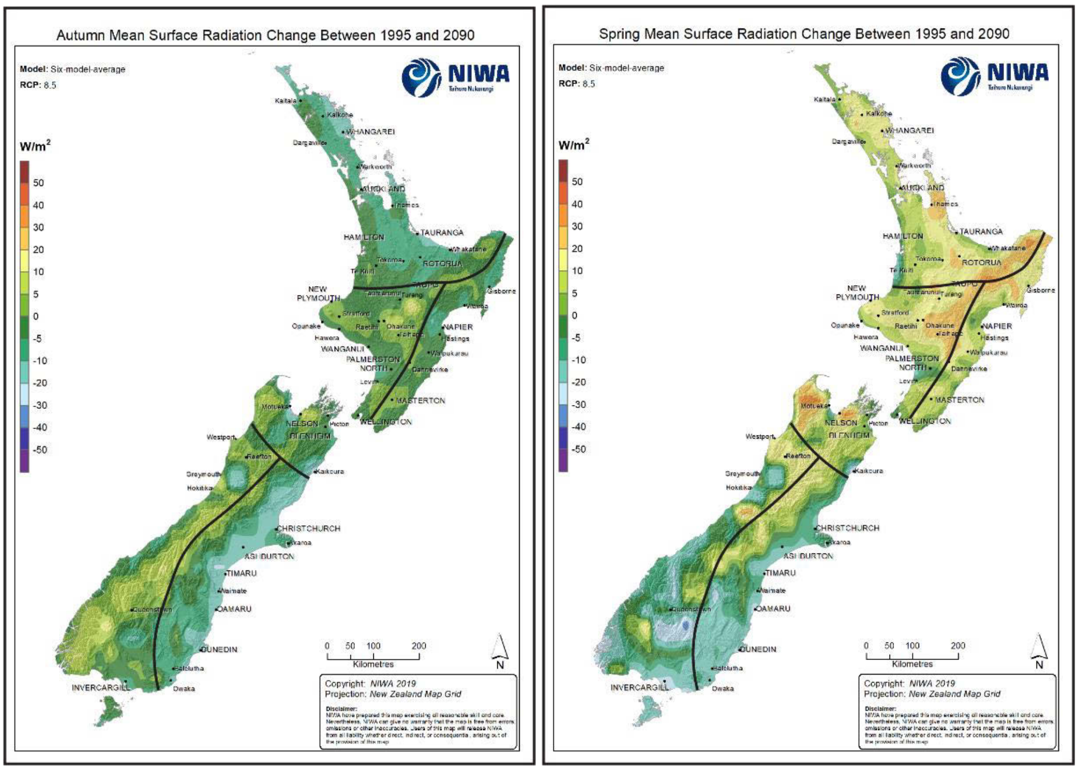
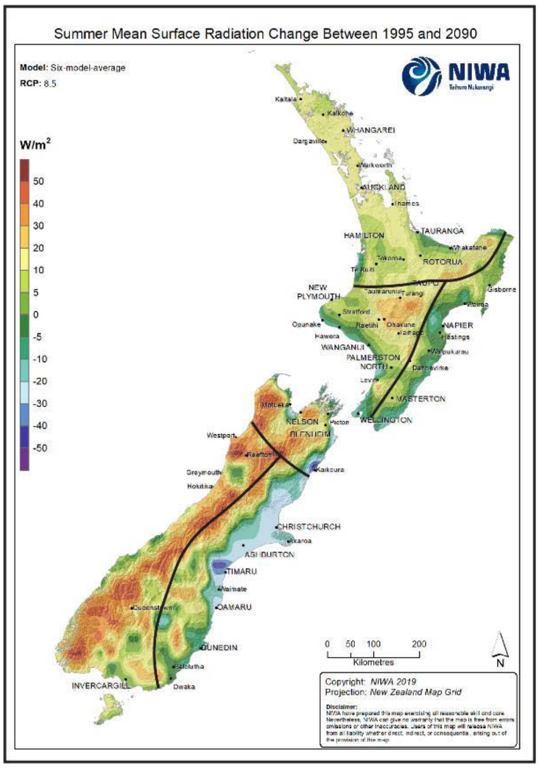
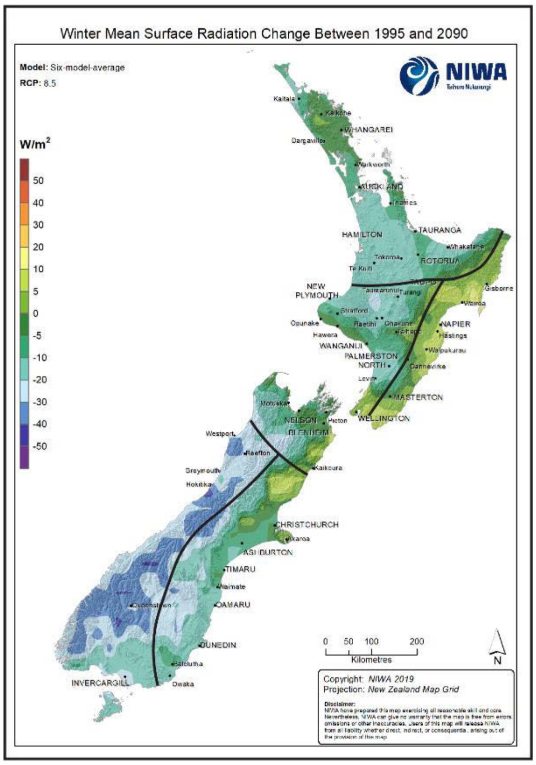


Figure 13: Change in seasonal surface radiation 1995–2090 under RCP8.5 [W/m²] (NIWA, 2016a)







2.10 Relative humidity

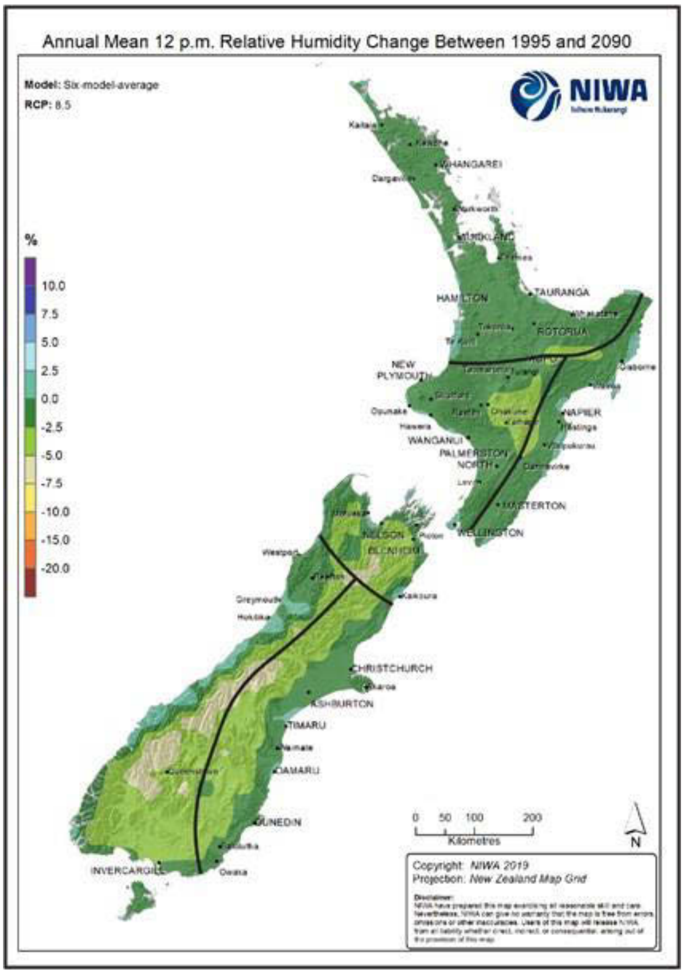
Table 17: Relative humidity

Relative humidity	
Description	**Map**
Relative humidity is a function of rainfall, temperature and solar radiation.	
Projections	

Relative humidity projections show reduced relative humidity almost everywhere in all seasons (figure 14), with the largest decreases in the South Island. The only notable exception to this pattern is an increase in relative humidity in a narrow strip down the West Coast of the South Island in winter, a reflection of increased rainfall, reduced number of dry days and reduced solar radiation.

For more information on the direction of change for each zone, see appendix B *More and longer dry spells and drought*.

Figure 14: Change in annual mean relative humidity 1995–2090 under RCP8.5 (NIWA, 2016a)



2.11 Coastal and marine

2.11.1 Mean sea-level rise

Table 18: Mean sea-level rise

Sea-level rise
Description

Relative sea-level rise is a measure of the absolute change in sea level combined with local uplift, subsidence, or vertical land movement caused by tectonic activity. This measure is more useful for understanding local and regional implications than the absolute change in sea level (which does not account for land movement). Relative sea-level rise includes:

- changes in ocean dynamics, heat content, and salinity (including thermal expansion of water as its temperature increases)
- melting and movement of land ice sheets such as in Antarctica and Greenland and mountain glaciers
- net changes in freshwater storage (reservoirs) and groundwater pumping
- changes in Earth's gravitational field and crustal height due to the redistribution of mass between land-ice and the ocean
- glacial isostatic adjustment, or post-glacial rebound, which is the ongoing movement of land once unburdened by the weight of glaciers (NOAA, 2018)

Sea-level rise

Description

- vertical land movement due to seismic events, ongoing inter-seismic slow slip, local groundwater and hydrocarbon withdrawal, and natural sediment or peat compaction.

Projections

Globally, sea levels have risen by 1.5 millimetres each year during 1901–90, accelerating to 3.6 millimetres per year during 2005–15 (IPCC, 2019).

Percentiles are used to quantify the distribution of the various sea-level rise projections for each RCP, with the median representing the 50th percentile. Median sea-level rise for the wider New Zealand region for RCP8.5, based on the latest projections, is projected to reach 0.28 metres in the near future (2040) and 0.79 metres in the next 70 years (2090), but could be higher (see table 19 for the RCP8.5 H^+ scenario[3]) if the global emissions trajectory follows RCP8.5.

The recently published *Special Report on the Ocean and Cryosphere in a Changing Climate* (SROCC) (IPCC, 2019) updates these projections, and reviews new findings published since the *Fifth Assessment Report* (IPCC, 2014). Compared with the *Fifth Assessment Report*, the SROCC revises the late-century contribution from the Antarctic ice sheet higher.

Table 19: Projected median sea-level rise (metres above 1986–2005 baseline) for the wider New Zealand region under RCP8.5 and RCP4.5, shown by the top three scenarios (Ministry for the Environment, 2017b)

	Mid-century (30 years)	End of century (80 years)
RCP8.5: *Coastal Hazards and Climate Change: Guidance for Local Government* (Ministry for the Environment, 2017b): median and (H^+) for New Zealand	0.28 m (0.37 m) [2050]	0.79 m (1.05 m) [2100]
RCP8.5: Updated rise for New Zealand including offsets from *IPCC Special Report on the Ocean and Cryosphere in a Changing Climate* (IPCC, 2019) – median and (H^+) for New Zealand	0.33 m (0.42 m) [2050]	0.89 m (1.15 m) [2100]
RCP4.5: *Coastal Hazards and Climate Change: Guidance for Local Government* (Ministry for the Environment, 2017b): median for New Zealand	0.24 m [2050]	0.55 m [2100]
RCP4.5: Updated rise for New Zealand including offsets from *IPCC Special Report on the Ocean and Cryosphere in a Changing Climate* (IPCC, 2019) – median for New Zealand	0.26 m [2050]	0.58 m [2100]

Regions within New Zealand will also be affected by vertical land movement, and local changes in tides (for example, harbours and estuaries) need to be considered, as each region needs to adapt to the local relative sea-level rise.

For more information on the direction of change for each zone, see appendix B *Coastal and estuarine flooding: increasing persistence, frequency and magnitude; Sea-level rise and salinity stresses on brackish and aquifer systems and coastal lowland rivers;* and *Increasing coastal erosion: cliffs and beaches*.

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[3] A higher, more extreme upper 83rd percentile RCP8.5 scenario.

2.11.2 Ocean temperature

Table 20: Ocean temperature and marine heatwaves

Ocean temperature and marine heatwaves
Description
Ocean temperature is the water temperature close to the ocean's surface. Marine heatwaves occur when the seawater temperature exceeds a seasonally varying threshold (usually the 90th percentile) for at least five consecutive days.
Projections
Changes in ocean surface temperatures are already being experienced globally, although regional variations are significant. New Zealand straddles the boundary between subtropical and subantarctic waters, with its climate influenced by the Tasman Sea and the Southern Ocean (Law et al, 2016). Projections for the southwest Pacific show an increase in sea surface temperature by 2040 and 2090, regardless of RCP. The mean increase from the present day (taken to be the 30-year period between 1976 and 2005) is about 1 degree Celsius by 2040, and about 2.5 degrees by 2090 for RCP8.5, with the latter representing a 16 per cent increase relative to present-day sea-surface temperature (Law et al, 2016). The largest absolute temperature change in the New Zealand exclusive economic zone (EEZ) occurs in the Tasman Sea under both scenarios and both timeframes, with warming exceeding 3.1 degrees for 2090 under RCP8.5. According to Australian research (Hobday et al, 2016), warm sea-surface temperature events are considered marine heatwaves if they last for five or more days, with temperatures warmer than the 90th percentile, based on a 30-year historical baseline. They can extend up to thousands of kilometres. Marine heatwaves are projected to increase in frequency and intensity with ongoing atmospheric and ocean warming (Law et al, 2016). In New Zealand, marine heatwaves are already occurring in parts of the Tasman Sea. For more information on the direction of change for each zone, see appendix B *Marine heatwaves: more persistent high summer sea temperatures*.

2.11.3 Ocean chemistry

Table 21: Ocean chemistry

Ocean chemistry
Description
Ocean acidification is caused by the uptake of carbon dioxide by the oceans, increasing their acidity (that is, reducing their pH). This is caused by increasing atmospheric greenhouse gas concentrations.
Projections
The longest record of acidity of New Zealand's oceans is from measurements in the subantarctic ocean off the Otago coast. Since 1998, the pH in the east subantarctic ocean had an average decrease of 0.0015 units/year (Ministry for the Environment, 2016). Ocean pH is projected to decrease by 2040 and 2090, regardless of RCP. The pH of surface water will decline by 0.33 under RCP8.5, with the resulting pH (7.77), and associated rate of change in pH, being unprecedented in the last 25 million years (Law et al, 2016). The Chatham Rise region has greater interannual pH variation than the EEZ mean, with a higher but not significantly different pH at 2100, due in part to higher phytoplankton productivity. As a result, carbon dioxide uptake in this region is likely to be higher (Chiswell et al, 2013). For more information on the direction of change for each zone, see appendix B Ocean chemistry changes: nutrient cycling and pH changes .

3 Natural environment domain | Rohe taiao

3.1 Domain description

The natural environment domain includes all aspects of the natural environment that support the full range of our indigenous species, he kura taiao – living treasures, and the ecosystems they form in terrestrial, freshwater and marine environments. The links between the natural environment and other domains, particularly the human and economic domains, mean that impacts on New Zealand's natural environment have cascading impacts in other domains. Box 4 outlines a Māori perspective on this domain and gives an overview of the significance of the risks to Māori values and wellbeing.

Box 4: Māori perspective on rohe taiao – the natural environment domain

Rohe taiao | natural environment domain

Climate change risks to the rohe taiao (natural environment) are profoundly significant to Māori due to their impact on human–environment relationships, expressed through whakapapa (genealogy) – the descent of all living things, such as maunga (mountains) and awa (rivers) from creation to present day. This profound connection means that the rohe taiao is inextricably linked to the risks outlined in the rohe tangata (human domain) and to people's wellbeing.

The risks presented in this section include:

- the ability to meet responsibilities of kaitiakitanga (duties of care, stewardship or guardianship of the environment)
- the loss of specific knowledge surrounding mahinga kai (food-gathering areas or sites) and the tikanga (culture and customs) associated with such practices
- the ability of tangata whenua (local people) to maintain their traditional relationships with taonga species as those species decline in their abundance or shift in their distribution.

These relationships, knowledge and skills have been widely acknowledged as critical to Māori wellbeing and community resilience. Some Māori, along with other New Zealanders, will also be particularly affected by cascading impacts into economic activities (for example, fishing and tourism).

3.2 Snapshot of issues and themes

New Zealand's natural environments range from alpine ecosystems up to nearly 4000 metres above sea level, to ocean trenches more than 10,000 metres deep. The marine environment within the 200-nautical-mile exclusive economic zone (EEZ) is the fourth-largest internationally, covering about 1.7 million square kilometres (Ministry of Foreign Affairs and Trade, 2020). The EEZ extends from the subtropical waters around the Kermadec Islands in the north, to the subantarctic waters around the Campbell, Auckland and Antipodes Islands in the south.

New Zealand is recognised as a globally significant biodiversity hotspot (Macinnis-Ng et al, nd). More than 80 per cent of our vascular plants are endemic, along with 90 per cent of insects, all reptiles, a quarter of birds and all terrestrial mammals (several species of bats/pekapeka) (Department of Conservation, 2020a). New Zealand's terrestrial ecosystems are highly distinctive, including kauri forests (in the northern North Island), lowland podocarp and podocarp-broadleaved forests, and extensive southern beech forests mostly on upland sites. Together these forests once made up nearly 90 per cent of New Zealand's ecosystem cover. Other distinctive ecosystems include extensive braided rivers in the eastern South Island, karst landscapes, restiad peat bogs, non-forest ecosystems on infertile coal measures, geothermal ecosystems, and tussock grassland and herbfield ecosystems above the treeline. Distinctive marine ecosystems include numerous estuaries, rocky reefs, open sandy beaches, zones of intense tidal flow (Cape Reinga and Cook Strait), highly productive areas of ocean mixing (along the Chatham Rise) and deepwater seamounts.

As in most temperate countries, many of New Zealand's natural systems are already under intense pressure from human activity, including land use and destructive impacts from introduced species. Climate change is likely to exacerbate many of these human-induced pressures, which can make it difficult to quantify the additional impacts of climate change. Due to their variety and complexity, very few of New Zealand's ecosystems are well enough understood to reliably predict how climate change will affect them. It is likely that many of New Zealand's ecosystems and species will be highly vulnerable to the projected changes in climate, due to their limited ability to adapt (sensitivity) to changing environmental conditions.

3.3 Summary of climate change risks

Table 22: Summary of climate change risks in the natural environment domain

Natural environment		
	Ratings	
Most significant risks	**Urgency**	**Consequence**
N1 Risks to coastal ecosystems, including the intertidal zone, estuaries, dunes, coastal lakes and wetlands, due to ongoing sea-level rise and extreme weather events.	78*	Major**
N2 Risks to indigenous ecosystems and species from the enhanced spread, survival and establishment of invasive species due to climate change.	73	Major
Other priority risks examined in stage 2		
N3 Risks to riverine ecosystems and species from alterations in the volume and variability of water flow, increased water temperatures and more dynamic morphology (erosion and deposition) due to changes in rainfall and temperature.	68	Major
N4 Risks to wetland ecosystems and species, particularly in eastern and northern parts of New Zealand, from reduced moisture status due to reduced rainfall.	68	Major
N5 Risks to migratory and/or coastal and river-bed nesting birds due to reduced ocean productivity, ongoing sea-level rise and altered river flows.	65	Major
N6 Risks to lake ecosystems due to changes in temperature, lake water residence time, and thermal stratification and mixing.	65	Major
N7 Risks to terrestrial, freshwater and marine ecosystems due to increased extreme weather events, drought, and fire weather.	60	Major
N8 Risks to oceanic ecosystem productivity and functioning due to changes in sea surface temperature, ocean mixing, nutrient availability, chemical composition and vertical particle flux.	55	Major
N9 Risks to sub-alpine ecosystems due to changes in temperature and a reduction in snow cover.	55	Major

Natural environment		
	Ratings	
Most significant risks	Urgency	Consequence
N10 Risks to carbonate-based, hard-shelled species from ocean acidification due to increased atmospheric concentrations of carbon dioxide.	55	Major
N11 Risks to the long-term composition and stability of indigenous forest ecosystems due to changes in temperature, rainfall, wind and drought.	53	Major
N12 Risks to the diverse range of threatened and endangered species that are dependent on New Zealand's offshore islands for their continued survival due to ongoing sea-level rise, changes in terrestrial climates, and changes in ocean chemistry and productivity.	45	Major

* Urgency rating refers to the total adaptation and decision urgency rating for this risk (between 1 and 100).

** Consequence rating refers to the highest consequence rating assigned to this risk out of all three time periods (now, 2050, 2100). Section 3.4 provides the consequence rating for each time period for all the risks.

3.4 Climate change risks

3.4.1 N1 Risks to coastal ecosystems, including the intertidal zone, estuaries, dunes, coastal lakes and wetlands, due to ongoing sea-level rise and extreme weather events

Risk summary

Climate change will impact on coastal ecosystems in a number of ways, with strong potential for wider effects on the inland ecosystems to which they are connected (O'Meara et al, 2017). Sea-level rise, predominantly expressed as ongoing, gradual change, can be expected to affect coastal ecosystems in various ways and is likely to be exacerbated by discrete but sporadic extreme storm events. As well as extreme storm events, moderate storm and flooding events are likely to increase in frequency and sequencing, putting recurring stress on coastal ecosystems. This combination of gradual change and episodic extreme events can be expected to become progressively more severe over time, profoundly affecting indigenous ecosystems in intertidal zones, estuaries, dune systems, coastal wetlands, and coastal rivers, streams and lakes, along with the species they support. This will be intensified by existing human-induced pressures, including direct effects such as coastal development and other land-use changes causing sediment runoff and reduced water quality, and the indirect effects of physical occupation of coastal sites. The latter effects reduce the availability of sites that would otherwise be available for landward migration by ecosystems and species as sea levels rise, a phenomenon that is generally referred to as coastal squeeze (Rouse et al, 2017).

Exposure

Extreme storm events and the ongoing, gradual threat of sea-level rise are projected to increase in severity and frequency towards the end of the century. Sea-level rise will affect coastal areas throughout New Zealand, building on the existing 20 centimetres of rise since 1900 (Ministry for the Environment, 2017b). Projections for these hazards are outlined in section 2. Increased frequency of storm events poses a significant risk to ecosystems and species, both through direct physical damage (for example, wave surge) and through increased sediment deposition.

Sea-level rise, along with increased frequency of extreme storm events, will pose direct and major risks to a diverse range of coastal ecosystems, including mangroves, dunes, estuaries, salt marsh, coastal turfs, boulder beaches and coastal cliffs.

This will threaten the survival of large numbers of species that are restricted to the coastal zone; for example, the many threatened plant species that occur in coastal turfs (Johnson and Rogers, 2003).

As sea levels rise, the zone of influence of tides will extend further inland, affecting lowland rivers and coastal lakes and wetlands. Inundation events of low-lying areas from tides, storm surges and waves surpassing natural or human barriers will become more frequent, and increase in spatial extent (Rouse et al, 2017). For example, a 1-metre sea-level rise will result in salinity intrusion extending up to 5 kilometres further inland on the Waihou River, in the Hauraki Plains (McBride et al, 2016).

Sensitivity

A recent national analysis of the susceptibility of New Zealand’s shoreline (Rouse et al, 2017) concluded that the east coasts of both the North and South Islands are likely to be more sensitive to climate change-induced coastal inundation and erosion. This is due to their currently low wave exposure, low tidal range, and deficits in sediments in proximity to tidal inlets. By contrast, the west coasts of both islands have a lower sensitivity due to their existing exposure to high wave energy (Rouse et al, 2017).

Natural responses to these risks will be impeded in many locations by existing high intensities of human use and development in the coastal zone, particularly where these prevent landward migration of coastal ecosystems and species from sea-level rise (coastal squeeze) (Rouse et al, 2017).

Adaptive capacity

While many coastal ecosystems and species should have some adaptive capacity away from human-induced pressures, most are exposed to the effects of introduced species, inputs of nutrients and sediments (for example, from agricultural practices – see Wilcock et al, 2011), and direct physical disturbance from development activities such as coastal subdivisions and construction of buildings, roads, marinas and other structures. These are likely to reduce their adaptive capacity, particularly in locations with intensive human activity, such as around major towns and cities.

Ecosystems and species with greater tolerance to periodic exposure to saline waters, and those with some degree of dispersal ability, are likely to have a greater adaptive capacity.

How much coastal ecosystems are able to adapt will rely on implementation of effective management approaches, rather than on the characteristics of the ecosystems themselves.

Consequence

Sea-level rise, coupled with increased frequency of extreme storm events, poses risks to a broad range of coastal ecosystems and threatens the populations of many species, including a large number that occur only in coastal environments. This includes highly productive coastal ecosystems with important breeding, roosting and foraging habitat for indigenous bird species. Some of these ecosystems, including Kaipara Harbour, the Firth of Thames and Farewell Spit, provide crucial habitat for internationally significant migratory bird species (McGlone and Walker, 2011), while others provide important nursery habitats for juvenile fish (Francis et al, 2011).

Saline intrusion into freshwater ecosystems will result in shifts in species distributions. For example, the biological character of Lake Waihola is predicted to progressively shift to greater dominance by estuarine and marine species. Although this will increase the richness of salt-tolerant species, it is likely to be offset by losses of indigenous freshwater species (Schallenberg et al, 2003). The risks of invasion by introduced species more tolerant of saline environments will increase where these changes trigger mortality events among the current indigenous species occupants.

Increased frequencies of storm events pose a risk to ecosystems and species through both direct physical damage (for example, wave surge) and increased sediment deposition. The latter is likely to have negative impacts on inshore and estuarine marine ecosystems by decreasing light penetration, increasing turbidity and reducing primary productivity (Thrush et al, 2004). Changes in sediment size can also reduce habitat suitability, in some cases directly causing species mortality; for example, when fine silts are deposited over coarser sandy sediments (Rouse et al, 2017).

Risk response in many places will be impeded by high-intensity human use and development in the coastal zone.

Interacting risks

Impacts on coastal ecosystems affect oceanic productivity and functioning (N8), with cascading impacts on bird species (N5). Freshwater ecosystems (N3, N4, N6) may be impacted by saline intrusion from coastal inundation.

Coastal environments are innately connected with social and economic systems, with cascading impacts across these systems as well. There will also be impacts on the tourism sector (E4) and fisheries and aquaculture (E5).

Ongoing sea-level rise and extreme storm events threaten New Zealand’s coastal development (B2), which is likely to result in the displacement of coastal communities (H1). They are also a threat to Māori social, economic, cultural capital and cultural heritage values and spiritual wellbeing, where these are strongly connected to coastal ecosystems (H5, H6, H8).

Maladaptation or inadequate adaptation actions aimed at protecting coastal ecosystems and managing retreat, and uncoordinated governance, will have significant consequences for these systems and will also impact on social and economic systems (G1).

Effective governance mechanisms will be key to building adaptive capacity for coastal environments. However, a significant risk lies in scientists’ ability to understand, predict and respond to climate change impacts on New Zealand’s biodiversity, due to under-investment in biodiversity science (G5). There is also a risk of failing to allocate funding for conservation management in a timely and effective manner (G2).

Confidence: High agreement, medium evidence

There is a high level of agreement that ongoing sea-level rise and extreme storm events will result in coastal inundation and salinity intrusion, with significant negative impacts on a wide range of coastal ecosystems and species. Although there is very strong agreement on the mechanisms driving this risk, and a reasonable amount of knowledge on impact pathways, extensive knowledge gaps remain on how these effects will manifest for particular ecosystems and species, and in different locations.

Adaptation

Regional councils and local community groups are driving risk management actions for coastal ecosystems, although most of these actions are focused on protecting human infrastructure rather than biodiversity. Actions include developing frameworks and implementation plans, and engaging communities. Highly exposed regions such as Hawke’s Bay have developed coastal hazard strategies to define the problem, provide a framework for decision-making, apply this to hazard risk response and outline actions (Bendall, 2018; Hawke’s Bay Regional Council, 2016).

Takutai Kāpiti and the Makara Beach Project are examples of community-led collaborative projects that have developed action plans. The Makara Beach Project has put community-endorsed recommendations to the Wellington City Council for how the wider community should prepare for and adapt to sea-level rise and extreme weather events (The Makara Beach Project, nd).

Table 23: N1 Risks to coastal ecosystems: Urgency profile

<table>
<tr><th colspan="7">N1 Risks to coastal ecosystems: Urgency profile</th></tr>
<tr><th>Urgency category</th><th colspan="2">Proportion of urgency</th><th colspan="4">Description of actions</th></tr>
<tr><td>More action needed</td><td colspan="2">40</td><td colspan="4">Active adaptive management to avoid and reduce coastal squeeze, particularly by regional and unitary councils. These should focus on management of the impacts of human development and maladaptations on environments of high biodiversity value, while taking account of likely changes in sea level.</td></tr>
<tr><td>Research priority</td><td colspan="2">40</td><td colspan="4">Identify the most vulnerable types of hydro-systems, and how they will respond and change their biophysical functioning. For example, this might include supporting significant biodiversity values on exposed coasts, coastal lakes, lowland rivers or systems subject to current or projected high levels of human development and land use.</td></tr>
<tr><td>Sustain current action</td><td colspan="2">10</td><td colspan="4">Continue current management of coastal ecosystems and species to maintain their resilience and maximise their ability for natural adjustments to sea-level changes.</td></tr>
<tr><td>Watching brief</td><td colspan="2">10</td><td colspan="4">Monitor the status of a representative range of high-value coastal ecosystems, to look for evidence of change.</td></tr>
<tr><td>Adaptation urgency</td><td colspan="2">78</td><td>Confidence</td><td colspan="3">High agreement, medium evidence</td></tr>
<tr><td>Consequence</td><td>Now</td><td>Minor</td><td>2050</td><td>Moderate</td><td>2100</td><td>Major</td></tr>
</table>

3.4.2 N2 Risks to indigenous ecosystems and species from the enhanced spread, survival and establishment of invasive species due to climate change

Risk summary

New Zealand is a globally significant biodiversity hotspot, with very high levels of endemism, including more than 80 per cent of vascular plants, 90 per cent of insects, all reptiles, a quarter of birds and all terrestrial mammals (several species of bats/pekapeka) (Department of Conservation, 2020a). A significant number of endemic species are vulnerable to extinction (Macinnis-Ng et al, nd).

New Zealand’s indigenous ecosystems and taonga (indigenous) species are already under considerable pressure from introduced pest species, with the country being described as one of the most invaded places on Earth (Mooney and Hobbs, 2000). As temperatures warm, climatic conditions are likely to favour introduced species, which are better adapted to or have a higher tolerance of warmer conditions (Thuiller et al, 2007). Increased temperatures are likely to support the spread of currently problematic introduced species and the establishment of new introduced species; both of these events will increase pressure on indigenous ecosystems and species. Predicting the impacts of this is challenging, with complex effects across different trophic levels (Macinnis-Ng et al, nd; Tompkins et al, 2013). Interactions with human-induced pressures such as habitat fragmentation and harvesting may further complicate the situation.

Exposure

Ongoing, gradual changes in climate and extreme weather events will increase the threat of invasive or exotic species. These changes are projected to increase in severity and frequency towards the end of the century, with the greatest increases projected under representative concentration pathway (RCP) 8.5. Key climatic hazards influencing this risk include warming temperatures, changes in the amount and distribution of rainfall, drought and heatwaves, and associated natural hazards including floods. Projections for these are discussed in section 2.

Most sub-national climate zones will experience some degree of climatic change. Increases in average temperature are expected to be generally uniform across New Zealand, with slightly higher increases in the northeast than in the southwest. As a result, the North Island is expected to experience slightly greater warming than the South Island. Frosts are also predicted to become less frequent, with much of the northern North Island expected to become largely frost free by 2100.

The predicted changes in temperature, rainfall and frequency of extreme events are expected to support the geographic spread of many invasive species already established in New Zealand, with these likely to occur both southwards and to higher elevations (McGlone and Walker, 2011). Many of these species have functional or behavioural traits that aid their invasion of new habitats, including wide dispersal of propagules, fast reproductive or growth rates, or the ability to establish or persist in harsh environments.

Species already established in New Zealand but not currently problematic are also likely to become problematic, as changing climates support their ability to reproduce or alter their relative competitive advantage over indigenous species, and the latter come under increasing stress from changing conditions (Thuiller et al, 2007).

Increased temperatures will also favour the establishment of new warm-climate invasive species. Some of these species will be introduced through human transport (for example, plant or insect species accidentally transported with imported goods or products, marine invertebrates transported in ship ballast water). Others, however, are likely to establish through natural dispersal processes (for example, windborne plant pathogens, or marine species moving southward in response to warmer ocean temperatures).

Sensitivity

Many of New Zealand’s indigenous ecosystems and taonga (indigenous) species are already under high pressure from introduced species such as plants, vertebrates, invertebrates and pathogens, and their impacts, including predation, competition and, in some cases, mortality.

These pressures reduce native dominance in indigenous ecosystems and the abundance of vulnerable species, in some cases leading to their endangerment or even extinction.

Climate change will exacerbate these pressures by aiding the range expansion of existing invasive species. For example, wilding conifers will be able to spread to higher elevations, rodents may extend their altitudinal ranges, and freshwater pest fish that currently thrive in warmer northern lakes and rivers are more likely to spread southwards and to higher elevations.

Climate change will also encourage some established non-problematic species to become invasive, and increase the likelihood of novel species establishing from warm climates outside New Zealand. A proportion of these are also likely to become invasive in indigenous ecosystems. At the same time though, higher water temperature in some areas may reduce the abundance of introduced salmonids, enhancing the survival of indigenous fish species (Robertson et al, 2016).

Human-mediated alteration of the natural environment supports invasion by introduced species. The greatest numbers of established plant weeds are close to human population centres, providing reservoirs for spread into surrounding landscapes (Timmins and Williams, 1991). Humans are also responsible for widespread introduction of freshwater pest fish, particularly in northern waters, through both accidental and deliberate release (Hamilton et al, 2013). Fragmentation makes many lowland terrestrial indigenous ecosystems more vulnerable by increasing the ratio of edge habitats to core ones. This provides more opportunities for invasion from surrounding exotic-dominated landscapes (McGlone and Walker, 2011). In drier environments where deliberate firing by humans replaced the former woody cover with tussock grasslands, indigenous-dominated landscapes are particularly vulnerable to invasion by wilding conifers. Some of these conifers are able to survive at higher elevations than the indigenous species (which normally occur at treeline), allowing them to invade sub-alpine ecosystems.

Predicting the overall impacts of invasive species on New Zealand's indigenous ecosystems and taonga (indigenous) species under climate change is difficult given the complex nature of interactions between invasive and indigenous species, and between different invasive species (Tompkins et al, 2013). An increase in disturbance events such as droughts or heatwaves may give more opportunities for invasive species to expand their range; for example, when formerly dominant indigenous species are lost through stress-induced mortality (Thomsen et al, 2019).

Adaptive capacity

Many of New Zealand's indigenous ecosystems and taonga (indigenous) species have low adaptive capacity in the face of human-induced pressures such as introduced alien species, the clearance and fragmentation of indigenous terrestrial cover, discharge of nutrients and sediments into water bodies, and harvesting of marine fish. This is a common feature of island biotas, particularly those that have experienced long, genetic isolation (Frankham, 1997; Williams et al, 2008). For example, most of our indigenous bird species have proven vulnerable to decline through predation by introduced mammals (Innes et al, 2010). Many of our forests have undergone significant compositional and functional modification by introduced mammalian browsers (Wardle et al, 2001). Also, our distinctive freshwater galaxiids have suffered major population declines with the introduction of predatory salmonid fish (McDowall, 2003; McIntosh et al, 2010).

Although there is a general lack of site-specific studies, it is highly likely that the existing impacts of introduced species, along with other human activities such as harvesting, habitat clearance and fragmentation, have substantially reduced the adaptive capacity of many of our indigenous ecosystems and species. This will also have reduced their ability to adapt to further pressure from introduced species. It is therefore crucial that management of introduced species aims to maintain adequate and representative examples of a full range of ecosystems in a state that is as healthy as possible, while also maintaining populations of species at particular risk of decline.

The adaptive capacity of species and natural ecosystems is somewhat limited without effective governance. It may be possible to increase the adaptive capacity of some ecosystems and systems through adaptive management interventions to reduce the impact of invasive species, at least in the short to medium term. Conservation techniques to eradicate invasive species and protect taonga and indigenous species have shown some success in New Zealand; however, there are major knowledge gaps and challenges with achieving lasting eradication of invasive predators (Macinnis-Ng et al, nd).

Consequence

Overall, the expansion of current pest species, and addition of new ones, are likely to significantly compromise our ability to maintain the integrity and functioning of our indigenous ecosystems, and will make the work of protecting our at-risk and threatened species even more challenging. Because of their pervasive nature, these risks are also likely to interact with and be compounded by all 11 of the other natural environment climate-related risks identified by this assessment.

A number of taonga species are already under threat because of invasive species, including the brown kiwi, kākā, mohua, whio, *Powelliphanta* snails and the North Island kōkako (Department of Conservation, 2020b). Without continued effective conservation management, increases in temperature may add pressure on taonga species from the further spread and establishment of invasive species.

Interacting risks

The interconnectedness of the natural environment with social and economic systems will see the threat of invasive species cause cascading impacts into other domains. Natural ecosystem disruption by invasive species will impact sectors that rely on indigenous species and natural landscapes, particularly the tourism (E4) and land-based primary (E3) sectors, and fisheries and aquaculture (E5). Another risk is that changes in land use will make existing uses unsustainable, creating cascading impacts into the natural environment.

Invasive species threaten indigenous species and ecosystems that are fundamental to Māori social, economic, cultural capital and cultural heritage values and spiritual wellbeing (H5, H6, H8).

The invasion of exotic species also brings the threat of vector-borne diseases and associated health implications (H3).

Confidence: High agreement, medium evidence

There is a high level of agreement that changing climatic conditions, including increases in temperature, will increase the establishment and spread of both existing and novel introduced species, with likely modification of ecosystems and loss of taonga and indigenous species.

However, evidence of impacts on specific ecosystems and species is limited largely to a few well-studied systems. Further research is needed to identify the specific vulnerabilities of a wider range of indigenous ecosystems and species.

Adaptation

Adaptation action to reduce spread, survival and establishment of exotic or invasive species is largely driven by the Department of Conservation (DOC), the Ministry for Primary Industries (MPI) and regional councils. Non-governmental organisations (NGOs) and community groups also contribute. For example, Predator Free 2050 is supported by NGOs such as World Wildlife Fund, Kiwis for Kiwi, Forest & Bird, and Sanctuaries of New Zealand (Predator Free New Zealand, nd). Adaptive management currently includes:

- risk assessments (including anticipation of emerging risks)
- early detection/rapid response
- border management
- marine biosecurity
- pest management
- eradication of predators
- assisted migration (translocation) (Champion, 2018; Department of Conservation, nd.1).

MPI is accountable for the end-to-end management of the biosecurity system under the Biosecurity Act 1993. Under this legislation, regional councils are driving action by updating and implementing regional pest management plans, providing a framework for the efficient and effective management or eradication of particular species (Auckland Council, 2019). Other examples of current action include Predator Free 2050, War on Weeds, The Kauri Dieback Programme, Myrtle Rust Strategy, and Land Information New Zealand control programmes.

Table 24: N2 Risks to indigenous ecosystems and species: Urgency profile

<table>
<tr><th colspan="7">N2 Risks to indigenous ecosystems and species: Urgency profile</th></tr>
<tr><th>Urgency category</th><th colspan="2">Proportion of urgency</th><th colspan="4">Description of actions</th></tr>
<tr><td>More action needed</td><td colspan="2">40</td><td colspan="4">Proactively detect and manage existing and new pest species as they become established, with an emphasis on reducing the impacts of species that induce major changes in ecosystem structure, including those that become invasive after disturbance events such as fire or marine heatwaves.</td></tr>
<tr><td>Research priority</td><td colspan="2">10</td><td colspan="4">Identify new and emerging risks from invasive species across terrestrial, freshwater and marine domains. Then identify and develop effective ways to manage identified risks.</td></tr>
<tr><td>Sustain current action</td><td colspan="2">50</td><td colspan="4">Aggressively continue current pre-border, border and post-border biosecurity measures and control of already established problematic species.</td></tr>
<tr><td>Watching brief</td><td colspan="2">0</td><td colspan="4">Proactively detect and manage existing and new pest species as they become established, emphasising reducing the impacts of species that cause major changes in ecosystem structure, including those that become invasive after disturbance events such as fire or marine heatwaves.</td></tr>
<tr><td>Adaptation urgency</td><td colspan="2">73</td><td>Confidence</td><td colspan="3">High agreement, medium evidence</td></tr>
<tr><td>Consequence</td><td>Now</td><td>Minor</td><td>2050</td><td>Moderate</td><td>2100</td><td>Major</td></tr>
</table>

3.4.3 N3 Risks to riverine ecosystems and species from alterations in the volume and variability of water flow, increased water temperatures and more dynamic morphology (erosion and deposition) due to changes in rainfall and temperature

Risk summary

New Zealand's freshwater riverine ecosystems support diverse biota, including fish, invertebrates, plants, birds and micro-organisms, many of which are endemic (Robertson et al, 2016; Weeks et al, 2016). Up to 74 per cent of indigenous freshwater fish species are listed as endangered or at risk, making New Zealand's freshwater fish species among the most threatened in the world (Weeks et al, 2016). In riverine ecosystems, disturbance by high river and stream flows plays an important role in structuring invertebrate communities and broader ecosystem function (Death et al, 2015; Townsend et al, 1997). However, riverine ecosystems are already under significant pressure from human activities such as hydro-power generation, agricultural intensification, and urbanisation. These activities impede the movement of migratory species, reduce river flows and their variability, and increase inputs of sediments, nutrients and other contaminants (Weeks et al, 2016). There are also 21 introduced freshwater fish species and more than 70 introduced aquatic plant species in New Zealand's rivers and streams, reducing the abundance of indigenous fish through competition, predation and change of biodiversity and habitat (Weeks et al, 2016).

Exposure

There will be ongoing, gradual change in rainfall and water temperatures, with impacts increasing towards the end of the century. An increase in the frequency and intensity of more severe extreme weather events will also affect riverine communities, acting as discrete hazard events (Robertson et al, 2016). These climate hazards are projected to increase in severity and frequency as the century progresses, with the largest increases projected under RCP8.5. These effects are likely to be more severe in eastern and northern parts of New Zealand, but increased peak flows during high-intensity rainstorms are likely to affect all of New Zealand. Further detail on the projections for these hazards are outlined in section 2.

Climate change is predicted to result in ongoing, gradual increases in mean annual rainfall in the west and south of New Zealand, but decreased rainfall in the north and east. Rainfall seasonal distribution is also predicted to change, with an increased prevalence of westerly winds in winter and spring delivering more rainfall in the west of both islands, but reduced rainfall in the east and north. This is likely to alter patterns of flow variability in many rivers and streams, and reduce the frequency of bed-disturbing flows in eastern and northern New Zealand, but increase high-flow events in the west and south.

Increases in rainfall intensity are predicted across all sub-national climate zones, with the greatest increases in zones 1, 3 and 6. Resulting increased peak flows are likely to increase rates of channel sediment transport and bed instability, particularly in the south and west. Conversely, predicted increases in intensity and duration of dry periods are likely to result in more extended periods of low flow and reduced flow variability.

Sensitivity

Changes in river flows and increased temperatures have the potential to profoundly alter many of New Zealand's riverine ecosystems. They are likely to be most affected by alterations to annual and seasonal river flows as a result of changing rainfall, reflecting the importance of flow variability in structuring the composition and functioning of riverine ecosystems (Death et al, 2015; Townsend et al, 1997). Increased temperatures are likely to have a more muted effect, but are likely to lead to some changes in the distributions of both indigenous and problematic introduced species (Robertson et al, 2016). New Zealand's non-migratory fish species will be more sensitive to changes in temperature than migratory ones, because of their more restricted dispersal ability (McGlone and Walker, 2011).

Riverine ecosystems that are already fragmented, and species that are already threatened, are likely to be more sensitive to the predicted changes in river flow, particularly due to their limited ability for unassisted distribution and recolonisation (Robertson et al, 2016). This may ultimately lead to a loss of habitat and breeding locations for a number of organisms. Isolated populations of fish and invertebrate species, such as brown mudfish *Neochanna apoda*, will be more sensitive to an increased frequency of extreme drought events, because of the increased potential for extinction of entire populations (Robertson et al, 2016).

Adaptive capacity

Adaptive capacity will be largely limited in New Zealand's riverine ecosystems, as they are already subject to a high level of pressure from human activities. The fragmentation and vulnerability of these ecosystems will make shifts in distribution difficult for a number of aquatic organisms. A substantial number of range-restricted species are constrained in east- or west-flowing river systems, and are likely to be unable to move southwards to cooler waters as temperatures rise (McGlone and Walker, 2011). This difficulty will be further compounded by the fragmented nature of New Zealand's riverine ecosystems, where human-made barriers restrict migration ability and reduce adaptive capacity (Weeks et al, 2016). Conversely, some indigenous fish communities in New Zealand's gravel-bed rivers appear to be resilient to both floods and droughts, provided refuges are available during low river flows (McGlone and Walker, 2011).

Adaptive capacity of riverine ecosystems is somewhat limited without effective governance. However, a risk is that uncoordinated governance will lead to inadequate adaptation actions (G1).

Measures to manage impacts and build adaptive capacity in riverine ecosystems could include protecting critical habitat for the survival of rare and range-restricted fish, plant and invertebrate freshwater species, establishing monitoring and recovery plans, and establishing and maintaining appropriately wide riparian zones that connect across water catchments (Weeks et al, 2016). Challenges may arise in protecting freshwater environments, due to the potential lobbying power of the agricultural industry (G7).

Current legislation around freshwater biodiversity has a number of inadequacies, with conflicting objectives for the management of freshwater systems. For example, the Freshwater Fisheries Regulations 1983 protect introduced fish species, including trout and salmon, but do not protect indigenous fish species (Weeks et al, 2016); and some indigenous species that have been classified as nationally vulnerable are still able to be commercially harvested.

Consequence

Climate change-driven alteration in rainfall amount and variability, along with increased temperatures, are likely to significantly increase already high pressure on New Zealand's riverine ecosystems and species.

Alterations to flow regimes are likely to have the greatest impact on biological communities in rivers, with more severe floods, changes to the timing of floods, and ecologically significant floods becoming less frequent and smaller in magnitude (Robertson et al, 2016). A combination of increased temperatures and reduced flow due to climate change is likely to intensify human pressure on riverine ecosystems. Changes in land use and river channels will inhibit refugia and recolonisation pathways; nutrient and sediment influx from flood events may compromise ecosystem function; invasive species may change their distributions; and the frequency of toxic algal blooms may increase (Robertson et al, 2016). All of these effects will alter riverine ecosystems and negatively impact freshwater biodiversity through the loss of species.

Interacting risks

The disruption to riverine ecosystems will interact with risks to wetland and lake ecosystems (N4, N6), leading to significant impacts on New Zealand’s freshwater biodiversity. Forest instability will also impact on freshwater ecosystems and species (N11); risk to riverine ecosystems and the loss of species may result in cascading impacts into other domains – disruption of riverine ecosystems may have impacts on the agriculture sector (E3), which uses freshwater systems.

At the same time, the agriculture sector may further impact on freshwater riverine ecosystems through water extraction and nutrient runoff. This risk could also pose a threat to Māori social, economic, cultural capital and cultural heritage values and spiritual wellbeing (H5, H6, H8).

Confidence: High agreement, limited evidence

There is considerable agreement on the mechanisms by which climate change-induced alteration of flow variability, temperature increase and extreme events are likely to affect riverine ecosystems and species. However, the evidence is only limited on the likely impacts on particular ecosystems and species, and how these impacts might vary between geographic regions.

Adaptation

Regional councils and communities are running projects to manage this risk, focusing on the development of frameworks and action plans to better address resource management, and restoration projects to increase ecosystem resilience. In response to the National Policy Statement for Freshwater Management issued by the Ministry for the Environment in 2014, regional councils have established implementation programmes to identify actions and future targets for freshwater resource management and ecosystems resilience (Ministry for the Environment, 2019). Many regional councils also have action plans for rivers; for example, the Rangitāiki River Action Plan published by Bay of Plenty Regional Council (Rangitāiki River Scheme Review Panel, 2017). The Million Metres Streams Project, supported by the Sustainable Business Network, plans to plant a million metres of riparian margins to enhance ecosystem resilience (Million Metres Streams Project, nd). The Sustainable Business Network is also working to reduce sediment flow and restore the Hauraki Gulf through the GulfX project.

Table 25: N3 Risks to riverine ecosystems and species: Urgency profile

<table>
<tr><th colspan="7">N3 Risks to riverine ecosystems and species: Urgency profile</th></tr>
<tr><th>Urgency category</th><th colspan="2">Proportion of urgency</th><th colspan="4">Description of actions</th></tr>
<tr><td>More action needed</td><td colspan="2">30</td><td colspan="4">Intensify actions to protect and restore riverine ecosystems, particularly in regions most vulnerable to periodic drought. Include measures to maintain or restore natural flows in systems subject to high levels of water abstraction or over-allocation.</td></tr>
<tr><td>Research priority</td><td colspan="2">10</td><td colspan="4">Impacts on riverine ecosystem dynamics, including identifying regions most vulnerable due to spatial variation in rainfall changes, water abstraction or over-allocation.</td></tr>
<tr><td>Sustain current action</td><td colspan="2">60</td><td colspan="4">Continue current policies and management actions to protect and restore riverine ecosystems.</td></tr>
<tr><td>Watching brief</td><td colspan="2">0</td><td colspan="4"></td></tr>
<tr><td>Adaptation urgency</td><td colspan="2">68</td><td>Confidence</td><td colspan="3">High agreement, limited evidence</td></tr>
<tr><td>Consequence</td><td>Now</td><td>Moderate</td><td>2050</td><td>Moderate</td><td>2100</td><td>Major</td></tr>
</table>

3.4.4 N4 Risks to wetland ecosystems and species, particularly in eastern and northern parts of New Zealand, from reduced moisture status due to reduced rainfall

Risk summary

New Zealand’s wetland ecosystems and species are already vulnerable due to widespread land-use changes, with about 90 per cent of their former cover lost since European settlement in the 1840s, most notably in lowland environments (Robertson et al, 2019). Despite this widespread loss, wetlands still support a high proportion of the country’s threatened plant species, many of which survive in ephemeral wetlands (Holdaway et al, 2012). Climate change is predicted to alter annual and seasonal rainfall distribution, which, combined with higher temperatures and increased windiness, will affect the moisture status of many of New Zealand’s freshwater wetland ecosystems and species. These changes are likely to have greatest impact in drier (predominantly eastern) environments, where wetland loss has generally been greater than in high-rainfall (predominantly western) environments.

Many wetlands surviving in drier environments have high conservation value because of their irreplaceability and are likely to be susceptible to ongoing decline in their ecological integrity, given the expected deterioration in their moisture status. These changes are likely to lead to further loss of indigenous wetland species, and invasion by introduced species.

Exposure

Climate change is predicted to bring ongoing, gradual increases in mean annual rainfall in the west and south of New Zealand, but decreases in the north and east. The seasonal rainfall distribution is also predicted to change, with increased prevalence of westerly winds in winter and spring bringing increased rainfall to the west of both islands, but reduced rainfall in the east and north. Along with predicted increases in temperature and windiness, this change is likely to alter the moisture status of many of New Zealand’s surviving wetlands, and particularly those of lowland wetlands in eastern and northern parts of New Zealand. Conversely, increases in rainfall may increase the moisture status of wetlands in the south and west of New Zealand. These changes in rainfall patterns are projected to increase in magnitude towards the end of the century, with the greatest changes projected under RCP8.5. Rainfall pattern and distribution projections are detailed in section 2.

Sensitivity

The sensitivity of New Zealand's wetland ecosystems and species to climate-related change in moisture status will vary widely, with those in dry climates in eastern and northern New Zealand likely to show higher sensitivity than those in the wetter climates of southwestern New Zealand (Robertson et al, 2016). Ephemeral wetlands that support high numbers of threatened species may show high sensitivity to these changes in moisture status, given the natural fluctuations in moisture status they currently experience (Johnson and Rogers, 2003).

Adaptive capacity

As in other terrestrial ecosystems, the adaptive capacity of New Zealand's wetland ecosystems is likely to be substantially impaired due to high pressure from human activities, including through: large-scale reductions in wetland extent and resulting fragmentation of surviving wetlands; changes in moisture status; invasion by weeds; and nutrient inputs from adjacent agricultural land uses (Robertson et al, 2016, 2019; Weeks et al, 2016). These changes will impede species' ability to shift in response to increased temperatures, change in moisture or change in nutrient status. Active conservation management could restore this adaptive capacity (at least in part), particularly where it targets the reinstatement of hydrological status, reduction in artificial inputs of nutrients, removal of weeds, and the restoration of wetlands to connect isolated fragments.

Adaptive capacity of wetland ecosystems will mainly rely on effective governance. Adaptive management will play a key role in increasing the adaptive capacity of wetland ecosystems where impacts from changes in rainfall can be somewhat mitigated.

Actions to mitigate risks to New Zealand's freshwater wetlands should include strengthening policies and regulations to restrict the drainage of wetlands, particularly in dry environments and during drought periods, as well as protecting freshwater biodiversity. Discharges into wetlands, including nutrients and sediments, should also be reduced to improve and maintain water quality.

Consequence

Climate-related changes in moisture status pose significant risk to the integrity and survival of wetland ecosystems and species that occur predominantly in drier eastern and northern parts of New Zealand. For many lowland wetlands, these risks are compounded by past drainage and conversion to pasture, resulting in high levels of fragmentation and modified drainage. Declines are likely to occur both through loss of existing wetland species as conditions become unsuitable for them and through invasion by introduced weeds such as willows (*Salix* spp), blackberry (*Rubus fruticosus* agg) and gorse (*Ulex europaeus*) (Robertson et al, 2016). Given the high number of plant species that are confined to wetland habitats (for example, Johnson and Rogers, 2003), these changes are likely to further reduce the viability of populations of a number of at-risk plant species, as well as endemic mudfish (Weeks et al, 2016). Further losses or degradation of surviving wetlands in drier, lowland environments would have the greatest conservation significance, given the irreplaceability of wetland fragments in those environments, and their already high levels of loss.

Interacting risks

Disruption to riverine ecosystems (N3) will interact with this risk and risks to lake ecosystems (N6), leading to significant impacts on New Zealand's freshwater biodiversity. Increasing instability of New Zealand's indigenous forests will add pressure on lowland freshwater ecosystems (N11), and this risk may be intensified by the increased risk from invasive species (N2).

With the invasion of exotic species comes the threat of vector-borne diseases and subsequent health implications (H3). Impacts on wetland ecosystems and loss of species would likely result in cascading impacts into other domains. The disruption of wetland ecosystems is likely to impact on the agriculture sector (E3), which uses freshwater systems. At the same time, the agriculture sector may further impact on those ecosystems.

This risk could also pose a threat to Māori social, economic, cultural capital and cultural heritage values and spiritual wellbeing from climate change impacts on wetland ecosystems and freshwater species (H5, H6, H8).

Maladaptive or inadequate adaptive management actions may restrict the ability of New Zealand's wetland ecosystems to adequately adapt to a changing climate (G1). A lack of funding, or lack of measures to protect wetlands in a timely and effective manner, may amplify this risk (G2).

Confidence: High agreement, medium evidence

There is a high level of agreement that New Zealand's wetland ecosystems and species are likely to be highly vulnerable to reductions in moisture status occurring under climate change. Further research is needed to identify those specific ecosystems and species most at risk, so that high-value sites can be protected and managed, to prevent further avoidable loss.

Adaptation

Table 26: N4 Risks to wetland ecosystems and species: Urgency profile

<table>
<tr><th colspan="7">N4 Risks to wetland ecosystems and species: Urgency profile</th></tr>
<tr><th>Urgency category</th><th colspan="2">Proportion of urgency</th><th colspan="4">Description of actions</th></tr>
<tr><td>More action needed</td><td colspan="2">30</td><td colspan="4">Strengthen regional council enforcement of rules related to wetland drainage, and proactively intensify wetland protection measures in dry environments; for example, through landowner education, active management of hydrology, and weed control.</td></tr>
<tr><td>Research priority</td><td colspan="2">10</td><td colspan="4">Identify regions and specific sites with highest vulnerability.</td></tr>
<tr><td>Sustain current action</td><td colspan="2">60</td><td colspan="4">Maintain protection measures for wetlands through mechanisms such as regional plans and implementation of the National Policy Statement for Indigenous Biodiversity.</td></tr>
<tr><td>Watching brief</td><td colspan="2">0</td><td colspan="4"></td></tr>
<tr><td>Adaptation urgency</td><td colspan="2">68</td><td>Confidence</td><td colspan="3">High agreement, medium evidence</td></tr>
<tr><td>Consequence</td><td>Now</td><td>Minor</td><td>2050</td><td>Moderate</td><td>2100</td><td>Major</td></tr>
</table>

DOC and regional councils primarily manage risks to wetlands. In 2007 DOC launched Arawai Kākāriki, a flagship wetland conservation and science programme, to provide leadership in freshwater research and restoration. A 2019 update includes pest and weed control, fire prevention, mapping of vegetation changes, and research to improve water-level management (Department of Conservation, 2019a). Most regional councils, and some district and city councils, also place a high priority on the protection of wetlands, as shown in various planning documents. For example, in the Waikato Region the Lake Waikare and Whangamarino Wetland Catchment and Management Plan outlines a range of current wetland restoration projects, maintaining water security for wetlands and protecting against invasive species (Lawrence and Ridley, 2018). Other plans that identify wetlands protection work include the

Regional Freshwater Plan for Taranaki (Taranaki Regional Council, 2018), the Auckland Council Regional Plan: Air, Land and Water (Auckland Council, 2013) and the Wellington City Council's Biodiversity Strategy and Action Plan (Wellington City Council, 2015).

3.4.5 N5 Risks to migratory and/or coastal and riverbed nesting birds due to reduced ocean productivity, ongoing sea-level rise and altered river flows

Risk summary

New Zealand supports an abundance of marine and coastal bird species, making it one of the most significant regions for seabird diversity globally; about 80 seabird species breed in New Zealand (McGlone and Walker, 2011). In addition, a number of other endemic riverine and coastal bird species permanently reside in New Zealand, but migrate annually from summer breeding grounds on braided rivers to coastal sites for overwintering. Changing climatic conditions such as altered river flows and flood frequencies, extreme weather events, sea-level rise, warming ocean temperatures and drought are likely to impact on migratory, coastal and riverbed nesting birds in many ways. These impacts are likely to include availability of food resources, productivity and availability of coastal habitats, and breeding success (Law et al, 2017b; Robertson et al, 2016).

Exposure

Threats posed by climate change to a large number of New Zealand's migratory, coastal and river-nesting birds include ongoing sea-level rise, alteration to river flows and decline in ocean productivity. The ongoing, gradual changes of these climate hazards are projected to increase in severity over this century, with the greatest increases projected under RCP8.5. Projections for these hazards are detailed in section 2.

Permanent-resident coastal species, and those migratory species that breed in the northern hemisphere but overwinter in New Zealand during our summer, will be at risk from sea-level rise. It will threaten the stability and productivity of important breeding, feeding and resting habitats (detailed in N1).

Other coastal bird species that breed predominantly on predator-free islands but feed in the open ocean (for example, petrels and albatross) are likely to be affected by climate change-related reductions in the primary productivity of the oceans. These changes are expected to have wide flow-on effects to other ecosystem components (detailed in N8).

Altered river flows and flood frequencies, coupled with extreme rainfall events, are likely to impact on habitat and food availability as well as breeding success for river-nesting birds. This is likely to be most significant for species that breed on the beds of wide braided rivers. These rivers occur in the east of both main islands, where altered seasonal rainfall and changing patterns of snow accumulation could substantially alter seasonal river flows (Robertson et al, 2016).

Sensitivity

The degree of sensitivity for migratory, coastal and river-nesting birds will be largely dictated by environmental factors rather than physiological and behavioural sensitivities. Pressure on seabird and river-nesting birds from human disturbance and changes in the landscape is likely to increase as the climate changes.

Many of New Zealand's coastal and riverine bird species are already under pressure from a range of factors, including human disturbance of their breeding areas, introduced predators, reduction in the abundance of their food through marine harvesting, and direct mortality from fishing operations such as long-lining (Robertson et al, 2016). For example, recent declines in populations of yellow-eyed penguins (*Megadyptes antipodes*) have been linked to reduced food availability, with both inshore harvesting and declines in ocean productively suggested as the driving forces behind this reduction (McGlone and Walker, 2011).

Altered river flows and increased drought frequency will increase habitat fragmentation, leading to habitat and breeding location loss for a number of bird species. These altered flow regimes may allow invasive predators to reach critical habitats, including islands in river channels that are used by nesting birds (Robertson et al, 2016). Reduced summer and spring flows may also restrict food availability for specialist river birds that are dependent on riffle fauna, such as the wrybill plover (*Anarynchus frontalis*).

Migratory species are also under pressure from modification of their migration stopover areas, contributing to population decline in the majority of species (Wilson, 2009). These pressures are likely to increase the sensitivity of many species to additional threats from climate change.

Adaptive capacity

Only a limited degree of adaptive capacity can be expected for most coastal, migratory and river-nesting birds, due to the high pressure they already experience from predation, habitat loss and human disturbance. While migratory and dispersal ability may be high in most of these species, their ability to adapt to climate change will be limited by lack of suitable alternative habitats, feeding areas and breeding sites. Active conservation management may alleviate some of these pressures. This should include protection of braided river habitats, continuing predator control, and careful management of coastal habitats to maintain critical feeding and roosting areas, such as those at Farewell Spit and Ohiwa Harbour and in the Firth of Thames.

Consequence

Coastal habitats for a range of internationally significant migratory and all-year resident bird species are at risk from sea-level rise, with some also potentially at risk from declines in ocean productivity. Some of New Zealand's inland river-nesting bird species are forced to nest on islands in the middle of braided rivers as a result of predator pressure and river-edge habitat modification, making them vulnerable to habitat modification through alteration in the frequency of droughts or extreme flood events. Given the extent of migratory, coastal and river-nesting bird species that are already in decline, it seems inevitable that a number of these species will be placed at serious risk of extinction in the longer term, unless supported by effective management interventions.

The breeding success of a number of threatened river-dwelling bird species, including wrybill plover (*Anarhynchus frontalis*), black-fronted tern (*Chlidonias albostriatus*) and blue duck (*Hymenolaimus malacorhynchos*), is already significantly impacted from flooding. Therefore, predicted changes in the frequency and magnitude of floods may significantly impact population viability of these species (Robertson et al, 2016). Sea-level rise is likely to lead to loss of intertidal feeding areas for shorebirds, reduced availability of breeding habitat and reduced ocean productivity, which will affect food availability.

For migratory bird species that use New Zealand's rivers for only part of their life cycle, the effects of changing climatic conditions on these habitats may influence survival in the long term. This is the case for the wrybill plover, which breeds on 22 braided rivers on the east coast of the South Island, but stops over at coastal lakes, estuaries and river mouths before nearly the entire population reaches their overwintering sites on estuaries in the northern region of the North Island, particularly the Firth of Thames and Manukau Harbour (Robertson et al, 2016).

Interacting risks

It is likely that climate change impacts from other domains and elements of the natural environment will result in cascading impacts on migratory, coastal and riverine bird species. Reduced ocean productivity (N8) would see the loss of food resources for many seabird species, and threats to coastal environments (N1) will see the loss of coastal habitats. This risk could also pose a threat to Māori social, economic, cultural capital and cultural heritage values and spiritual wellbeing from climate change impacts on ecosystems and species (H5, H6, H8).

Uncoordinated governance may risk maladaptation or inadequate adaptation actions aimed at protecting migratory, coastal and riverbed nesting birds that restrict the ability of these species to adapt to changing climate (G1). A lack of funding for timely and effective conservation management may amplify this risk (G5, G7). There may also be a risk of maladaptation due to competing needs, where protection of people takes priority over the natural environment.

Confidence: High agreement, limited evidence

There is a high level of agreement that migratory, coastal and riverine bird species in New Zealand will face increased threat to their survival from climate change. However, only limited evidence is available as to which species are most likely to be affected.

Adaptation

Limited adaptive action or management is being undertaken to reduce the risk to migratory and/or coastal and riverbed nesting birds. Regional councils and NIWA are currently driving research and management actions, such as registering nesting sites.

Table 27: N5 Risks to migratory and/or coastal and riverbed nesting birds: Urgency profile

<table>
<tr><th colspan="9">N5 Risks to migratory and/or coastal and riverbed nesting birds: Urgency profile</th></tr>
<tr><th>Urgency category</th><th colspan="2">Proportion of urgency</th><th colspan="6">Description of actions</th></tr>
<tr><td>More action needed</td><td colspan="2">20</td><td colspan="6">Proactively increase management around the most vulnerable habitats of migratory and/or coastal and riverbed nesting birds, including through control of development, management of human disturbance, and active control of weeds and predators.</td></tr>
<tr><td>Research priority</td><td colspan="2">20</td><td colspan="6">Identify coastal and riverine breeding sites most vulnerable to climate change impacts; for example, through altered seasonality of riverine flows or weed invasion, or through coastal inundation and extreme events.</td></tr>
<tr><td>Sustain current action</td><td colspan="2">60</td><td colspan="6">Continue current actions for the protection and management of breeding, feeding and resting habitats of migratory and/or coastal and riverbed nesting birds.</td></tr>
<tr><td>Watching brief</td><td colspan="2">0</td><td colspan="6"></td></tr>
<tr><td>Adaptation urgency</td><td colspan="2">65</td><td>Confidence</td><td colspan="5">High agreement, limited evidence</td></tr>
<tr><td>Consequence</td><td>Now</td><td>Minor</td><td>2050</td><td>Moderate</td><td>2100</td><td>Major</td><td>2150</td><td>N/A</td></tr>
</table>

3.4.6 N6 Risks to lake ecosystems due to changes in temperature, lake water residence time, and thermal stratification and mixing

Risk summary

New Zealand's 3820 lakes with a surface area greater than 1 hectare collectively account for 1.3 per cent of the country's land area (Hamilton et al, 2013). These lakes are already subject to significant degradation due to alteration of inflows and outflows, invasive species (algae, fish and macrophytes) and increased nutrient inputs from land-use changes, including agricultural intensification. Climate change poses a diverse range of risks to these lakes, several of them interacting with existing pressures (Hamilton et al, 2013). Many coastal lakes are likely to be susceptible to periodic or permanent increases in salinity through sea-level rise, resulting in major changes in ecosystem composition and structure.

Rising temperatures, coupled with more frequent strong winds, are likely to alter mixing and thermal regimes in many deeper lakes, extending the period over which stratification is maintained, and increasing the risk of deoxygenation of bottom waters and change in nutrient status through the release of phosphorus and ammonium. Warmer temperatures are also likely to increase the risk of regime shifts from macrophyte- to algal-dominance in shallow lowland lakes, and favour the wider spread of a number of problematic introduced plant and fish species currently most widespread in warmer northern lakes. Increased temperatures are also likely to lead to the loss of New Zealand's highly distinctive but little studied sub-alpine lake ecosystems.

Exposure

The ongoing, gradual changes in temperature and wind that will impact on New Zealand's lake ecosystems are projected to increase in severity over the century. Projected changes in temperature and windiness are greater under RCP8.5. Further details on these climate hazards are outlined in section 2.

Increasing temperatures and windiness will mostly constitute an ongoing, gradual change climate hazard, although effects may be intensified by more discrete, extreme events such as heatwaves and windstorms.

Climate change is predicted to increase temperatures across all of New Zealand, with slightly higher increases in the north and east than in the south and west. Coupled with predicted sea-level rise and increases in windiness, this is likely to affect New Zealand's lake ecosystems in a number of ways. These include:

- increases in saline influence in coastal lakes
- increased risk of regime shifts in shallow lowland lakes
- altered thermal mixing regimes in larger lakes
- loss of distinctive sub-alpine and alpine lake ecosystems.

Sensitivity

This high sensitivity of New Zealand's lake ecosystems to climate change will be intensified by the significant degradation to which many lakes are already exposed, including harvesting of indigenous species, alteration of inflows and outflows, invasion by introduced species (algae, fish and macrophytes) and increased nutrient inputs from land-use changes, including agricultural intensification. National water-quality testing found that 84 per cent of monitored lakes in pastoral catchments are now classed as nutrient polluted (Weeks et al, 2016).

Previous studies of shallow lakes across New Zealand identified 37 lakes that have undergone regime shifts from a clearwater to a turbid state. There is a strong correlation between temperature and regime shifts; the optimum temperature range in which regime shifts tend to occur in New Zealand lakes is 10–13 degrees Celsius (Hamilton et al, 2013). This suggests that warming temperatures may move regime shifting south, making lakes in the south more sensitive to changing climatic conditions.

For New Zealand's shallow polymictic lowland and coastal lakes, the effect of warming temperatures may be more significant than for deep monomictic lakes. Polymictic lakes in New Zealand could be more sensitive to changing climatic conditions, due to longer and more frequent stratification events, with the potential for deoxygenation to increase in the bottom waters of eutrophic lake systems (Hamilton et al, 2013). This is particularly important in eutrophic systems where bottom waters have greater potential for anoxia, due to the associated release of nutrients.

Adaptive capacity

The natural adaptive capacity of New Zealand's lake ecosystems is likely to be significantly impaired by the high pressure they are already exposed to from human activities. The ability of many indigenous freshwater species to respond to climate change by dispersal to new sites is likely to be limited by the discrete and scattered distribution of lakes across our landscapes, and by the common occurrence of human-constructed barriers such as dams and culverts. Migratory indigenous fish species are likely to have greater dispersal than non-migratory ones, given their ability to disperse around New Zealand's coast (Hamilton et al, 2013). Other species may have sufficient behavioural or genetic plasticity to adapt fast enough to survive changing environmental conditions. However, the thermal tolerance of New Zealand's freshwater aquatic species is mostly unknown (Hamilton et al, 2013).

Active management to reduce the impacts of pressures on lakes is likely to partially restore the adaptive capacity of at least some lakes, although some attempts at restoring the integrity of eutrophic lowland lakes have been notable for their lack of significant success (Parliamentary Commissioner for the Environment, 2006). Adaptive capacity of lake ecosystems is likely to rely on implementing effective governance. Adaptive management will be key in improving adaptive capacity for lake ecosystems, to mitigate impacts of rising temperatures. Action will be needed to improve land-use management in lake catchments, to reduce nutrient and sediment loads in lakes, particularly from agricultural land. This will in turn provide greater resilience (Hamilton et al, 2013). Actions that increase efforts to monitoring, control and eradication efforts of invasive species will also be critical.

Consequence

New Zealand's lakes are likely to be subject to climate change-associated hazards and processes (Hamilton et al, 2013). Saline water intrusion into coastal lakes and regime shifts in shallow lowland lakes are likely to significantly and mostly irreversibly alter ecosystem composition and function. Temperature- and wind-induced changes to the mixing regimes of deeper lakes could fundamentally alter their dynamics, with consequences including the deoxygenation of bottom waters and release of nutrients stored in lake sediments. The distinctive ecosystems of sub-alpine and alpine lakes will also be subject to ongoing change in temperatures, allowing invasion by species normally restricted to lower elevations. Increased temperatures will favour the spread of warm water invasive fish and macrophyte species both southwards and to higher elevations, potentially affecting all New Zealand lakes (N2).

Climate change-driven changes to environmental conditions, combined with human-mediated pressures, are a significant threat to the long-term integrity of New Zealand's lake ecosystems and the distinctive species they support, including large numbers of endemic species (Hamilton et al, 2013). Changes will likely include:

- alterations to the distributional ranges and abundance of indigenous species
- increases in the distributions and abundance of introduced species
- fundamental changes in the trophic structure and functioning of vulnerable shallow lowland lakes
- alteration of the thermal dynamics and functioning of deeper lakes
- irreversible changes to New Zealand's distinctive sub-alpine lakes, with potential risks to the endemic species that they support.

Interacting risks

The disruption to riverine ecosystems (N3) will interact with this risk and the risk to wetland ecosystems (N4), which may result in significant impacts to New Zealand's freshwater biodiversity. Increasing instability of New Zealand's indigenous forests will add pressure to lowland freshwater ecosystems (N11). This risk may be intensified by the risk of invasive species (N2). With the invasion of exotic species comes the threat of vector-borne diseases and subsequent health implications (H3). Potential impacts to lake ecosystems and loss of freshwater species may affect other domains.

The disruption of lake ecosystems may impact on the agriculture sector (E3), which relies on freshwater systems. At the same time, the agriculture sector may further negatively impact on freshwater lake ecosystems through sedimentation and nutrient runoff.

Risks to lake ecosystems and species could also pose a threat to Māori social, economic, cultural capital and cultural heritage values and spiritual wellbeing (H5, H6, H8).

Uncoordinated governance may risk maladaptation or inadequate adaptation actions for river conservation, which will have significant consequences for riverine ecosystems (G1). Failure to allocate funding for adequate land management practices in a timely manner may amplify this risk (G2, G5). Challenges may also arise in protecting freshwater environments, due to the potential lobbying power of the agricultural industry (G7).

Confidence: High agreement, medium evidence

There is a high level of agreement that New Zealand's lake ecosystems and species are likely to be highly sensitive to climate change, reflecting both the expected change to several fundamental drivers of lake functioning and ecosystem character, and the reduced resilience of many lakes due to high levels of degradation, particularly in lowland environments. Only limited evidence is available from a relatively small number of studies that have explicitly considered the potential impacts of climate change on lake ecosystems and species.

Adaptation

Action to reduce risks to lakes is largely driven by regional councils. Several regional councils have outlined lake protection and restoration projects. For example, the Lake Waikare and Whangamarino Wetland Catchment and Management Plan outlines both existing work and future actions; it covers control of predators and invasive species, shoreline revegetation, riparian zone management, monitoring of water levels to understand supply and demand, and working with landowners to mitigate sediment intrusion (Lawrence and Ridley, 2018). Similarly, the Northland Regional Council's Dune Lakes water quality improvement project is working with a range of partners on activities that include eradicating waterweeds, controlling pest fish and remedying nutrient and sediment inputs, with the overall objective of improving water quality.

Table 28: N6 Risks to lake ecosystems: Urgency profile

<table>
<tr><th colspan="7">N6 Risks to lake ecosystems: Urgency profile</th></tr>
<tr><td>Urgency category</td><td colspan="2">Proportion of urgency</td><td colspan="4">Description of actions</td></tr>
<tr><td>More action needed</td><td colspan="2">30</td><td colspan="4">Intensify actions for protecting and restoring lake ecosystems, particularly in lakes subject to elevated nutrient inputs, those likely to undergo significant change in mixing regime and those likely to face increased risks from invasive species.</td></tr>
<tr><td>Research priority</td><td colspan="2">20</td><td colspan="4">Risks posed to alpine lakes, and ongoing risks posed by invasive species under higher temperatures.</td></tr>
<tr><td>Sustain current action</td><td colspan="2">30</td><td colspan="4">Continue policies and management actions to protect and restore lake (and riverine) ecosystems.</td></tr>
<tr><td>Watching brief</td><td colspan="2">20</td><td colspan="4">Continue monitoring of a representative selection of lakes to detect early signs of significant change.</td></tr>
<tr><td>Adaptation urgency</td><td colspan="2">65</td><td>Confidence</td><td colspan="3">High agreement, medium evidence</td></tr>
<tr><td>Consequence</td><td>Now</td><td>Minor</td><td>2050</td><td>Moderate</td><td>2100</td><td>Major</td></tr>
</table>

3.4.7 N7 Risks to terrestrial, freshwater and marine ecosystems due to increased extreme weather events, drought, and fire weather

Risk summary

Natural disturbance has long been recognised as playing an important role in many of New Zealand's terrestrial indigenous ecosystems, which are adapted to, and in many cases structured by, disturbances like earthquakes or extreme weather events that cause mortality through wind, drought, heatwaves, hail or frost (for example, Ogden et al, 1996). Climate change is predicted to increase the frequency of extreme and moderate climatic events, and alter the sequencing and seasonal timing of events, which is likely to affect indigenous ecosystems and species.

While little specific evidence is available from New Zealand studies, it has been argued that extreme climate events are likely to have a greater impact on ecosystems and species than the more gradual shifts in mean temperature and rainfall also expected (Jentsch and Beierkuhnlein, 2008). In particular, species that are able to persist under stable conditions may not be able to reproduce in a more disturbance-prone environment, while disruptions to ecosystem structure and composition are likely to provide greater opportunities for competing introduced species to establish (Thuiller et al, 2007). The ability of many lowland ecosystems and species to persist under intensified disturbance regimes is likely to be further compromised by pressures such as habitat loss and fragmentation, and competition with or predation by already established introduced species (Macinnis-Ng et al, nd).

Exposure

Climate change scenarios for New Zealand predict increasing frequency and magnitude of extreme weather events over the century, including drought, heatwaves and storms, with projected increases greatest under RCP8.5. Projections for these hazards are detailed in section 2.

Terrestrial and freshwater ecosystems in all sub-national climate zones are likely to experience increased frequency in heatwaves, with more hot days and longer periods of warming. All marine ecosystems are expected to experience more persistent, higher summer sea temperatures, and marine heatwaves are projected to increase in both frequency and intensity.

Predicted reductions in both annual and seasonal rainfall are likely to result in more intense and prolonged dry spells and droughts, particularly in eastern and northern New Zealand; that is, in sub-national climate zones 1, 2 and 3. Drought severity is projected to increase in most areas of the country, except for Taranaki–Manawatu, West Coast and Southland (Collins and Zammit, 2016). Decreased humidity and increased frequency of strong winds are predicted for much of the South Island, with the largest changes predicted for the east. Increased storminess is expected to affect all of New Zealand, including increases in the frequency of high-intensity rainstorms, particularly in zones 1, 3 and 6 (southeast) (Carey-Smith et al, 2018).

These predicted changes in climate are expected to increase the risk of wildfires in all sub-national climate zones. By 2100, the fire season is predicted to increase in length, with hazardous fire conditions beginning earlier in the summer. Fire severity is also likely to increase in climate zones 1, 2 and 3, due to the combination of decreased rainfall, lower humidity and increased windiness. Terrestrial ecosystems in the east and south of the South Island, especially coastal Otago and Marlborough and southeastern Southland, and in the west of the North Island (particularly around Whanganui) are most likely to see an increase in frequency and severity of fires.

Sensitivity

Exogenous disturbance regimes, such as wildfire, heatwaves, drought and storms, have been a continuous part of New Zealand’s climate for hundreds of years (Ogden et al, 1996). Changes in the frequency and timing of these disturbance events, as well as in their intensification, will impact on ecosystems and species across New Zealand that have a limited ability to survive such shock events. Extreme climatic hazards may also increase the vulnerability of rare ecosystems to invasive species (N2).

The combination of heat and moisture stress in terrestrial ecosystems could significantly impact species occupying sites close to their environmental limits (Niu et al, 2014). However, thresholds for thermal tolerance and acclimation will vary between species, and some will have greater capacity to adapt and recover following extreme events. The degree to which New Zealand species will be able to tolerate heat stress before reaching mortality is not well quantified or documented. Intensified disturbance regimes are also likely to increase the sensitivity of many lowland ecosystems and species to climate change hazards.

The sensitivity of many lowland freshwater ecosystems to drought and increased temperatures is likely to be increased by: existing degradation of lakes, rivers and streams resulting from flow obstructions (dams, diversions, culverts); abstraction for power generation or irrigation with resulting change to natural flow variability; elevated inputs of sediments and nutrients; and pressures from introduced species including aquatic plants, fish and algae.

Flood events in some river systems may favour the survival of endangered indigenous galaxiids, as they are much less affected by flooding events than predatory salmonids (Robertson et al, 2016).

Some marine ecosystems have been observed to be vulnerable to extreme climatic events, particularly heatwaves, with prolonged warming events causing significant thermal stress of marine biota and sometimes mortality (for example, Thomsen et al, 2019), as species are exposed to conditions outside their thermal tolerance (Rahel and Olden, 2008). Loss of structurally important species is likely to have broader negative impacts on other indigenous species, while also favouring invasion by introduced species (Wernberg et al, 2013).

Because wildfires have generally not been a major influence on New Zealand's ecosystems and species, most New Zealand ecosystems and species have very low resilience to their impacts (Perry et al, 2014). Wildfires are likely to become more frequent and severe, potentially causing widespread loss of indigenous species, which are generally poorly adapted to withstand fire.

Adaptive capacity

Many New Zealand ecosystems and species, and particularly those in terrestrial and freshwater environments, exhibit relatively high adaptive capacity when affected by recurrent natural disturbance. However, it is likely this capacity has been impaired to at least some degree by existing human-induced pressures such as introduced browsers and predators, habitat clearance and fragmentation, and nutrient enrichment of fresh waters. Species with limited geographic ranges, limited population size, low reproduction rates or poor dispersal are also likely to have lower adaptive capacity than widespread, common species, particularly those with high reproduction rates and good dispersal ability.

It may be possible to increase the adaptive capacity of New Zealand's ecosystems and species to increased disturbance frequencies through appropriate conservation management, in particular reducing pressures from introduced invasive species such as predators, browsers and weeds.

Consequence

More frequent extreme and moderate climatic events will inevitably have direct and potentially substantial impacts on New Zealand's indigenous ecosystems and species. It is likely these events will interact with and intensify the effects of prevailing natural disturbance regimes. Predicting the exact impact of more frequent extreme events is problematic, despite our partial understanding of the roles already played by disturbance in some indigenous ecosystems. This is due to both the difficulty in forecasting when and where extreme events will occur, and the highly variable impacts that extreme events can have on ecosystems and species.

A further complication is that the degree of imbalance in distribution between both ecosystems and species and average climate conditions is expected to progressively increase. In particular, ecosystems and species subject to chronic stress from increased average temperatures, reduced rainfall or extended periods of low stream flows are likely to be less resilient to damage caused by extreme events. These factors are likely to lead to increased risk of invasion by introduced species (Hellmann et al, 2008; Thuiller et al, 2007).

Increased frequency of wildfires will pose perhaps the most severe and tangible threat to ecosystems and species in eastern and northern New Zealand, due to the degree of devastation that can occur during these events. Wildfires have generally not been a major influence on New Zealand's ecosystems and species, resulting in low selection pressures for fire adaptation (Perry et al, 2014).

Interacting risks

Social, economic and natural environment systems are intrinsically linked; changes in natural disturbance regimes and the increased risk of invasive species will have cascading impacts on other domains. Extreme climatic events that result in the disturbance of natural ecosystems will see impacts on the tourism sector (E4) and land-based primary sector (E3), as well as on fisheries and aquaculture (E5) that rely on indigenous species and natural landscapes. Invasive species pose a threat to Māori social, economic, cultural capital and cultural heritage values and spiritual wellbeing from climate change impacts on indigenous species and ecosystems (H5, H6, H8).

With the invasion of exotic species due to warmer climatic conditions comes the threat of vector-borne diseases and the subsequent health implications (H3).

The threat of invasive species could lead to a reduction in, or loss of, māhinga kai (food-gathering areas or sites) through impacts on taonga species. Although there is a threat to these cultural relationships, there is also an opportunity for mātauranga Māori to inform environmental management practices, including protection of taonga species from invasive species and climate change (Bond et al, 2019).

Confidence: High agreement, limited evidence

There is a high level of agreement that predicted increases in the frequency of climate change hazards, including wildfire, drought, heatwaves and storms, have the potential to have a profound impact on New Zealand's indigenous ecosystems and species. However, only very limited evidence is available relating to the vulnerability of different indigenous ecosystems and species to these more frequent extreme disturbance events.

Adaptation

The Ministry for the Environment is leading action relating to this risk. Actions include conservation management techniques to eradicate invasive species (N2), policy adaptation frameworks and action plans, and community programmes to increase ecosystem resilience – such as the Green Corridors programme. In 2014 the Ministry issued the National Policy Statement for Freshwater Management, and it is leading the development of a National Policy Statement for Indigenous Biodiversity. Regional councils have established programmes identifying work already undertaken and setting future targets for freshwater resource management and ecosystem resilience (Ministry for the Environment, 2019b). The *New Zealand Biodiversity Action Plan 2016–2020* outlines the goal to improve the status of biodiversity through safeguarding ecosystems (Department of Conservation, 2016).

Community programmes such as the Million Metres Stream Project, One Billion Trees, the Green Corridors programme and others will contribute to increasing local ecosystem resilience.

Table 29: N7 Risks to terrestrial, freshwater and marine ecosystems: Urgency profile

<table>
<tr><th colspan="7">N7 Risks to terrestrial, freshwater and marine ecosystems: Urgency profile</th></tr>
<tr><th>Urgency category</th><th colspan="2">Proportion of urgency</th><th colspan="4">Description of actions</th></tr>
<tr><td>More action needed</td><td colspan="2">20</td><td colspan="4">Implement a systematic approach to the identification, monitoring and reporting of extreme and more frequent moderate events and their impacts; carry out remedial actions as appropriate.</td></tr>
<tr><td>Research priority</td><td colspan="2">30</td><td colspan="4">How best to identify, monitor and report on significant extreme events and their impacts in terrestrial, freshwater and marine realms.</td></tr>
<tr><td>Sustain current action</td><td colspan="2">20</td><td colspan="4">Continue current terrestrial, freshwater and marine ecosystem conservation actions to maintain resilience at high levels.</td></tr>
<tr><td>Watching brief</td><td colspan="2">30</td><td colspan="4">Monitor extreme and more frequent moderate event impacts and their sequencing and seasonal timing on natural ecosystems, to measure trends and provide early warning of systems likely to become increasingly vulnerable over time.</td></tr>
<tr><td>Adaptation urgency</td><td colspan="2">60</td><td>Confidence</td><td colspan="3">High agreement, limited evidence</td></tr>
<tr><td>Consequence</td><td>Now</td><td>Minor</td><td>2050</td><td>Moderate</td><td>2100</td><td>Major</td></tr>
</table>

3.4.8 N8 Risks to oceanic ecosystem productivity and functioning due to changes in sea surface temperature, ocean mixing, nutrient availability, chemical composition and vertical particle flux

Risk summary

New Zealand lies across a zone of enhanced ocean productivity located along the subtropical front, an important oceanic boundary that separates warmer northern (subtropical) waters, characterised by low nutrients and productivity, from colder southern (subantarctic) waters, which have higher nutrient levels and generally greater phytoplankton productivity (Bradford-Grieve et al, 2006). Projected increases in ocean temperatures and windiness will alter physical and biogeochemical processes in these oceanic waters, particularly at their surface (Law et al, 2017a). Ocean productivity and function will be altered mostly through changes in the depth of the surface mixed layer, affecting both light penetration and the exchange of nutrients across the mixed layer boundary. This is expected to reduce primary productivity, with likely flow-on effects on broader marine food webs and ecosystems by reducing the vertical flux of organic particles to the sea floor (Law et al, 2017b). This may see regional shifts in ecosystem composition, with changes to both the distributions and abundance of marine species.

These changes in oceanic functioning will most likely be ongoing and gradual, with the magnitude of changes in ocean temperature and chemistry expected to increase toward the end of the century. Human activities have already had an extensive impact on New Zealand’s marine environment, including from bottom trawling, land-based discharge of sediments, nutrients and pollutants, and the introduction of invasive species. These impacts are likely to interact with the effects of climate change by reducing the natural resilience of ecosystems and species.

Exposure

Climate change is predicted to result in New Zealand’s oceans experiencing gradual, ongoing increases in both sea surface temperatures and windiness. These climatic changes are projected to increase in severity towards the end of the century, with the greatest increases under RCP8.5. Atmospheric warming has already increased sea surface temperature in the Tasman Sea, at four times the observed rate for the rest of the world's oceans over the same period (Law et al, 2017b).

Increases in sea surface temperatures and windiness are predicted to change the depth of the surface mixed layer, which will affect both light penetration and the exchange of nutrients across the mixed layer boundary (Law et al, 2017a). The magnitude of these changes is predicted to be greater in already nutrient-poor subtropical waters than in more nutrient-rich subantarctic waters; significant reductions in productivity are predicted for the highly productive zone of mixing between these two water bodies along the Chatham Rise. Further details on climate hazard projections are outlined in section 2.

Sensitivity

Assessing the sensitivity of the oceans around New Zealand to projected declines in their productivity is difficult due to the complex linkages and interrelationships between ecosystems and species, and the complexity of the physical environment. This reflects the wide latitudinal span and complex ocean dynamics, which include zones of intense mixing along boundaries and between water bodies. As a consequence, while modelling studies can provide broad projections of physical changes in ocean attributes such as surface mixing, with reasonably confident forecasts of expected declines in productivity, only very broad predictions can be made of the likely flow-on effects on the distributions and abundance of species, and consequent changes in their interactions with each other.

The potentially far-reaching extent of these changes is illustrated by expected reductions in the vertical flux of organic particles that transport energy from surface waters to demersal communities on or near the sea floor. Preliminary results from modelling studies show a range of demersal fish species are likely to be affected by this reduced energy supply, reducing fish condition, affecting recruitment and lowering fisheries productivity (Law et al, 2016). Further uncertainty is generated by likely changes in the abundance and distributions of marine species in more direct response to changes in ocean climate, including increased temperatures, particularly in surface waters, and ongoing reductions in pH.

The sensitivity of some oceanic ecosystems is likely to be increased by the impacts of commercial trawling, which reduces the resilience of many benthic ecosystems through recurrent disturbance (Thrush et al, 2016).

Adaptive capacity

It is difficult to assess the adaptive capacity of ocean ecosystems and species to predicted declines in primary productivity. This is because the systems involve very complex and, in some cases, only partially understood physical and biological processes and interactions. Opportunities for human interventions to increase the adaptability of these systems are likely to be extremely limited due to this complexity and the enormous geographic scales over which change is occurring.

Adaptive capacity of natural ecosystems is somewhat limited without implementing effective governance. However, for the case of ocean productivity, there is very limited scope for action in building adaptive capacity and managing potential impacts.

Consequence

Predicted increases in ocean temperature and windiness are expected to reduce the depth of the ocean surface mixed layer, reducing light availability and nutrient supply. Together with lowered pH, this change is predicted to reduce marine productivity, affecting primary producers such as phytoplankton and macro-algae. There will be inevitable flow-on effects on the functioning of broader marine food webs and ecosystems, including through reductions in the vertical flux of organic particles to the sea floor (Law et al, 2017b). This has the potential to impact on the functioning of both broader ecosystems and commercial fishing, as well as on broader food-web components and bottom-dwelling species. Combined with more direct effects of climate change on ocean temperature and pH, this could result in regional-scale shifts in the distribution and abundance of marine species, and changes in ecosystem patterns.

Interacting risks

Through the interactions between New Zealand’s marine environment and social and economic systems, the loss of ocean productivity will have cascading impacts into other domains. Reductions in phytoplankton abundance and changes to ecosystem function and structure will affect the broader marine food web and biotic interactions, disrupting fisheries and aquaculture (E5). Cascading impacts are likely to affect many benthic species that rely on pelagic productivity, including a significant number of commercially important species (N10).

Impacts on ocean productivity and marine ecosystems will affect Māori social, economic, cultural capital and cultural heritage values and spiritual wellbeing connected to marine ecosystems (H5, H6, H8). Changes or reductions in ocean productivity are likely to have cascading impacts on Māori fishing and marine farming activities, including loss of value to fisheries quotas, reducing revenue and allocation of supplies to Māori organisations from current fisheries settlement arrangements.

The risk of maladaptation or inadequate adaptation actions may have significant consequences for marine environments. However, the scope for managing potential impacts of ocean ecosystems and species (G1) is currently very limited. Challenges may arise in protections over marine environments, due to potential lobbying power of the fishing industry (G7). Failure to allocate funding adequately for relevant research in a timely and effective manner may amplify this risk (G2, G5).

Confidence: High agreement, medium evidence

There is a high level of agreement that changes in sea surface temperatures and windiness will trigger a cascade of effects, reducing ocean productivity around New Zealand, with broader impacts on ecosystem dynamics and functioning. While there is strong agreement on this risk and a reasonable amount of knowledge of the processes that will drive these changes, considerable uncertainties remain around the specific impacts, the rates at which changes will occur and how these will vary spatially.

Adaptation

Action relating to this risk is currently driven by MPI, Fisheries New Zealand, regional councils, the Environmental Protection Authority and the private sector. Efforts are focused on research projects, including Sustainable Seas, the Coastal Acidification – Rate, Impacts and Management (CARIM) project and the Moana Project. These seek to understand how ecosystem indicators such as temperature, nutrient availability and chemical composition are changing, and the impacts that these changes are likely to have on oceanic ecosystem productivity.

The Moana Project seeks to understand ocean circulation, connectivity and marine heatwaves, to inform and support the seafood industry (Moana Project, 2018). The CARIM project (N10), led by NIWA, is examining the ecosystem effects of acidification on primary production and food quality. DOC's *New Zealand Biodiversity Action Plan 2016–2020* also outlines goals to understand the impacts of climate change on oceanic ecosystem productivity (Department of Conservation, 2016).

Table 30: N8 Risks to oceanic ecosystem productivity and functioning: Urgency profile

<table>
<tr><th colspan="7">N8 Risks to oceanic ecosystem productivity and functioning: Urgency profile</th></tr>
<tr><td>Urgency category</td><td colspan="2">Proportion of urgency</td><td colspan="4">Description of actions</td></tr>
<tr><td>More action needed</td><td colspan="2">0</td><td colspan="4"></td></tr>
<tr><td>Research priority</td><td colspan="2">50</td><td colspan="4">Further develop understanding of the effects of climate change on ocean dynamics and productivity, and flow-on effects on ecosystem composition and species distributions.</td></tr>
<tr><td>Sustain current action</td><td colspan="2">20</td><td colspan="4">Continue developing a representative set of marine protected areas to maintain resilience and provide baseline measures of ecosystem composition and function in the absence of harvesting.</td></tr>
<tr><td>Watching brief</td><td colspan="2">30</td><td colspan="4">Monitor ecosystem composition across a representative range of marine ecosystems, to enable early detection of change in ecosystem composition.</td></tr>
<tr><td>Adaptation urgency</td><td colspan="2">55</td><td>Confidence</td><td colspan="3">High agreement, medium evidence</td></tr>
<tr><td>Consequence</td><td>Now</td><td>Minor</td><td>2050</td><td>Moderate</td><td>2100</td><td>Major</td></tr>
</table>

3.4.9 N9 Risks to sub-alpine ecosystems due to changes in temperature and a reduction in snow cover

Risk summary

New Zealand's sub-alpine ecosystems support a diverse array of indigenous species, characterised by high levels of endemism; about 93 per cent of vascular alpine plant species are endemic (Halloy and Mark, 2003). Many of these species are distributed locally as relatively isolated populations in habitat 'islands' on range crests that are often widely separated from other similar habitats. This relatively high degree of local geographic isolation is often intensified by clearance and fragmentation of surrounding lower elevation habitats. The resulting limited potential for southwards or upslope migration in response to rising temperatures could result in considerable vulnerability for these ecosystems and their distinctive species (Macinnis-Ng et al, nd).

An earlier study identified around 40–70 of New Zealand's alpine species that are already at risk of extinction due to increased temperatures (Halloy and Mark, 2003). In addition, temperatures predicted under RCP8.5 (about 2.8–3.1 degrees Celsius by 2100) (Ministry for the Environment, 2018, Pearce et al, 2018) are likely to result in the loss of 200–300 indigenous vascular plant species, which represent about half of New Zealand's total alpine flora (Halloy and Mark, 2003). Increased temperatures are also likely to increase risks of invasion by introduced plant species such as *Pinus contorta* and *Calluna vulgaris* L. (Giejsztowt et al, 2019; Tomiolo et al, 2016). Warmer temperatures may also increase the suitability of sub-alpine environments for introduced vertebrate predators such as ship rats, further increasing predation pressures on sub-alpine birds, lizards and invertebrates from stoats, mice and hedgehogs.

Exposure

The ongoing, gradual warming of temperatures is projected to increase over the century, with the greatest increases projected under RCP8.5. Projections for temperature increases are detailed in section 2.

Increases in average temperatures are expected to be broadly uniform across New Zealand, with slightly higher increases in the north and east than in the south and west; as a consequence, the North Island is expected to experience slightly greater warming than the South Island. Greater warming is also predicted for higher altitude areas than for lowland areas; snow cover is also predicted to decrease. With a warming of 3 degrees Celsius under RCP8.5, alpine vegetation zones are expected to rise 500 metres.

Some alpine areas in New Zealand have already experienced climatic warming. Tongariro National Park is experiencing a greater rate of climatic change than average global rates. It is presently 1.5 degrees warmer, and receives 5 millimetres less precipitation annually, compared with 50 years ago (Giejsztowt et al, 2019).

A recent assessment of New Zealand's sub-alpine region (Halloy and Mark, 2003), identified 441 fragmented 'alpine islands' above an elevation of 1000 metres, with the majority of them (364) occurring above 1500 metres. A temperature increase of 3 degrees Celsius would reduce the total extent of these sub-alpine islands from 30,000 km^2 to 15,400 km^2, approximately 50 per cent (Halloy and Mark, 2003). In the North Island, 81 of the 87 current alpine islands would be lost, with the remaining six islands likely to be fragmented into 20 smaller islands. In the South Island, 273 of the current 354 alpine islands will be lost, with the remaining ones being further fragmented (Halloy and Mark, 2003).

Sensitivity

New Zealand's sub-alpine ecosystems and species are likely to be highly sensitive to increasing temperatures, in part reflecting the highly fragmented distribution of sub-alpine environments. These are widely scattered habitat 'islands' on range crests that are often distant from other similar habitats. This isolation has resulted in high levels of species endemism both nationally and locally (Halloy and Mark, 2003).

The combination of geographic isolation and many species with geographically restricted ranges means these ecosystems are highly vulnerable to climate change (Halloy and Mark, 2003; Macinnis-Ng et al, nd), with very limited ability to spread into new geographic locations as temperatures rise (Thuiller et al, 2007). Local endemic species, and low dispersal and specialist species, will likely be the most at risk of extinction (Halloy and Mark, 2003).

Many of the indigenous forests forming New Zealand's natural treelines are dominated by slow growing 'southern beech' species (formerly *Nothofagus*, now reclassified into *Fuscospora* and *Lophozonia*), which to date have shown little upward expansion in response to warming temperatures (Tomiolo et al, 2016). This relative stasis may allow sub-alpine species to persist even under elevated temperatures, provided their thermal tolerances are not exceeded, or mortality is not caused by climate change hazards such as heatwaves and droughts or associated hazards such as wildfire. However, the resulting disequilibrium may increase the vulnerability of these ecosystems to invasive tree species that are able to persist at the treeline and above (Tomiolo et al, 2016).

Adaptive capacity

Low adaptive capacity to human-induced pressures is a common feature of island biotas, and particularly those that have experienced long genetic isolation (Frankham, 1997; Williams et al, 2008). This, coupled with the geographic isolation of many subalpine habitats, sometimes intensified by clearance of surrounding indigenous cover, indicates that many sub-alpine ecosystems and their species will have low adaptive capacity to climate change. Adaptive capacity will likely be higher in more extensive sub-alpine habitats, particularly those at higher elevations, which allow for upslope migration over time. Even in these environments, however, species with limited geographic ranges, limited population size, low reproduction rates, and/or poor dispersal are likely to have low adaptive capacity.

Adaptive capacity may be increased through appropriate conservation management, although there will be challenges in maintaining the genetic integrity of species that have occupied isolated habitat patches for a long time (Williams et al, 2008).

Consequence

Increased temperatures pose a significant risk to New Zealand's sub-alpine ecosystems and species, particularly in locations where there is limited opportunity for upslope migration or longer distance dispersal to more suitable habitats. Modelling indicates that an increase of 3 degrees Celsius in mean annual temperatures may eventually result in the extinction of up to 300 of New Zealand’s indigenous vascular plant species, approximately half the species recorded as occurring in sub-alpine environments. This warming of 3 degrees would also result in the loss of 81 out of 87 sub-alpine habitat islands in the North Island, and 273 of 354 subalpine islands in the South Island. Surviving islands are likely to also become further fragmented (Halloy and Mark, 2003).

However, lack of contemporary evidence of treeline adjustments in response to recent warming may indicate a relatively high degree of stasis in current ecosystem boundaries. This suggests that distributional adjustments may be relatively slow, provided extreme events do not cause widespread mortality among current occupants of the sub-alpine zone. The resulting disequilibrium between climate and the distributions of ecosystems and species may reduce resilience to disturbance, with increased risks of invasion by introduced species with greater dispersal ability and/or environmental tolerances.

Interacting risks

The loss of indigenous alpine species will increase the threat of invasive species extending into both sub-alpine ecosystems and terrestrial ecosystems (N2). Changes in New Zealand’s sub-alpine ecosystems will interact with social and economic systems, and cascade impacts into other domains. Losing indigenous alpine species, and the disruption of alpine ecosystems from invasive species, will impact the tourism sector (E4) as well as Māori social, economic, cultural capital, cultural heritage values and spiritual wellbeing (H5, H6 and H8). With the invasion of exotic species due to warmer climatic conditions comes the threat of vector-borne diseases and the subsequent health implications (H3).

Reduced snow cover and storage over winter periods will result in changes to seasonality of snowmelt and river flows (N3 and N6).

Effective governance is likely to play a key role in building adaptive capacity of sub-alpine ecosystems, so the risk of inadequate or maladaptive adaptation actions through uncoordinated governance is a critical consideration (G1). There is a significant limit to our ability to understand, predict and respond to climate change impacts on New Zealand's sub-alpine ecosystems due to under-investment in biodiversity science (G5).

Confidence: High agreement, medium evidence

There is a high level of agreement that changing climatic conditions, and in particular increased temperatures, pose a significant threat to New Zealand's indigenous sub-alpine ecosystems and species, increasing the risk of invasion by introduced species. Most of the limited evidence for this risk comes from fundamental studies of the physiology of individual species and broad-scale studies of current distributions of ecosystems and species in relation to climate.

Adaptation

There has been very limited action to reduce the risk posed by higher temperatures and a reduction in snow cover to sub-alpine ecosystems. DOC has identified the need to manage high-altitude biodiversity, understand the potential effects of climate change and manage alpine predator control (Department of Conservation, nd.2).

Table 31: N9 Risks to sub-alpine ecosystems: Urgency profile

<table>
<tr><th colspan="7">N9 Risks to sub-alpine ecosystems: Urgency profile</th></tr>
<tr><th>Urgency category</th><th colspan="2">Proportion of urgency</th><th colspan="4">Description of actions</th></tr>
<tr><td>More action needed</td><td colspan="2">10</td><td colspan="4">Expand active conservation management to cover a representative range of New Zealand's sub-alpine ecosystems, to maintain their resilience at high levels.</td></tr>
<tr><td>Research priority</td><td colspan="2">30</td><td colspan="4">Detect climate change-triggered changes in the distributions of ecosystems and species, and identify possible remedial actions to maintain viable populations of threatened species.</td></tr>
<tr><td>Sustain current action</td><td colspan="2">30</td><td colspan="4">Continue existing conservation management actions (control of browsers, predators, weeds) of sub-alpine ecosystems to maintain their resilience at high levels.</td></tr>
<tr><td>Watching brief</td><td colspan="2">30</td><td colspan="4">Monitor ecosystem composition across a representative range of sub-alpine and treeline sites, to detect evidence of treeline extension or loss of sub-alpine species.</td></tr>
<tr><td>Adaptation urgency</td><td colspan="2">55</td><td>Confidence</td><td colspan="3">High agreement, medium evidence</td></tr>
<tr><td>Consequence</td><td>Now</td><td>Minor</td><td>2050</td><td>Moderate</td><td>2100</td><td>Major</td></tr>
</table>

3.4.10 N10 Risks to carbonate-based hard-shelled species from ocean acidification due to increased atmospheric concentrations of carbon dioxide

Risk summary

Increasing atmospheric carbon dioxide concentrations are leading to ocean acidification, creating conditions that threaten the survival of a broad range of species with carbonate-based exoskeleton. Those under threat include molluscs, some plankton, echinoderms and corals (Law et al, 2017a; Rouse et al, 2017). For these species, ocean acidification is likely to lead to reduced development rates, impaired shell forming and maintenance, and decreased survival of larvae (Rouse et al, 2017). Many of these hard-shelled species play an important role in controlling ecosystem structure or function. For example, phytoplankton are critical to ocean productivity and provide food resources critical for broader marine food webs (Law et al, 2017a). Similarly, many New Zealand mollusc species, including pāua, cockles and flat oysters, play complex and important roles in maintaining healthy ecosystem function and structure, through biogeochemical processing, nutrient recycling, controlling phytoplankton biomass, and the provision of food and habitat structure for benthic organisms (Gazeau et al, 2013; Law et al, 2017a); some of these species are also of economic importance.

Exposure

Ocean acidification is ongoing and gradual, and will increase in severity over the century. Ongoing, gradual reductions in pH are predicted throughout the oceans surrounding New Zealand; measurements in subantarctic waters off the Otago coast between 1998 and 2016 indicate a current rate of decline of 0.0015 units per year (Law et al, 2017a). Differences in the rate of decline between scenarios are not expected to become apparent until around 2035, when faster reductions are predicted under RCP8.5 than under RCP4.5. Further details on ocean acidification projections are provided in section 2.

The effects of ocean acidification are likely to interact with and be intensified by existing human activities (trawling, sedimentation, contaminants and pathogens, introduced species) that have already had a negative impact on populations of carbonate-based hard-shelled species (Gazeau et al, 2013).

Sensitivity

All marine species that use calcium carbonate in their shells or exoskeletons are potentially at risk from the lowering of pH in the oceans, which creates corrosive conditions that threaten the maintenance of their body structures; such species include some plankton, molluscs, echinoderms and cold-water corals (Law et al, 2017a; Rouse et al, 2017). For these species, this change may lead to reduced developmental rates, impaired shell forming and maintenance, and reduced survival of larvae (Rouse et al, 2017). However, predicting the overall effects of reducing pH on the abundance of different species is complicated by variations in their susceptibility (Chan et al, 2016; Cross et al, 2016; Law et al, 2017a; Long et al, 2017). Susceptibility is in part governed by the relative proportions of aragonite and calcite used in body structures, with the first of these more vulnerable to dissolution under lower pH (Law et al, 2017a).

Many of these hard-shelled species play important roles in controlling ecosystem structure or function. For example, phytoplankton are critical to ocean productivity and provide food resources that are critical in supporting broader marine food webs (Law et al, 2017a). Similarly, many New Zealand mollusc species, including pāua, cockles and flat oysters, play complex and important roles in maintaining healthy ecosystem function and structure, through biogeochemical processing, nutrient recycling, controlling phytoplankton biomass and the provision of food and habitat structure for benthic organisms (Gazeau et al, 2013; Law et al, 2017a). Some of these species are also of economic importance.

Broader ecosystem sensitivity will be heightened by effects from ocean acidification that are particular to individual species, where each of these effects and changes will contribute to overall community dynamics in complex ways. Small or slight variations in species response to changes in ocean acidification may be amplified over successive generations, potentially driving major reorganisation and restructuring of ecosystems (Doney et al, 2009).

Adaptive capacity

The ability of hard-shelled species to persist under ocean acidification is likely to vary depending on their ability to maintain their normal growth and development mechanisms, with adaptive ability greatest in species with high phenotypic and genotypic plasticity (Gazeau et al, 2013) or with long-distance dispersal capacity. Results from a range of studies suggest that adaptive capacity varies widely between species (Chan et al, 2016; Cross et al, 2016; Long et al, 2017).

A study of Sydney rock oysters by Parker et al (2011) determined that exposure of adult individuals to elevated carbon dioxide during the reproductive phase had positive carry-over effects on larvae, which showed faster rates of development. Further studies looking at heritable traits in sea urchins found that although they have a lower population turnover rate, their phenotypic and genotypic plasticity may result in faster adaptation to ocean acidification (Gazeau et al, 2013). These studies indicate that adaptive capacity is possible in hard-shelled species, and will be reliant on evolutionary mechanisms, behavioural plasticity and reproductive rates (Williams et al, 2008).

The ability for cold-water coral species to disperse or migrate to more suitable habitat is likely to strongly influence their capacity to adapt. For example, although much of the current habitat for the New Zealand cold-water coral species *S. variabilis* is likely to decline in suitability by 2100, new areas of suitable habitat are likely to develop on the fringes of the Chatham Rise, on other sea-floor features in the west and north, and in the deeper waters of Campbell Plateau in the southeast (Law et al, 2017b). Different topographic regions across New Zealand’s waters could provide important refuge for cold-water coral species.

Consequence

The impacts of ocean acidification on species such as some plankton, molluscs and cold-water corals could have profound and far-reaching consequences for marine biodiversity, given the important functional roles played by many of these species. These roles include contributing to primary productivity, biogeochemical processing, nutrient recycling, and the provision of food and habitat structure for benthic organisms. Impacts on them are therefore likely to have flow-on effects on broader marine food webs and ecosystem functioning (Gazeau et al, 2013).

Cold-water coral species are important in benthic ecosystems in the northern regions of New Zealand, such as around the Kermadec Islands. Increasing acidification of New Zealand’s waters poses a threat to the abundance and distribution of these deep-sea corals, by inhibiting their ability to construct and maintain their skeletons (Law et al, 2017b). Alterations in the distribution of deep-sea corals will indirectly affect the future distribution of deep-sea fish, with consequential implications for fisheries.

Interacting risks

Any loss of hard-shelled species is likely to result in cascading impacts into other domains. Losses of molluscs, phytoplankton and cold-water corals will disrupt marine ecosystems and ocean productivity (N8) leading to a disruption in fisheries and aquaculture (E5), and cascading impacts on reliant species (N5). Impacts on carbonate-shelled organisms will directly affect Māori social, economic, cultural capital and cultural heritage values and spiritual wellbeing connected to marine ecosystems (H5, H6, H8). Ocean acidification will impact on the abundance of traditional food sources such as pāua, pipi, kina, tuatua, toheroa, oysters and mussels. Changes or reduction in ocean productivity are likely to have cascading impacts on Māori fishing and marine farming activities.

The risk of maladaptation or inadequate adaptation actions may have significant consequences for marine environments (G1). However, implementation of effective governance will only be beneficial to some extent, as there is little scope for action to protect carbonate-based hard-shelled species. There may be challenges in protecting marine environments, due to potential lobbying power of the fishing industry (G7).

A significant risk lies in our ability to understand, predict and respond to climate change impacts on New Zealand's marine biodiversity, due to under-investment in biodiversity science (G5). Failure to allocate funding for relevant research in a timely manner may amplify this risk (G2).

Confidence: High agreement, medium evidence

There is a high level of agreement that ocean acidification will have a negative impact on the shell-forming process of carbonate-based shelled organisms, which in turn affects benthic and broader marine ecosystems. While there is agreement on this risk, and a reasonable amount of knowledge on impact pathways, gaps in knowledge remain, particularly around the vulnerability of different taxa and thresholds of impact, as well as the adaptive capacity of shelled species in increasingly acidifying conditions. Finally, only limited information is available on geographic variation in the relative magnitude of these likely changes.

Adaptation

Adaptation efforts are primarily driven by MPI and Fisheries New Zealand. Efforts are focused on research, establishing baseline data and monitoring programmes, and developing strategies for action. The New Zealand Government's *Aquaculture Strategy*, released in 2019, included an action to assess the ability of shellfish to buffer ocean acidification (New Zealand Government, 2019).

NIWA is engaged in research on ocean acidification to enhance the protection and management of coastal ecosystems as part of the Coastal Acidification – Rate, Impacts and Management research project (NIWA, 2016b). NIWA has also developed an ocean acidification observing network (NZOA-ON) to establish baseline conditions and quantify future change (NIWA, 2015).

Table 32: N10 Risks to carbonate-based hard-shelled species from ocean acidification: Urgency profile

<table>
<tr><th colspan="7">N10 Risks to carbonate-based hard-shelled species from ocean acidification: Urgency profile</th></tr>
<tr><th>Urgency category</th><th colspan="2">Proportion of urgency</th><th colspan="4">Description of actions</th></tr>
<tr><td>More action needed</td><td colspan="2">0</td><td colspan="4">Very limited scope for action.</td></tr>
<tr><td>Research priority</td><td colspan="2">50</td><td colspan="4">Distributions and resilience of carbonate-dependent species, including those important for aquaculture or playing important functional roles in ecosystems.</td></tr>
<tr><td>Sustain current action</td><td colspan="2">20</td><td colspan="4">Continue development of a representative set of marine protected areas that are free from recurrent harvesting, to provide refugia for vulnerable species.</td></tr>
<tr><td>Watching brief</td><td colspan="2">30</td><td colspan="4">Monitor distributions of vulnerable species to allow early detection of change in population status.</td></tr>
<tr><td>Adaptation urgency</td><td colspan="2">55</td><td>Confidence</td><td colspan="3">High agreement, medium evidence</td></tr>
<tr><td>Consequence</td><td>Now</td><td>Minor</td><td>2050</td><td>Moderate</td><td>2100</td><td>Major</td></tr>
</table>

3.4.11 N11 Risks to the long-term composition and stability of indigenous forest ecosystems due to changes in temperature, rainfall, wind and drought

Risk summary

Indigenous forests were once the dominant land-cover across most of New Zealand; substantial clearance since human settlement has reduced their extent by about 75 per cent, to their current area of about 6.4 million hectares (Forestry New Zealand, 2020). Forest loss has been greatest in lowland environments, with many surviving lowland forests highly fragmented. Evidence from analyses of both the historical and current distributions of dominant forest species (for example, Leathwick, 1995; McGlone et al, 1993) indicate high degrees of landscape-scale sorting of forest ecosystems and species in relation to climate parameters, such as temperature and moisture stress. While this might suggest that future changes in climate will change the distributions of forest ecosystems and species, evidence of adjustments in species distribution in response to contemporary warming is very limited (McGlone and Walker, 2011), suggesting a degree of stasis in the distribution of many forest ecosystems and species. These changes may be slowed, however, both by reductions in the abundance of avian dispersers and high levels of fragmentation in many lowland environments. Detecting such changes is likely to be complicated by the pervasive effects of introduced browsers.

Exposure

The ongoing, gradual changes of temperature, wind and rainfall are projected to increase in severity towards the end of the century, with the greatest change expected under RCP8.5. Projections for these climate hazards are detailed in section 2. All sub-national climate zones will see higher mean average temperatures; however, warming will be greatest in the northeast and slightly less in the south. All sub-national climate zones are likely to see an increase in extreme winds, but these will be greater in the southern half of the North Island and in the South Island. Increases in rainfall intensity will also occur across all sub-national climate zones, with zones 1, 3 and 6 likely to experience the greatest increase.

New Zealand's indigenous forest ecosystems and species are predicted to experience higher temperatures under climate change, with greater warming in the north and east; forests in eastern and northern parts of New Zealand will also be exposed to reduced rainfall and more frequent drought, with many also exposed to increased frequencies of drying winds.

Sensitivity

Estimating the sensitivity of New Zealand's forest ecosystems and species is complicated by conflicting evidence, which indicates both sensitivity to and sorting in relation to climate, and a relative lack of evidence of response to contemporary changes in climate. Prediction of responses is also complicated by a plethora of existing pressures on New Zealand's forest ecosystems and species (McGlone and Walker, 2011).

Evidence from palynological studies indicates large shifts in forest distribution and composition in recent geological time in response to gradual changes in climate (associated with glacial-interglacial cycles) (for example, McGlone et al, 1993). Studies of the current distributions of forest species indicate considerable sorting along gradients of temperature, rainfall and humidity (Leathwick, 1995). While these insights might suggest that New Zealand's forest species have a strong inbuilt capacity to adjust naturally to human-induced climate change, past distributional changes occurred over an extended time in response to gradually changing climates; human-induced climate change is predicted to occur much more rapidly. In addition, past forest climate adjustments occurred across continuously forested landscapes that offered few physical impediments to species movement, and with abundant avian dispersers. Contemporary landscapes generally support discontinuous forest cover, with high levels of fragmentation in lowland environments, and many have suffered substantial reductions in bird populations.

Adaptive capacity

As discussed above, the circumstances of the current climate change are significantly different to those in the past, so ecosystem response is likely to be substantially different. The adjustment ability of at least some dominant forest species is further compromised by introduced herbivores, which filter forest regeneration through their selection of palatable species.

This suggests a general compromising of natural adaptive capacity in New Zealand's forests, although this is likely to vary widely between species and will be dictated by their physiological tolerance of stress, and reproductive and dispersal capabilities (Whitehead et al, 1992). Generalist species with good long-distance dispersal capabilities or short generation times are likely to have greater adaptive capacity than those that are site-specialised, are long-lived or have poor dispersal capability (Whitehead et al, 1992).

Sustained conservation management is likely to enhance the adaptive capacity of many of our forests and species, and should be carefully targeted to improve the integrity of representative examples of a full range of forest ecosystems. This will require active management of browsers, predators and weeds, and restoration of previously forested sites to reconnect fragments along gradients of elevation and moisture stress.

Consequence

It seems highly likely that climate change, along with other human-induced pressures, in the medium- to long-term will lead to decreased stability in New Zealand's forest ecosystems, with flow-on effects on ecosystem functioning. This includes providing habitat for other species that depend on forest habitats for their survival.

The relative lack of evidence of contemporary change in forest composition and species range adjustments suggests the most visible impacts of climate change on indigenous forest ecosystems will become apparent through the reduced ability of ecosystems and species to recover from disturbance events. This includes the effects of both physical disturbance (for example, tectonics) and climate-related disturbance from droughts, windstorms or rainstorms, with the latter expected to become more frequent under climate change (N7). These effects are likely to increase susceptibility to invasion by introduced weeds (see N2, N9).

Interacting risks

Forest instability will affect freshwater ecosystems and species (N3, N4). This risk will interact with the increased threat of invasion by exotic species from both increased temperatures (N2) and increased frequency of disturbance events (N7), leading to a reduction in native dominance.

Through the interactive dynamics of the natural environment with social and economic systems, the growing instability of forest ecosystems and loss of species will have cascading impacts into other domains. Disruptions to forest ecosystems will impact on the tourism sector (E4) and land-based primary forestry sector (E3), which are both reliant on natural landscapes and forest ecosystems. This risk could also pose a threat to Māori social, economic, cultural capital and cultural heritage values and spiritual wellbeing from climate change impacts on forest ecosystems and species (H5, H6, H8).

Maladaptive or inadequate adaptive management actions may restrict indigenous forest ecosystems from adequately adapting to a changing climate (G1). A lack of funding or efforts for active conservation management in a timely and effective manner may amplify this risk (G5).

Confidence: High agreement, medium evidence

There is a high level of agreement that changing climatic conditions will have long-term impacts on the integrity and stability of New Zealand's forest ecosystems and species. Most of the limited evidence for this risk comes from both fundamental studies of the physiology of individual species and broad-scale studies of the current distributions of ecosystems and species in relation to climate. Significant gaps in our knowledge remain about how quickly these impacts will occur, which ecosystems and species will be most susceptible and how these effects will vary geographically.

Adaptation

To manage the sensitivity of indigenous forest ecosystems, DOC undertakes a range of actions to manage and maintain resilience. DOC's *New Zealand Biodiversity Action Plan 2016–2020* outlines actions, including control of introduced weeds, browsers and predators (Department of Conservation, 2016). Some predator control is undertaken in collaboration with Predator Free 2050. Many community and philanthropic groups are undertaking management to control predators in different ecosystems, including forests, and some of these control browsers or weeds. Most of New Zealand's regional councils carry out or support management of introduced species in indigenous forest ecosystems (see Willis, 2017).

Table 33: N11 Risks to the long-term composition and stability of indigenous forest ecosystems: Urgency profile

<table>
<tr><th colspan="7">N11 Risks to the long-term composition and stability of indigenous forest ecosystems: Urgency profile</th></tr>
<tr><th>Urgency category</th><th colspan="2">Proportion of urgency</th><th colspan="4">Description of actions</th></tr>
<tr><td>More action needed</td><td colspan="2">10</td><td colspan="4">Expand active conservation management to cover a representative range of New Zealand’s forest ecosystems, to maintain resilience at high levels.</td></tr>
<tr><td>Research priority</td><td colspan="2">20</td><td colspan="4">Detect climate change-triggered changes in the distribution of ecosystems and species, and identify possible remedial actions to maintain viable populations of threatened species.</td></tr>
<tr><td>Sustain current action</td><td colspan="2">40</td><td colspan="4">Continue existing conservation management actions (control of browsers, predators, weeds) in forest ecosystems to maintain resilience at high levels.</td></tr>
<tr><td>Watching brief</td><td colspan="2">30</td><td colspan="4">Continue monitoring of a systematically chosen set of permanent forest sites, to enable early detection of large-scale changes.</td></tr>
<tr><td>Adaptation urgency</td><td colspan="2">53</td><td>Confidence</td><td colspan="3">High agreement, medium evidence</td></tr>
<tr><td>Consequence</td><td>Now</td><td>Insignificant</td><td>2050</td><td>Moderate</td><td>2100</td><td>Major</td></tr>
</table>

3.4.12 N12 Risks to the diverse range of threatened and endangered species that are dependent on New Zealand’s offshore islands for their continued survival due to ongoing sea-level rise, changes in terrestrial climates, and changes in ocean chemistry and productivity

Risk summary

New Zealand’s offshore islands play a critical role in the conservation of a large proportion of its at-risk and threatened indigenous species. In particular, they provide critical refugia from introduced vertebrate pests including rodents, mustelids and feral cats, which have severely reduced or eliminated a significant number of vulnerable indigenous species from mainland New Zealand (Mortimer et al, 1996). As a result, New Zealand’s offshore islands now provide critical habitat for around 6 per cent of indigenous vascular plant species, 25 per cent of indigenous reptiles and frogs, and around 50 per cent of breeding seabird species (Bellingham et al, 2010; Mortimer et al, 1996). Many of these offshore islands support more than one threatened species; the Chatham Island group alone, for example, supports 20 per cent of New Zealand’s threatened bird species (Aikman et al, 2001).

Ongoing, gradual sea-level rise and reduced ocean productivity (N8), coupled with more frequent extreme storm events, are likely to be serious long-term threats to those species dependent on New Zealand’s offshore islands for their continued survival. Although most of these islands are nature reserves with strict public access restrictions, this threat is likely to be intensified by interaction with other human-mediated threats to these species (Bellingham et al, 2010; Mortimer et al, 1996). For example, reductions in ocean productivity are likely to further compromise populations of species such as albatross (*Diomedea exulans*), which already suffer high levels of mortality from long-line ocean fishing (Pryde, 1997).

Exposure

New Zealand's offshore islands will experience a range of climate change impacts. The ongoing, gradual changes and extreme events posing risks to New Zealand's offshore islands include sea-level rise, warming air and sea surface temperatures leading to reduced productivity, and an increased frequency of storm events. These hazards are projected to increase in intensity, frequency and magnitude over the century, with greatest increase projected under RCP8.5. Islands in the north and east are predicted to experience reduced rainfall, and drought events are likely to become more severe. Projections for these climate hazards are detailed in section 2.

Sea-level rise will impact on all coastal areas across New Zealand, including offshore islands, which will be increasingly exposed to extreme storm tides as a result of sea-level rise. Ocean warming is projected to be greatest in subantarctic waters south of and including the Chatham Rise. Subtropical waters north and northeast of New Zealand are also predicted to experience a greater degree of warming, which will impact on offshore island species through reduced ocean productivity. Increased storminess will impact all sub-national climate zones, and increases in extreme wind are projected in the southern half of the North Island and the South Island (Climate Change Adaptation Technical Working Group, 2017; Ministry for the Environment, 2018).

Sensitivity

Island species are naturally insular and therefore already vulnerable to extinction. With the added pressures of sea-level rise and more frequent storm events, the risk of extinction for these species becomes greater (Macinnis-Ng et al, nd). Globally, the majority of vertebrate species extinctions have occurred on islands, because insular species are more sensitive to rapid changes than species that occur on large land masses (Pryde, 1997).

The combination of small population size, limited distribution and lack of abundance leaves species vulnerable to extreme weather events. An increase in frequency of extreme climate hazards will mean more environmental perturbations on population dynamics, which in turn will reduce population strength and fitness through effects such as inbreeding (Pryde, 1997). The smaller the local population of a species is (and small populations are typical on many of New Zealand's offshore islands), the more sensitive it will be to extinction from climatic events. These extinctions will lead to a loss of ecological interactions, including food availability and predator distribution, ultimately eroding ecosystem function (Macinnis-Ng et al, nd).

Reduced ocean productivity will impact on a number of bird species on New Zealand's offshore islands. The alteration of biogeochemical properties in the upper ocean is raising concerns around the stability of marine food webs and ecosystems, and the effects on food resources for seabirds (Law et al, 2017a). Land-nesting seabirds have shown ongoing declines, likely due to reduced food availability as a result of commercial fishing. Warming temperatures are likely to reduce ocean productivity and food resources, worsening this decline in seabird species. A reduction in food resources coupled with the isolated nature of offshore islands will pose a serious threat to the survival of many seabird species.

Adaptive capacity

Paradoxically, the feature that currently makes these offshore island so valuable from a conservation perspective is likely to decrease their adaptive capacity to climate change. In particular, their geographic isolation, which largely prevents introduced predators and browsers from invading them, will also undermine the ability of many species to move unassisted to other more suitable islands if climate change makes their current habitats unsuitable (Macinnis-Ng et al, nd). In addition, many of the species have arguably already shown limited adaptive capacity to pressures from introduced species, and from predators in particular. For this reason, continued adaptive management of these islands is likely to be needed to:

- prevent incursions of introduced species
- spread populations of vulnerable species across a number of sites to minimise their exposure to extreme events
- move species to more suitable locations when their existing habitats become unsuitable.

Adaptive capacity of offshore island species will be driven by effective governance. Actions to mitigate the impacts of reduced ocean productivity and food availability will be challenging due to the interactions with fisheries management. Continued conservation efforts on offshore islands to protect critical habitat will be key in providing greater resilience. However, even with protection measures in place on New Zealand's offshore islands, species on protected islands are still vulnerable to changing climate conditions, such as extreme storm events, due to demographic and genetic disruptions (Pryde, 1997).

Consequence

Offshore islands play a critical role in the conservation of many of New Zealand's at-risk species, including birds, reptiles and marine mammals (Bellingham et al, 2010). Although their geographic isolation enhances their value as pest-free refugia, this isolation – which typically is coupled with small size and strong coastal influence – makes these islands highly vulnerable to ongoing sea-level rise, changing terrestrial climates, reductions in ocean productivity, and extreme storm events. It also provides significant obstacles against species moving unassisted in response to elevated temperatures. The continued value of these islands for conservation is therefore likely to be highly dependent on continuing active management to ensure survival of the full range of species currently on these islands.

Changes under climate change will have a variety of impacts on New Zealand's offshore islands:

- rising sea level will threaten coastal habitats and increase coastal erosion
- increased air temperatures may reduce the suitability of habitat for some terrestrial species on some islands
- increased sea surface temperatures, coupled with increased windiness, are likely to reduce primary productivity in the oceans, with flow-on effects expected to cascade through coastal and marine ecosystems
- more severe droughts are likely to impact on the survival of terrestrial species, particularly on islands that have limited surface freshwater
- extreme storm events will directly threaten island habitats through physical damage, for example, by wind, waves, storm surges and wind-blown salt spray.

The sensitivity of a range of coastal bird species to reduced ocean productivity is likely to be intensified by fishing, in both inshore and offshore waters.

Interacting risks

Reduced ocean productivity (N8) will see the loss of food resources for many seabird species, as well as threats to the coastal island environments (N1) that will see the loss of coastal habitats. This risk could also pose a threat to Māori social, economic, cultural capital and cultural heritage values and spiritual wellbeing from climate change impacts on ecosystems and species (H5, H6, H8).

This risk will be worsened by difficulties in understanding, predicting and responding to climate change impacts on bird species due to under-investment in biodiversity science (G5).

A lack of coordinated governance may result in inadequate adaptation actions, undermining the adaptive capacity of New Zealand's offshore islands (G1). Government lobbying challenges may arise from the fishing industry if actions to control impacts on surrounding marine environments and seabirds (G7) look to impact on that industry.

Confidence: High agreement, limited evidence

There is a high level of agreement both on the extremely high conservation value of New Zealand's offshore islands and on the risks to which they will be exposed by a range of predicted changes. However, only limited analysis has been carried out to date to identify which islands and species are likely to be at greatest risk.

Adaptation

Stakeholder engagement for the National Climate Change Risk Assessment for Aotearoa New Zealand revealed limited information or adaptation actions are planned or under way. DOC is responsible for, and actively managing, most of New Zealand's offshore islands to maintain populations of a range of threatened species. Community groups actively manage a small number of islands.

Table 34: N12 Risks to the diverse range of threatened and endangered species: Urgency profile

<table>
<tr><th colspan="7">N12 Risks to the diverse range of threatened and endangered species: Urgency profile</th></tr>
<tr><th>Urgency category</th><th colspan="2">Proportion of urgency</th><th colspan="4">Description of actions</th></tr>
<tr><td>More action needed</td><td colspan="2">0</td><td colspan="4">Intensify freshwater protection measures for vulnerable lakes.</td></tr>
<tr><td>Research priority</td><td colspan="2">20</td><td colspan="4">Forecast the likely vulnerability of individual, island-dependent species, and identify management actions to ensure their survival in the face of climate change.</td></tr>
<tr><td>Sustain current action</td><td colspan="2">40</td><td colspan="4">Maintain current conservation management measures on all offshore island sites.</td></tr>
<tr><td>Watching brief</td><td colspan="2">40</td><td colspan="4">Actively monitor the status of all species dependent on offshore islands for their continued survival, to allow early detection of population decline.</td></tr>
<tr><td>Adaptation urgency</td><td colspan="2">45</td><td>Confidence</td><td colspan="3">High agreement, limited evidence</td></tr>
<tr><td>Consequence</td><td>Now</td><td>Minor</td><td>2050</td><td>Moderate</td><td>2100</td><td>Major</td></tr>
</table>

3.5 Gaps in knowledge

While experts overwhelmingly agree that changing climatic conditions will worsen a range of existing threats to and pressures on New Zealand's natural environment, detailed knowledge on individual sites and species knowledge is generally lacking, reflecting past funding shortfalls for climate change-related research and/or sites subject to long-term monitoring and study. Because of this, most of our understanding for different groups of ecosystems and/or species comes from detailed studies of a few sample systems or species, extrapolated across the broader natural environment domain. More research is urgently needed to understand the specific vulnerability of a wider range of individual ecosystems and species, and how these will vary geographically depending on spatial variation in environment and degrees of human modification.

Our ability to monitor and detect change in indigenous ecosystem and species distribution in response to climate change is frequently constrained by New Zealand's poor management of spatial biological data (Halloy and Mark, 2003; McKim, 2016). In particular, New Zealand lacks a single easily accessible repository for distribution data (as provided for example by the Atlas of Living Australia[4]). Critical data are stored in a disjointed fashion that lacks coordination, with access constrained by the competitive model used to fund and manage New Zealand's research organisations.

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[4] www.ala.org.au/

4 Human domain | Rohe tangata

4.1 Domain description

The human domain encompasses people’s skills, knowledge, and physical and mental health (human), the norms, rules and institutions of society (social), and the knowledge, heritage, beliefs, arts, morals, laws, and customs of society (cultural). Box 5 gives an overview of the significance of the risks in this domain to Māori values and wellbeing.

Box 5: Māori perspective on rohe tangata – the human domain

Rohe tangata | human domain

The rohe tangata (human domain) is focused on the waiora (wellbeing) of people. For Māori, waiora can be understood in many ways. One model applied from the health sector (Durie, 1994) highlights that waiora can be derived from the intertwining of taha tinana (physical health), taha wairua (spiritual health), taha hinengaro (mental health) and taha whānau (family health), providing the basis for all other interactions for sustaining life. Complementing this understanding with the importance and connection of the taiao (environment) to waiora gives a foundation for understanding the risks to people’s wellbeing. Māori oratory and kōrero tuku iho (oral history and traditions) have historically underpinned the transfer of Māori social, economic, and cultural wellbeing.

The rohe tangata risks outlined below include direct risks to this capital from the loss and degradation of land, species, ecosystems and sacred sites deeply connected with Māori identity. Degradation of whenua (land) and moana (sea) addressed in the rohe taiao (natural environment domain) also has the risk of eroding the mana (authority) that can be exercised by Māori.

The risks in this section also include those to vulnerable populations such as low-income families, in which Māori are disproportionately represented, and include risks to health, and the risk of displacement. Furthermore, Māori whakapapa (connection, lineage, or genealogy) relationships to the Pacific give rise to obligations and a desire to assist as whānau.

4.2 Snapshot of issues and themes

New Zealand is an incredibly successful multicultural country, with an ethnically, religiously, geographically, and economically diverse population of five million people. Māori and culture are integral to the politics, media, culture, and identity of New Zealand, with te reo Māori an official language. Māori are the second-largest ethnic group in New Zealand (after European New Zealanders), and represent 16.5 per cent of the total population (Stats NZ, 2019). Māori heritage is substantial, and is central to New Zealand’s unique identity. While te reo Māori is in revitalisation mode, and despite the recognised standing of tangata whenua, Māori still face prejudice at many levels. Unfortunately, they are often disadvantaged across most socio-economic indicators, including life expectancy, unemployment, educational attainment, income, and access to services and housing (Ministry of Health, 2018). Climate change will have major implications for the health of communities, for amenity, for maintaining cultural continuity, and for cultural survival. The coming century is likely to change Māori social, economic, and cultural landscapes.

Exposure and vulnerability to climate change risks depend on where people live. Most of New Zealand's population is urban, with more than 70 per cent of New Zealanders living in large urban areas, such as Auckland, New Plymouth, Hamilton, Nelson and Christchurch. Approximately 11 per cent live in smaller towns like Taupo, Picton and Greytown, 14 per cent in rural areas, and 1 per cent in highly remote rural areas (Stats NZ, 2004).

The impacts of climate change will be felt most strongly by those already marginalised in society. However, new inequities are likely to emerge as climate change impacts are experienced more widely. Climate change will impact on humans, society, and culture directly through exposure to hazards, and indirectly through the consequences and changes resulting from exposure to hazards. Key themes identified in the domain include how the safety and physical and mental health of individuals and communities may be affected by extreme weather events, ongoing, gradual changes, and social and environmental changes.

Climate change is also going to reconfigure people's ability to form and undertake their preferred habits, pursuits and activities, to access critical services and to continue to earn a livelihood. Ultimately the effects of climate change in any domain impact on humans, with ramifications for their wellbeing, identity, autonomy and sense of belonging.

4.3 Summary of climate change risks and opportunities

Table 35: Summary of climate change risks and opportunities in the human domain

Human		
	Ratings	
Most significant risks	**Urgency**	**Consequence**
H1 Risks to social cohesion and community wellbeing from displacement of individuals, families and communities due to climate change impacts.	88*	Extreme**
H2 Risks of exacerbating existing inequities and creating new and additional inequities due to differential distribution of climate change impacts.	85	Extreme
Other priority risks examined in stage 2		
H3 Risks to physical health from exposure to storm events, heatwaves, vector-borne and zoonotic diseases, water availability and resource quality and accessibility due to changes in temperature, rainfall and extreme weather events.	83	Major
H4 Risks of conflict, disruption and loss of trust in government from changing patterns in the value of assets and competition for access to scarce resources primarily due to extreme weather events and ongoing sea-level rise.	83	Major
H5 Risks to Māori social, cultural, spiritual and economic wellbeing from loss and degradation of lands and waters, as well as cultural assets such as marae, due to ongoing sea-level rise, changes in rainfall and drought.	80	Extreme
H6 Risks to Māori social, cultural, spiritual and economic wellbeing from loss of species and biodiversity due to greater climate variability and ongoing sea-level rise.	80	Extreme
H7 Risks to mental health, identity, autonomy and sense of belonging and wellbeing from trauma due to ongoing sea-level rise, extreme weather events and drought.	80	Major
H8 Risks to Māori and European cultural heritage sites due to ongoing sea-level rise, extreme weather events and increasing fire weather.	75	Major
HO1 Opportunity for reduction in cold weather-related mortality due to warmer temperatures.	45	n/a

* Urgency rating refers to the total adaptation and decision urgency rating (between 1 and 100).

** Consequence rating refers to the highest consequence rating assigned to this risk out of all three time periods (now, 2050, 2100). Section 4.4 provides the consequence rating for each time period for all the risks.

4.4 Climate change risks and opportunities

4.4.1 H1 Risks to social cohesion and community wellbeing from displacement of individuals, families and communities due to climate change impacts[5]

Risk summary

Extreme events such as flash floods, more frequent coastal flooding, and erosion or landslides, or a series of ongoing, gradual changes that accumulate over time, particularly ongoing sea-level rise, may result in some currently inhabited locations becoming uninhabitable.

This risk has two sides: first, the impact on those who move away; and second, the impacts on the community left behind. When people are displaced or mobilised,[6] they can suffer trauma from leaving familiar surroundings, the breaking of social and cultural bonds, and the challenges of resettlement. Mobilised populations, whether moving internally or across borders, will change the composition of communities, impact on housing and labour markets, require adjustment to regional development planning, and alter the level and pattern of demand for social services and other resources. Those who remain behind may experience a sense of loss and abandonment as the community diminishes, and similar trauma due to the breaking of family, social and cultural bonds. As a community reduces in size, essential services, such as education facilities, job opportunities or community services, may be eroded. This has been reported in rural New Zealand communities over the last 30 years, as a result of government reform in the mid-1980s. These risks to social cohesion and community wellbeing increase over time and are greater under representative concentration pathway (RCP) 8.5 than RCP4.5.

Exposure

New Zealand's low-lying coastal areas are exposed to ongoing sea-level rise and associated pressures such as groundwater rise and salinisation, and extreme events. Development intensification along coastal areas, and concentration of population through urbanisation, are increasing the number of people exposed to extreme weather events, landslides and coastal inundation (Glavovic et al, 2010). About 675,500 people live in areas currently prone to flooding. A further 72,065 people live in areas that are currently subject to 1 per cent annual exceedance probability (AEP) of extreme sea-level elevation (Paulik et al, 2019b).

Inland communities are exposed to extreme events and ongoing, gradual changes that may alter the viability of economic enterprises crucial to sustaining an area.

Sea levels are projected to increase by up to 0.9 metres by 2100 under RCP8.5 for all zones, leading to coastal inundation and salinisation of groundwater (Ministry for the Environment, 2017b). Extreme storm tides, winds and rainfall are also projected to increase in frequency and magnitude in all regions for both 2050 and 2100 under RCP8.5. The intensity of tropical cyclones in the North Island and northern South Island is also projected to increase (Pearce

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[5] Considering the impacts of internationally mobilised peoples, commonly referred to as 'climate refugees', is outside the scope of this report.

[6] Boas et al (2019) note that "the term migration does not capture the diverse ways in which people do or do not become mobile in response to a changing climate" and should therefore be avoided. People may temporarily or seasonally move, relocate to nearby urban areas, and people typically move within their country or region (UK Government Office for Science, 2011).

et al, 2018). This will result in flooding, landslides and erosion that can have immediate and long-term implications due to damage to belongings and households, displacement and trauma (Stephenson et al, 2018). Some areas are already highly exposed to flooding. For example, 4.3 per cent of Westport will be inundated by a 1-in-50-year flood. By 2080 this could rise to 80 per cent (IPCC, 2007a).

Sensitivity

Networks and relationships are particularly important in communities prior to, during and in the recovery process after extreme events and disasters (Jakes and Langer, 2012). As a result, erosion of these networks as a community shrinks can increase the sensitivity, and decrease the ability, of the community to respond to future events.

The communities that are most likely to be sensitive to this risk include those with livelihoods that depend on the natural environment. For example, farming communities are highly sensitive to events that disrupt farming practices, which lead to financial losses and have impacts on mental health, social cohesion and community wellbeing (Krishnamurthy, 2012).

This risk may cascade through the natural environment and economic domains rather than resulting directly from exposure to a hazard. Communities that are most likely to be exposed to this risk:

1. communities in low-lying areas facing the impacts of coastal erosion and ongoing sea-level rise. These hazards increase the risk of disruption to livelihoods and communities in both the short and long term (Stephenson et al, 2018). As the frequency of disruption increases, so does the likelihood that those who can move will move (Lawrence et al, 2018)
2. communities on floodplains, or in areas potentially affected by waterlogging (due to groundwater changes), which may cause parts or all of the community to be relocated
3. ethnically and culturally homogeneous communities, who generally experience a decline in social cohesion as diversity increases (Laurence and Bentley, 2016).

Individuals who rely on strong social networks for support (for example, the elderly) are more sensitive to loss of social cohesion (Wistow et al, 2015) and connectedness.

Adaptive capacity

A sense of community, social cohesion and community wellbeing is vital for resilience and adaptive capacity (Jakes and Langer, 2012; Tompkins and Adger, 2004). If this is eroded, by definition adaptive capacity is reduced.

The importance of this outlook is shown in community responses to historical events. When Mt Ruapehu erupted in 1995/96, a sense of community and self-efficacy was an important predictor of people’s resilience and the capacity to respond (Tompkins and Adger, 2004). The ability of this community to cope would have been compromised without such connections and cohesion.

Maintaining social cohesion and community wellbeing through displacement and movement of people requires a recognition that adaptation in other domains will affect this risk. For example, good governance and inclusive decision-making processes are needed to develop adaptation options that will be acceptable to communities, and minimise risks to cohesion and wellbeing.

Anticipatory governance and effective decision-making through uncertainty is needed to reduce exposure to this risk, by ensuring communities do not become established in areas prone to climate change hazards that may lead to displacement.

Consequence

Populations displaced by disasters and climate change will change the composition of communities, impact on housing and labour markets, require adjustment to regional development planning, and alter the level and pattern of demand for social services. Displaced people may also lose their local support networks, and communities receiving them might be unwelcoming of new and different community members, contributing to or causing tension and conflict (Boege, 2018; Campbell, 2019).

In New Zealand, for example, Kelso was a small town of 200 residents that experienced severe floods in 1978 and then again 15 months later. Flood mitigation works to increase protection were considered unaffordable, and residents relocated on an individual basis, dependent on the level of perceived risk to households (Glavovic et al, 2010). This led to the closure of community amenities and the eventual relocation of remaining residents to neighbouring towns (Glavovic et al, 2010). The townspeople have held reunions since then, but the social bonds in the community were ultimately broken.

It is likely that cultural capital and spiritual wellbeing will be adversely affected if Māori are forced to relocate from tribal lands and territories.

Interacting risks

The interaction between climate hazards, social cohesion and community wellbeing has the potential to amplify the vulnerability of individuals and communities to climate change. Loss of land and households will exacerbate physical and mental health issues (H3, H7), affect a sense of belonging and identity (H7), and perpetuate inequity (H2), adversely impacting social cohesion. Loss of or damage to cultural heritage sites (H8) may also reduce social cohesion and community wellbeing. Risks to lifeline infrastructures, such as energy networks (B8), transport networks (B6) and water (B1, B4) can increase pressures on populations and communities. Climate change-related economic pressures, particularly in agricultural communities (E3) will also interact with displacement and community cohesion.

Confidence: High agreement, moderate evidence

There is high agreement that climate change will expose community wellbeing and social cohesion to risks. However, the way in which communities will be impacted, the extent to which they will be impacted and the range of impact are not well understood.

Adaptation

Neither the literature review nor the consultation process identified any adaptation actions for this risk.

Table 36: H1 Risks to social cohesion and community wellbeing from displacement of individuals, families and communities: Urgency profile

<table>
<tr><th colspan="7">H1 Risks to social cohesion and community wellbeing from displacement of individuals, families and communities: Urgency profile</th></tr>
<tr><td>Urgency category</td><td colspan="2">Proportion of urgency</td><td colspan="4">Description of actions</td></tr>
<tr><td>More action needed</td><td colspan="2">70</td><td colspan="4">Action needed on how communities might relocate away from risk areas in an agreed and fair way. Policy and funding need to be considered first.</td></tr>
<tr><td>Research priority</td><td colspan="2">20</td><td colspan="4">Understand how to successfully retreat affected individuals and communities.</td></tr>
<tr><td>Sustain current action</td><td colspan="2">0</td><td colspan="4"></td></tr>
<tr><td>Watching brief</td><td colspan="2">10</td><td colspan="4">Need to establish a monitoring process to ensure actions are effective.</td></tr>
<tr><td>Adaptation urgency</td><td colspan="2">88</td><td>Confidence</td><td colspan="3">High agreement, moderate evidence</td></tr>
<tr><td>Consequence</td><td>Now</td><td>Minor</td><td>2050</td><td>Extreme</td><td>2100</td><td>Extreme</td></tr>
</table>

4.4.2 H2 Risks of exacerbating existing inequities and creating new and additional inequities due to differential distribution of climate change impacts

Risk summary

Exposure to extreme weather events such as flooding or heatwaves, or to ongoing, gradual changes such as inundation of low-lying areas, will be the same for communities and individuals in affected areas. However, the ability to respond or adapt to or cope with these risks is uneven, due to existing inequalities (Ellis, 2018). Those experiencing marginalisation due to demographic factors such as age, race, ethnicity, socio-economic status, gender, literacy or health may be unable to access resources to respond to climate risks (Ton et al, 2019). An inability to convert resources to action can also create and exacerbate existing inequities (Ton et al, 2019). New inequities may emerge, especially with respect to slowly emerging risks such as sea-level rise. Exacerbation of existing inequalities and creation of new ones can have cascading impacts on livelihoods and wellbeing.

Exposure

Extreme events and ongoing, gradual changes will be spread across all regions of New Zealand and may intersect with existing sources and experiences of social vulnerability and inequality. For example, flooding and waterlogging hazards often occur in the low-lying areas of South Dunedin. A significant proportion of this community has socio-economic deprivation scores of between 8 and 10 (Stephenson et al, 2018). Conversely, changing exposure may create new inequities as the hazards increase and impact on new groups of people and communities. Exposure to this risk will be greater under RCP8.5 than RCP4.5 and will increase over time, potentially compounded by factors of inequality spreading from other domains.

Sensitivity

Sensitivity is influenced by social, cultural, political and economic processes (Adger et al, 2004). Sensitivity and adaptive capacity are place-dependent; they differ depending on the climate hazard and vary over time (Cutter and Finch, 2008). For example, the Intergovernmental Panel on Climate Change's (IPCC's) *Climate Change 2014: Impacts, Adaptation, and Vulnerability* (2014) differentiates between vulnerability before a crisis or disaster (for example, drought or flood) and subsequent vulnerability in the post-disaster and recovery processes.

The following characteristics are understood to be key sources of sensitivity to extreme events associated with climate change.

- Socio-economic disparities: The socio-economic disparities between Māori and non-Māori communities mean that sensitivity to climate change impacts and risks are higher for Māori society (Manning et al, 2015). Māori communities are more sensitive to climate change impacts on ecological systems because of their dependence on primary industries for livelihoods, the impacts of climate change on cultural and spiritual wellbeing (H5, H6) as well as on coastal mahinga kai, and the proximity of housing and infrastructure to processes such as erosion and inundation (Stephenson et al, 2018).
- Socio-economic status: In general, people living in poverty are more sensitive to the impacts of climate change hazards (Fothergill and Peek, 2004).
- Ethnicity: Ethnic communities are often geographically and economically isolated from jobs, services and institutions. Discrimination also plays a major role in increasing the sensitivity of ethnic minorities (Fothergill et al, 1999). Where minorities are immigrants from non-English-speaking countries, language barriers can greatly increase vulnerability to a disaster (Trujillo-Pagan, 2007).
- Gender: Following disasters, women and children are often vulnerable. Evidence indicates that lower-income women experience and navigate ongoing job and house displacement, increased domestic violence, and reduced access to children's education and to childcare after extreme events (Freudenburg et al, 2008). Unequal participation in labour markets and decision-making processes compound inequalities (Enarson, 2007). Research also shows that the incidence of domestic violence increases following extreme events, such as fires (Parkinson and Zara, 2013).
- Age: Disruptions created by a disaster can have significant psychological and physical impacts on children. The elderly are likely to suffer health problems and experience a slower recovery, and tend to be more reluctant to evacuate their homes in a disaster (Ton et al, 2019).
- Disability: People living with mental or physical disabilities are less able to respond effectively to disasters, and require additional assistance in preparing for and recovering from disasters (McGuire et al, 2007).
- Other factors such as perceived risk, previous experiences and trauma, social networks and informed climate change knowledge all influence sensitivity to risks (Freudenburg et al, 2008).

Sensitivity associated with ongoing, gradual change is less well known, but it is becoming apparent that the distribution of climate change risk is changing across society. For example, wealthy asset owners of coastal properties, who may have significant mortgages, could enter more precarious situations if they experience insurance retreat and are impacted by an extreme event.

Adaptive capacity

Inequity and adaptive capacity are related; inequity can hinder adaptive capacity and a lack of adaptive capacity can intensify social vulnerability (Fisher, 2011). Those community members most likely to be affected are simultaneously the least empowered or accustomed to contributing to decision-making processes (Barnett and O'Neill, 2010). Decisions can lead to inequitable outcomes or maladaptation that further entrenches inequity (Barnett and O'Neill, 2010; Guerin, 2007).

Socio-economic conditions such as age, gender, social networks and social capital – in conjunction with past experiences, perceived risk and informed knowledge – impact on the ability to adapt.

Limited knowledge or understanding of climate change risks, which can be a consequence of lack of access to information, can result in maladaptation and path dependency and constrain adaptive capacity, further exacerbating inequity. For example, development of coastal areas and low-lying land that is exposed to inundation and flooding, or reliance on hard protection measures such as structural flood controls to mitigate risk, can lead communities to perceive that they are protected (Manning et al, 2015). Inclusive decision-making and adaptation strategies that help increase self-efficacy and empower individuals to participate may help to address existing inequities and limit future ones from arising (Stephenson et al, 2018; Tompkins and Adger, 2004).

Consequence

The ability to access resources to meet individual, family and community wants and needs is already unequally distributed across society, with some groups experiencing marginalisation and poor social outcomes (for example, in health, employment, access to education or welfare and support services) compared with others. Climate change is likely to exacerbate these existing inequities and generate additional and new inequities as communities experience climate change-related impacts.

One question is who will fund the response to climate hazards, particularly managed retreat (Boston and Lawrence, 2018). Financial assistance to affected communities and households after natural disasters is currently ad hoc (Boston and Lawrence, 2018). For example, the Government announced after severe flooding of Edgecumbe in 2017 that it would be responsible for the clean-up and repair of all affected properties, including the uninsured and those unable to afford repairs (Boston and Lawrence, 2018). However, many other communities affected by similar extensive flooding have not received such funding.

Changing climate conditions are also likely to exacerbate many of the health inequities already faced by Māori, so addressing this will demand careful societal responses that do not further exacerbate these inequities (Manning et al, 2015). Many Māori communities are concentrated around coastal areas, and this exposure makes them particularly vulnerable to rising sea levels.

Interacting risks

Inequity is both exacerbated by, and a product of, a changing climate that increases the sensitivity of already vulnerable individuals and communities to risk. Increased inequity is likely to exacerbate physical and mental health issues (H3, H7) and affect a sense of identity and belonging (H7); it may even lead to social conflict or disruption (H4) as a result of inadequate adaptation and action (G5, G1). Climate hazards that damage or limit access to infrastructure such as homes, transport networks (B6), energy (B8) and telecommunications have the greatest impact on marginalised people.

Confidence: High agreement, medium evidence

There is overall agreement that climate hazards will worsen existing inequities and create new ones. Greater understanding of local communities' vulnerability to specific impacts is required, along with development of governance that is inclusive of marginalised people.

Adaptation

Although efforts to address social inequities in a more general sense are under way, few have a component concerned with climate change adaptation.

Current efforts are usually targeted to specific existing vulnerable groups, such as rural populations or Māori groups, and focus on accessing resources, rather than responding to climate change in a way that considers potential and emerging inequities. Few targeted adaptation actions address this risk in a holistic and integrated manner. It is likely that climate change will create new groups of vulnerable people, yet this issue has not been explored.

Table 37: H2 Risks of exacerbating existing inequities and creating new and additional inequities: Urgency profile

<table>
<tr><th colspan="7">H2 Risks of exacerbating existing inequities and creating new and additional inequities: Urgency profile</th></tr>
<tr><th>Urgency category</th><th colspan="2">Proportion of urgency</th><th colspan="4">Description of actions</th></tr>
<tr><td>More action needed</td><td colspan="2">60</td><td colspan="4">Early policies, principles and practices to ensure inequity (both current and intergenerational) are considered in all future actions.</td></tr>
<tr><td>Research priority</td><td colspan="2">30</td><td colspan="4">Further research would be useful; however, some actions should and can be taken regardless.</td></tr>
<tr><td>Sustain current action</td><td colspan="2">0</td><td colspan="4"></td></tr>
<tr><td>Watching brief</td><td colspan="2">10</td><td colspan="4"></td></tr>
<tr><td>Adaptation urgency</td><td colspan="2">85</td><td>Confidence</td><td colspan="3">High agreement, medium evidence.</td></tr>
<tr><td>Consequence</td><td>Now</td><td>Major</td><td>2050</td><td>Extreme</td><td>2100</td><td>Extreme</td></tr>
</table>

4.4.3 H3 Risks to physical health from exposure to storm events, heatwaves, vector-borne and zoonotic diseases, water availability and resource quality and accessibility due to changes in temperature, rainfall and extreme weather events

Risk summary

New Zealanders are already experiencing physical health impacts from climate hazards such as wildfire, floods, heatwaves, droughts and storms (Jones et al, 2014b). These hazards are projected to increase in frequency and severity. New Zealanders will also become exposed to zoonotic and water-borne diseases, which result from changes in the distribution of species, and changes in hydrological systems (Cann et al, 2013; Derraik and Slaney, 2007). Human health will also be impacted indirectly from the influence of drought and heavy rainfall events on water availability and quality (McBride et al, 2014; Woodward et al, 2001). Further, climate change will alter the quality and access of resources that support human health and wellbeing, such as food, water, outside space and clean air (Royal Society | Te Apārangi, 2017). These climate change impacts will affect the physical health, safety and wellbeing of New Zealanders.

Exposure

Extreme weather events that have direct impacts on health, safety and wellbeing, particularly heatwaves, wildfire and flooding, are projected to increase in frequency, intensity and spatial extent (see section 2).

Heat mortality and other heat-related illnesses are likely to be exacerbated by the urban heat island effect. Urbanisation results in the replacement of natural vegetation with non-permeable materials; these materials store heat during the day and release it at night, exacerbating heat mortality and heat-related illnesses in urban areas (Oleson et al, 2015). Increased heat, particularly in urban areas, has also been shown to interact with and worsen air pollution (Xu et al, 2014).

Wildfires, as well as posing direct risks to life and health, can produce smoke that significantly impacts air quality, both locally and in other regions of New Zealand.

Although New Zealand is still relatively free of exotic vectors that transmit introduced parasites and pathogens to humans, an increase in average temperatures will extend the suitability of climate for exotic vectors, encouraging their migration and subsequent transmission of disease (Derraik and Slaney, 2007). Limited information is available on the exposure to vector-borne diseases; however, it is likely that exposure will increase under RCP8.5 (McBride et al, 2014).

Māori are particularly exposed to zoonotic, water-borne and food diseases, due to their heavy reliance on kaimoana (seafood) and because a high proportion of Māori communities live in coastal regions in the North Island, particularly around Northland and the Bay of Plenty (Jones et al, 2014a; Newcombe et al, 2014). These areas are most at risk from the establishment of vector-borne diseases (Jones et al, 2014a).

Warmer temperatures and changes in rainfall can impact on water quality and availability, causing contamination or shortages, and heavy rainfall events can cause animal excrement and other pollutants to run off into water sources, contaminating them (Royal Society | Te Apārangi, 2017). Higher temperatures can lead to the growth of bacteria, such as campylobacter and cryptosporidium, which thrive in a warmer climate (McBride et al, 2014). Drought places pressure on water sources, potentially reducing the supply of water needed for maintaining hygiene (Woodward et al, 2001). Eutrophication is likely to increase from persistent low-flow periods, or sequences of dry spells punctuated by intense rainfall – which could increase exposure to cyanobacteria and toxic algae (Hughes et al, 2019).

A combination of changing weather patterns and ongoing sea-level rise may reduce the supply of healthy fresh food, leading to nutrition-related risks to human health (Royal Society | Te Apārangi, 2017).

Sensitivity

Vulnerable populations (H2) are particularly sensitive to the health impacts of climate change. For example, adverse impacts on health are exacerbated by economic disadvantage and the existence of pre-existing health conditions (Jones et al, 2014b). Māori in particular are sensitive to physical risks from climate change, due to the disproportionate number of Māori living in deprived circumstances, and experiencing higher rates of most major diseases than non-Māori (Jones et al, 2014b). The elderly, infants, and people with pre-existing medical conditions are sensitive to changes in maximum daily temperatures; age is the greatest risk factor for heat-related mortality (Wilson et al, 2011).

Adaptive capacity

Changes to behaviour patterns and autonomous action will contribute to reducing this risk; however, the actions people can take are constrained by socio-economic and demographic factors (H2) and institutional arrangements (Adger et al, 2005). Considering equity and governance is therefore crucial to the adaptive capacity of New Zealanders. Anticipatory governance, appropriate planning decisions, and funding to support adaptation will be necessary to reduce direct exposure to climate hazards and to take actions that reduce the indirect impact of climate change on health (G2). Emergency management capacity must be supported to make rapid responses following extreme events. Further, the health system itself will need to build its adaptive capacity to cope with a higher proportion of physically injured and unwell individuals (Sampson et al, 2013).

Consequence

It is highly likely that climate change-related hazards will result in additional deaths, injury and illness. Climate change undermines many of the building blocks of good health, including clean air, plentiful safe drinking water, economic stability, and autonomy. The health effects of climate change will not be spread evenly across the population and will exacerbate existing health inequalities.

It is difficult, however, to measure and predict these changes. Data on how climate change-related hazards affect health are sparse. Some deaths can be attributed to extreme weather events or climate change hazards. In Auckland and Christchurch, an average of 14 heat-related deaths occur each year among people aged over 65 years. This total may rise to 88 deaths with 3 degrees Celsius of warming, as is projected in New Zealand by 2090 under RCP8.5 (see section 2) (Joynt and Golubiewski, 2019; McMichael et al, 2003). Floods, although frequent, disruptive and costly, on average result in few deaths. New Zealand has relatively high rates of water-borne illness; however, modelling indicates few additional deaths will result from gastroenteritis in a warmer climate (World Health Organization, 2014). The potential influence of climate change on vector-borne and non-vector-borne zoonotic diseases is poorly understood and difficult to predict (Mills et al, 2010).

Interacting risks

Health costs will increase fiscal need (E1) and are likely to entrench disadvantage (H2), erode trust in government, and lead to increased conflict (H4). In addition, physical health and mental health are strongly related: poor physical health can worsen mental health and vice versa (Ohrnberger et al, 2017).

Confidence: High agreement, low evidence

There is robust evidence and a high level of agreement that climate change will adversely impact the physical health of New Zealanders. More evidence is needed around the impacts and their geographical spread. More research is needed on vector-borne disease modelling, effects on water availability and quality, and the impacts on vulnerable groups (Woodward et al, 2001).

Adaptation

Adaptation actions in the human domain and across other domains reduce this risk, but there are no common goals for climate change adaptation, or health sector plans for it. The Ministry of Health (Minister of Health, 2016) acknowledges that climate change has health and social consequences, but provides limited additional information. District health boards are, in general, in their infancy in understanding the implications of climate change, but are starting to incorporate climate change into their plans. Some public health units also have institutional knowledge about climate change.

Table 38: H3 Risks to physical health from exposure to storm events, heatwaves, vector-borne and zoonotic diseases, water availability and resource quality and accessibility: Urgency profile

<table>
<tr><th colspan="7">H3 Risks to physical health from exposure to storm events, heatwaves, vector-borne and zoonotic diseases, water availability and resource quality and accessibility: Urgency profile</th></tr>
<tr><td>Urgency category</td><td colspan="2">Proportion of urgency</td><td colspan="4">Description of actions</td></tr>
<tr><td>More action needed</td><td colspan="2">50</td><td colspan="4">Early policies and practices are needed to ensure that potential actions are in place to mitigate this risk.</td></tr>
<tr><td>Research priority</td><td colspan="2">40</td><td colspan="4">Further research would be useful to understand how this risk might arise, or to what degree and where.</td></tr>
<tr><td>Sustain current action</td><td colspan="2">0</td><td colspan="4"></td></tr>
<tr><td>Watching brief</td><td colspan="2">10</td><td colspan="4">Need to establish a monitoring process to ensure actions are effective.</td></tr>
<tr><td>Adaptation urgency</td><td colspan="2">83</td><td>Confidence</td><td colspan="3">High agreement, low evidence</td></tr>
<tr><td>Consequence</td><td>Now</td><td>Minor</td><td>2050</td><td>Moderate</td><td>2100</td><td>Major</td></tr>
</table>

4.4.4 H4 Risks of conflict, disruption and loss of trust in government from changing patterns in the value of assets and competition for access to scarce resources primarily due to extreme weather events and ongoing sea-level rise

Risk summary

Climate change is likely to exacerbate the existing stressors that give rise to conflict and disruption, particularly as the value of assets changes and competition for resources intensifies. Ongoing, gradual change, and the increase in magnitude and frequency of extreme events, are likely to affect the value of existing assets and decrease the availability of some resources (for example, land, water and safe building sites) while also increasing demand for the resources and the value of other unaffected assets. Conflict is therefore likely to arise as people compete for increasingly scarce resources such as water and arable land, and are relocated and displaced (Boege, 2018). Ongoing, gradual changes may aggravate existing environmental, economic and social stressors such as water supply and food security, resulting in increased tension (Weir and Virani, 2011), and may also exacerbate existing socio-economic vulnerability. New tensions may also emerge if previously powerful groups in society have their interests affected and their wealth reduced due to the way climate change risks are distributed.

Perceptions of unfairness and opacity in processes could also lead to tensions, particularly for adaptation funding. Competition for adaptation resources is likely to emerge rapidly, and conflict may arise from land-use changes driven by climate events such as coastal inundation, but also in response to changes in regulations and financial priorities. In addition, inadequate government response or maladaptation pathways may increase tension and reduce trust in governments.

Exposure

As this report discusses, New Zealand's assets and resources, including buildings and transport infrastructure, cultural sites, natural ecosystems and economic sectors, are highly exposed to climate change hazards. These changes will alter the established, and sometimes contested, patterns of access to natural, economic, social and political resources. Further pressures and constraints on resource access may lead to conflict and disruption.

The issue of water illustrates how New Zealand is potentially exposed to these risks. Water is a shared natural resource that is used for community water supplies, irrigation, energy and industry (IPCC, 2007a). Changing hydrological regimes may impact on drinking water availability, particularly for rural communities that may be dependent on non-reticulated water resources (Climate Change Adaptation Technical Working Group, 2017). Irrigation has increased by about 55 per cent each decade since the 1960s, driving increased water demand in New Zealand (IPCC, 2007a). As early as 2007, Guerin concluded that:

> "New Zealand is now, however, reaching the limits of its ability to expand commercial and recreational use of natural resources (eg, freshwater and coastal space) in some regions without significant levels of direct conflict between competing users and interests." (p 7)

When these pressures are combined with changing rainfall regimes (see section 2), the many users of this valuable and scarce resource may come into conflict.

Other factors related to human activity, such as current land-use practices, may increase the potential for conflict by putting extra pressures on land and water resources (Boege, 2018). Population growth, agricultural intensification and social expectations each pose a challenge for managing natural resources (Guerin, 2007).

Sensitivity

Little evidence is available on how sensitive New Zealand is to this risk. However, some early anecdotal signs are emerging from debates over the fairness of water allocation in drought-prone regions.

Existing inequities and social tensions (H2) and real or perceived unfairness increase the sensitivity of relevant parties to conflict. Trusted institutions are needed to mediate the competing interests of stakeholders and help reduce this sensitivity (Boege, 2018).

Adaptive capacity

The ability to adapt to this challenge depends on governance processes that can actively manage stakeholder conflicts, identify future pressures, and are resilient and flexible enough to change with a changing climate (Guerin, 2007). The Resource Management Act 1991 is the core legislation for natural resource management, but has drawbacks in managing long-term resource allocations in a changing climate (Guerin, 2007). A key challenge will be finding a balance between providing certainty, being flexible and ensuring fairness so that trust can be maintained (Guerin, 2007). Wide engagement and representation of stakeholders can improve information flow, encourage buy-in to adaptation processes, and grow the trust necessary for building adaptive capacity (Guerin, 2007).

Consequence

Changing values of assets, particularly coastal assets, and competition over increasingly scarce and valuable resources such as water may contribute to conflicts between different parts of society. Conflicts over resource access can be expected, especially when actions or decisions benefit one section of society over another or are perceived as unfair.

Water is a potential source of conflict. Farmers are generally concerned about water supply changes and increases in severe droughts (Niles et al, 2016). In Australia, a history of over-allocation of water in the Murray-Darling Basin has heightened the effects of prolonged droughts and led to significant conflict between irrigators, environmentalists and other water users (Connell, 2007). Consultation for the National Climate Change Risk Assessment for Aotearoa New Zealand also noted that some medical practices, such as renal services, consume significant amounts of water, and raised concerns about the potential for competition over scarce water in times of drought.

The value of waters for Māori peoples also leads to tension, and the current water allocation process does not reflect the relationship that iwi and hapū have with freshwater. As a result, dissatisfaction is widespread among the Māori community and tension prevails in its relationship with governing bodies (Durette et al, 2009).

Changing land use may also have implications for conflict and governance. Between 1990 and 2008, 28 per cent of high-quality land that would be suitable for many uses was converted to urban development, concentrated predominantly in Canterbury and Auckland (Ministry for the Environment and Stats NZ, 2018). Loss of land that is considered highly productive for agricultural use is occurring at the same time as pressure on food production systems is increasing (Ministry for the Environment and Stats NZ, 2018). In the absence of adaptive capacity, conflict and distrust in governance structures may arise over competing interests for land use. Additionally, land and infrastructure assets in low-lying areas and coastal regions are likely to become increasingly devalued, leading to social disruption and conflict, particularly in wealthy enclaves (Bengtsson et al, 2007).

Competition for homes in 'safe' areas may also exacerbate other social and ethnic tensions (Bengtsson et al, 2007).

Interacting risks

Resource scarcity and changing asset values due to climatic changes can ultimately lead to conflict, disruption and loss of trust in governance structures. Land-based primary productivity (E3) is at risk of conflict through its reliance on natural resources for economic value. Scarcity and competition for resources may also increase risks to health and wellbeing (H3). To negate conflict, trust in government (G3) is essential for climate change adaptation. Likewise, the risk of uncoordinated actions to address (G1) and inadequate knowledge of (G5) the vulnerability of resources to climate variability could amplify conflict.

Confidence: Moderate agreement, limited evidence

There is a moderate level of agreement that climate change may lead to increased conflict, disruption and loss of trust in government institutions. However, the evidence base to support our understanding of this risk is limited.

Adaptation

Neither the literature search nor the consultation process identified any adaptation actions for this risk.

Table 39: H4 Risks of conflict, disruption and loss of trust in government from changing patterns in the value of assets and competition for access to scarce resources: Urgency profile

<table>
<tr><th colspan="7">H4 Risks of conflict, disruption and loss of trust in government from changing patterns in the value of assets and competition for access to scarce resources: Urgency profile</th></tr>
<tr><td>Urgency category</td><td colspan="2">Proportion of urgency</td><td colspan="4">Description of actions</td></tr>
<tr><td>More action needed</td><td colspan="2">50</td><td colspan="4">Early policies and practices are needed to ensure that potential actions are in place to mitigate this risk.</td></tr>
<tr><td>Research priority</td><td colspan="2">40</td><td colspan="4">Further research would be useful to understand how this risk might arise or to what degree and where.</td></tr>
<tr><td>Sustain current action</td><td colspan="2">0</td><td colspan="4"></td></tr>
<tr><td>Watching brief</td><td colspan="2">10</td><td colspan="4">Need to establish a monitoring process to ensure actions are effective.</td></tr>
<tr><td>Adaptation urgency</td><td colspan="2">83</td><td>Confidence</td><td colspan="3">Moderate confidence, limited evidence</td></tr>
<tr><td>Consequence</td><td>Now</td><td>Moderate</td><td>2050</td><td>Major</td><td>2100</td><td>Major</td></tr>
</table>

4.4.5 H5 Risks to Māori social, cultural, spiritual and economic wellbeing from loss and degradation of lands and waters, as well as cultural assets such as marae, due to ongoing sea-level rise, changes in rainfall and drought

Risk summary

Māori have unique spiritual, cultural and economic ties with the environment and mana whenua. Degradation and loss of land and waters are already taking place, and are likely to increase over time, with impacts on cultural wellbeing and spiritual health, identity and capacity to sustain livelihoods. Many Māori communities live in exposed areas and climate change-induced pressures will challenge the capacity of some Māori to cope and adapt (King et al, 2012).

Exposure

Māori freehold land – the majority of which is fragmented, uneconomic and located in the North Island – makes up about 5.6 per cent of the total landmass of Aotearoa New Zealand (Kingi, 2008; Te Aho, 2007). Ongoing sea-level rise, landslides and erosion, fire, drought, and changes to stream flows and water flows are expected to have significant impacts on land and primary sector assets and, by extension, on future economic investment and wellbeing.

Many Māori settlements and interests in coastal fringes and lowland areas are already exposed to flooding, erosion and sedimentation, and these risks are projected to increase with sea-level rise (Fraser, 1991; King et al, 2010; Ngāi Tahu, 2018; Packman et al, 2001) under both RCP4.5 and RCP8.5 scenarios. Other Māori-owned land is steep and susceptible to damage from high-intensity rainstorms (Harmsworth and Raynor, 2005). Most of New Zealand is projected to experience more dry days, but also more days of heavy rainfall, which may lead to more frequent flooding and erosion. Increasing dry spells are expected to amplify conditions in already drought-prone land in the east and north of the country, potentially reducing agricultural productivity and economic opportunities (Cottrell et al, 2004; King et al, 2010). Under a warming climate, fire – which is projected to become more frequent – is regarded as a significant threat to Māori resources and investment in the farming and forestry industries (King and Penny, 2006; King et al, 2012).

Sensitivity

Māori regularly use private and public lands, water and associated resources for activities ranging from hunting, fishing and recreation, to collection of cultural resources and the maintenance of traditional skills and identity (King and Penny, 2006; King et al, 2012). However, resource degradation, land-use modification and increasing competition have greatly transformed the ability of Māori to undertake these practices (IPCC, 2007b; King et al, 2012). The diversity of Māori society, and the presence of other sources of strengths and vulnerabilities, result in differential levels of sensitivity to changes in and to land and waters depending on location and cultural practice.

Adaptive capacity

As discussed in relation to the natural environment domain (section 3), beyond reducing local stressors, there is limited ability to reduce the consequences of climate change on ecosystems and land. In particular, it is unlikely that protection of all low-lying coastal regions, irrespective of their cultural, spiritual and economic importance, will be economically viable under high levels of warming (that is, RCP8.5). Some Māori communities are concerned about abandoning coastal spiritual sites and express strong reservations about the adequacy of managed retreat policies (Hayward, 2008b). Some Māori are less able to 'retreat' to other areas for many reasons, including their greatly circumscribed living arrangements, and deeply held values and beliefs about connections to place and people. About 80 per cent of the land- and ocean-based resources owned by Māori are held in multiple or communal ownership. While this is a source of opportunity and strength, it can also present challenges for governance structures that must balance economic and fiscal considerations with customary values around land use (Cottrell et al, 2004; King et al, 2010).

Many factors can limit the disruption caused by climate-related impacts and stresses. For example, Māori knowledge can help build resilience to weather and climate extremes (and related natural hazards) by promoting greater connections between people and natural world, and the inherent linkages between atmospheric and biophysical phenomena (King and Penny, 2006). Restoration of currently degraded Māori land, through applying new environmental management tools for long-term (50–100-year) visions, may also help reduce the vulnerability of some Māori to this risk (King and Penny, 2006).

Adaptive capacity is currently restricted by insufficient knowledge about the impacts of climate change on land and biodiversity (Te Aho, 2007) (G5). Other constraints are information asymmetries, inadequate coordination and knowledge-sharing processes between and within government and Māori peoples (G1), and inadequate access to funding for adaptation (G2).

Consequence

For many Māori, wellbeing is connected with the ability to use, develop and protect the natural environment (Hayward, 2008a). The importance of balancing cultural and spiritual values in the environment with using resources for social and commercial purposes is also widely recognised (Ministry for the Environment, 2007; Packman et al, 2001). If land becomes uninhabitable, as it almost certainly will with ongoing sea-level rise, the social and cultural impacts of relocation are likely to result in the loss of cultural capital (Okeroa, 2007).

Climate change-induced losses and degradation of land and waters are very likely to affect Māori economic opportunity, identity, and cultural wellbeing and spiritual health (Hayward, 2008a). Much of Māori economic development also relates directly to land and waters through agriculture, forestry and fishing. A healthy environment is a prerequisite for good health

(Durie, 1999). According to Jones et al (2014a), the loss of coastal land and sites of cultural significance will corrode the deep attachment to place and accentuate risks to mental health and wellbeing.

Interacting risks

The interconnectedness of Māori spiritual health and economic, physical, social and cultural wellbeing with the natural environment could amplify the vulnerability of some Māori to all other risks, by increasing sensitivity to climate change or reducing adaptive capacity. In particular, loss of land and waters is expected to exacerbate physical and mental health issues (H3, H7) and loss of identity and community cohesion (H1), as well as to impact on cultural heritage sites (H8). Importantly, the consequences of climate change on Māori peoples risk exacerbating inequity (H2) and may have ramifications for Treaty obligations and negotiations (G4).

Confidence: High agreement, robust evidence

There is robust evidence and a high level of agreement that loss and degradation of land and waters will have an adverse impact on Māori wellbeing.

Adaptation

Māori/iwi and many levels of government have efforts planned or under way to reduce this risk. Iwi appear to be in the early stages of collecting information on the potential impacts on them, and thinking about options for how they can respond. This includes Ngāi Tahu's *Te Tāhū o te Whāriki* climate change strategy (Ngāi Tahu, 2018) and *Te Poha o Tohu Raumati* (environmental management plan). However, Māori and iwi in general do not appear to have a good understanding of potential climate-related changes. Research is currently under way to build this understanding; for example, NIWA has carried out a number of studies on how it expects Māori society to be affected by climate change, including a series of place-based studies examining coastal Māori community adaptation and vulnerability. Ngāti Kahungunu is working in partnership with GNS Science to explore the connections between science and mātauranga-a-iwi, and the Deep South National Science Challenge has a particular focus on Māori and adaptation. Some local councils have commissioned their own research, natural hazard mapping, system and characteristic reports, and archaeological mapping, and are engaging with communities and Māori advisory boards. The extent of adaptation efforts varies across regions, and there are no clear funding mechanisms to respond to this risk.

Table 40: H5 Risks to Māori social, cultural, spiritual and economic wellbeing from loss and degradation of lands and waters, as well as cultural assets such as marae: Urgency profile

H5 Risks to Māori social, cultural, spiritual and economic wellbeing from loss and degradation of lands and waters, as well as cultural assets such as marae: Urgency profile

Urgency category	Proportion of urgency	Description of actions
More action needed	40	Actions can be taken to empower Māori communities and iwi to consider and act on their particular situations. Action should include support, financing and agreements to work together on understanding and adapting, and to support iwi/hapū to prepare climate change risk assessments and plans and reduce socio-economic disparities.
Research priority	50	Fill knowledge gaps and assist with building capacity to plan and adapt.
Sustain current action	0	

H5 Risks to Māori social, cultural, spiritual and economic wellbeing from loss and degradation of lands and waters, as well as cultural assets such as marae: Urgency profile

Urgency category	Proportion of urgency		Description of actions			
Watching brief	10		Establish a monitoring process to ensure actions are effective.			
Adaptation urgency	80		**Confidence**	High agreement, robust evidence		
Consequence	Now	Major	2050	Extreme	2100	Extreme

4.4.6 H6 Risks to Māori social, cultural, spiritual and economic wellbeing from loss of species and biodiversity due to greater climate variability and ongoing sea-level rise

Risk summary

Human pressures are already impacting on New Zealand's biodiversity, and climate change is expected to further change the abundance and distribution of indigenous flora and fauna. Loss of species and biodiversity is very likely to increase over time, with greater impacts under RCP8.5 than RCP4.5. Loss of species is expected to have adverse consequences for Māori, impacting on cultural practices, health and economic opportunity.

The loss of species and biodiversity will impact on Māori in many ways. For example, ongoing sea-level rise, oceanic temperature changes and changes to rainfall will alter the character of estuaries and water bodies, which in turn will affect the nesting sites of diadromous species, olfactory messaging in kōkopu egg releases, and tuna (freshwater eel) stocks. It is critical to identify and protect remaining habitat, as well as to consider how habitat suitability might change as climate change continues into the future (King et al, 2010). Because degradation of the environment has already advanced significantly, actions should be taken in the short term.

Exposure

The risks outlined in relation to the natural environment domain (section 3) show the significant risks that climate change will pose to terrestrial and aquatic ecosystems, from alpine regions to coasts, oceans, lakes and forests. Extreme events, ongoing, gradual changes, and changes to rainfall patterns, ocean acidification and warming, along with the enhanced spread, survival and establishment of exotic or invasive species, are also expected to have an adverse impact on Māori social, cultural, spiritual and economic wellbeing. These changes in exposure over time are anticipated to have major consequences under a RCP8.5 scenario.

Sensitivity

As noted in relation to risk H5, Māori use the natural environment for hunting, fishing and recreation, to collect cultural resources, and to maintain traditional skills and identity (King and Penny, 2006; King et al, 2012). Increasing pressures on ecosystems are already compromising the ability of Māori to engage in these practices (King et al, 2012; Woodward et al, 2001). Human activities have radically changed the ecology of New Zealand: currently less than half of New Zealand's vegetation is native (Cieraad et al, 2015) and more than 90 per cent of wetlands have been destroyed (McGlone, 2009). Species already under pressure may be unable to cope with climate change, possibly leading to extinctions of some indigenous species (Packman et al, 2001).

Adaptive capacity

There is limited ability to reduce the consequences of unmitigated climate change (that is, RCP8.5) on ecosystems. A persistent lack of investment in ecological and biological science (see G5) undermines the ability to take pre-emptive action, and the spatial extent of ecosystems limits the ability to adapt to change at a large scale. While some species will shift their geographic ranges, cultural responsibilities require Māori to maintain and use traditional resources within tribal boundaries and geographic regions (Harmsworth and Awatere, 2013; Stevens, 2006).

Consequence

Balancing cultural, spiritual, social and economic values while using, developing and protecting the natural environment is essential to Māori health and wellbeing (Hayward, 2008a; Harmsworth and Awatere, 2013; Ministry for the Environment, 2007; Packman et al, 2001; Stevens, 2006; Wehi and Lord, 2017). It is expected that any obstruction to accessing species due to climate change will have an adverse impact on customary practice, cultural identity and wellbeing. Some iwi and hapū are also known for their knowledge around specific species and cultural practices. Loss of that knowledge due to changes in the environment is likely to have consequences for identity, knowledge transfer, language, wellbeing and resilience. Changes to biodiversity can also impact on diet and compromise cultural relationships, cohesiveness and wellbeing (King and Penny, 2006). Economic wellbeing is also affected, as many iwi rely solely on fishing quotas for economic advancement (Turei, 2006). Changes to the ability to access valuable resources, such as kūmarahou or kuta, may also affect social connections at the national level (Charpentier, 2008; Gibbs, 2003; Kapa, 2010; Wehi and Lord, 2017).

Confidence: High agreement, robust evidence

There is robust evidence and a high level of agreement that loss of species will have an adverse impact on Māori wellbeing.

Adaptation

Efforts to adapt to ecosystem change are detailed in relation to the natural environment domain (section 3) and under risk H5 above. There is no national governmental coordination of adaptation efforts and very little, if any, effort beyond the early stages of data gathering and awareness raising. Many iwi have ongoing initiatives to further educate, adapt and mitigate climate change.

Table 41: H6 Risks to Māori social, cultural, spiritual and economic wellbeing from loss of species and biodiversity: Urgency profile

H6 Risks to Māori social, cultural, spiritual and economic wellbeing from loss of species and biodiversity: Urgency profile		
Urgency category	**Proportion of urgency**	**Description of actions**
More action needed	40	Actions can be taken to empower Māori communities and iwi to consider and act on their particular situations. Action should include support, financing and agreement to work together on understanding and adapting.
Research priority	50	Little knowledge is available on this risk in New Zealand; further research is needed to fill knowledge gaps.
Sustain current action	0	

H6 Risks to Māori social, cultural, spiritual and economic wellbeing from loss of species and biodiversity: Urgency profile						
Urgency category	**Proportion of urgency**		**Description of actions**			
Watching brief	10		Need to establish a monitoring process to ensure actions are effective.			
Adaptation urgency	80		**Confidence**	High agreement, robust evidence		
Consequence	Now	Major	2050	Extreme	2100	Extreme

4.4.7 H7 Risks to mental health, identity, autonomy and sense of belonging and wellbeing from trauma due to ongoing sea-level rise, extreme weather events and drought

Risk summary

Climate change has several implications for the mental health and wellbeing of New Zealanders, as the harm experienced or witnessed when exposed to extreme events can result in mental trauma (Berry et al, 2010). Mental health risks from exposure to climate hazards range from minor stress and distress through to clinically recognised disorders such as anxiety and post-traumatic stress disorders (Royal Society | Te Apārangi, 2017). Communities may also experience disruptions to environmental and social determinants of health; disruptions to an individual's relationship with their environment can cause risks to mental health (Royal Society | Te Apārangi, 2017), as can the loss of livelihood, poverty and displacement (Berry and Welsh, 2010). Loss of autonomy and feelings of helplessness from being unable to stop the beach in front of your property eroding, for example, can also impact mental health. Finally, fear and grief associated with climate change and expected loss itself can cause trauma (Cunsolo and Ellis, 2018; Jones et al, 2014a).

Exposure

Mental disorders are common in New Zealand; one in six adults has been diagnosed with a common mental disorder at some time in their lives and, in a 2014 study, 6 per cent of adults reported recent experiences of psychological distress (Mental Health Foundation, 2014). Mental health and mental disorders have many determinants, ranging from genetics, brain chemistry, stress, nutrition and life experiences, to social, cultural, economic and political factors (such as standards of living, working conditions, national policies, and community support) (World Health Organization, 2019). Exposure to environmental hazards is also a source of mental distress (World Health Organization, 2019). For example, mental trauma can be caused by the harm experienced or witnessed during an extreme weather event, as well as from the economic implications of damage to communities and property (Berry et al, 2010). Extreme weather events are projected to increase in frequency and intensity across all of New Zealand, and will interact with these risk factors.

Place attachment is the relationship between people and places, and is often intricately bound up with an individual's identity of self, wellbeing and belonging (Adams, 2016). Disruption to the relationship between individuals and their environment, as a result of changes to that environment or moving away from a place, can cause risks to mental health (Royal Society | Te Apārangi, 2017). Trauma can also come from relocation or loss of valued places when the ability to emotionally and physical connect with a place is lost. Impacts on place attachment may occur across all of New Zealand as environments change. Grief and anxiety linked to the anticipation of future losses are likely to be prevalent among children and youth (Cunsolo and Ellis, 2018).

New Zealanders may also experience a loss of autonomy – the ability to affect an outcome – due to climate change.

Sensitivity

Many factors influence individuals' sensitivity to mental health issues, loss of identity, autonomy, wellbeing and sense of identity. These relate closely to factors detailed in risk H3. Key influences of sensitivity are reiterated below.

- Māori and Pacific people, in general, experience greater psychological distress and psychological or psychiatric disability, and have higher suicide rates than the general population (Mental Health Foundation, 2014). Māori, in general, are particularly sensitive to mental health risks from climate change, because of their strong historical and present-day cultural connections with land and waterways (Jones et al, 2014a).
- Women across all age groups are more likely to have been diagnosed with a common mental disorder than men; however, men are at higher risk of suicide (Mental Health Foundation, 2014).
- People living in socio-economically deprived areas have poorer mental health, and higher levels of unmet need for health care. Adults living in the most deprived areas have a higher incidence of common mental disorders and psychological distress than the general population (Mental Health Foundation, 2014).
- People in rural and remote settings have heightened sensitivity to mental health risks from extreme weather events (Royal Australian and New Zealand College of Psychiatrists, 2020). Because of their geographical isolation, they can also face increased exposure to trauma, as they typically have delayed access to support services.
- Young people in particular are more sensitive to anxiety about the impacts of climate change (Jones et al, 2014b).

Adaptive capacity

Adaptive capacity at the individual level is likely to depend on a mix of personal characteristics and an individual's social, economic and cultural context. Economically disadvantaged individuals often live in areas that are most at risk of environmental degradation and have less adaptive capacity as they lack the financial capital to migrate away from these regions (Adams, 2016). As a result, they face increased mental health risks.

Individual adaptation actions are also impacted by institutional arrangements (Adger et al, 2005). For example, risks to mental health will worsen if emergency management responses are delayed or if efforts to reduce risk exposure are not transparent or seen as fair. There is limited investment in knowledge about the impacts of climate change on mental health, which will limit adaptation efforts.

Consequence

It is clear that New Zealanders' exposure to extreme weather events and ecosystem change will increase, increasing the impacts on mental health and wellbeing. Increased risks to mental health are likely to lead to an increasing incidence of mental health problems and may increase the likelihood of suicide mortality (Berry et al, 2010). In New Zealand, depression and anxiety are experienced by about 13 per cent of the population (World Health Organization, 2017). Further increases in mental illness will put pressure on individuals, families, communities, and New Zealand's health system and economy. Limited research in this area makes it difficult to assess to what extent consequences are being felt in the present day and will be felt in the future.

Interacting risks

Risks to mental health, identity, autonomy and belonging interact with several other risks in the human domain. There is a reciprocal relationship between physical (H3) and mental health, and identity and belonging support social cohesion (H1). A loss of autonomy may increase distrust in government and the risk of conflict (H4). Mental disorders may also entrench existing inequities (H2). If not seen as fair and transparent, governance processes may exacerbate this risk. Loss of cultural heritage (H8) may also impact identity and mental health.

Confidence: High agreement, limited evidence

There is high agreement but limited New Zealand-specific evidence to date on the mental health risks to New Zealanders as a result of climate change.

Most research has focused on the direct effects of climate change on mental health, such as impacts associated with acute weather events. More research is needed on the indirect impacts.

Adaptation

There are limited targeted adaptation actions under way to address this risk in a holistic, forward-looking and integrated manner. Local governments and specialist services are supporting communities and individuals to cope with specific events (for example, drought or earthquakes) as part of existing services. For example, rural support trusts provide the primary sector and rural communities with access to psycho-social support and other advice, and the Farmstrong programme provides psycho-social support targeted to rural communities. New Zealand also has a network of mental healthcare services that work with individuals in need and vulnerable communities.

The Ministry for the Environment has also made efforts to meet with youth representatives from social NGOs in Wellington to discuss their views on climate change adaptation, to empower this social group.

Table 42: H7 Risks to mental health, identity, autonomy and sense of belonging and wellbeing from trauma: Urgency profile

<table>
<tr><th colspan="7">H7 Risks to mental health, identity, autonomy and sense of belonging and wellbeing from trauma: Urgency profile</th></tr>
<tr><td>Urgency category</td><td colspan="2">Proportion of urgency</td><td colspan="4">Description of actions</td></tr>
<tr><td>More action needed</td><td colspan="2">50</td><td colspan="4">Early policies are needed to ensure support mechanisms are in place to mitigate this risk.</td></tr>
<tr><td>Research priority</td><td colspan="2">40</td><td colspan="4">We do not fully understand how this risk might arise, or to what degree, and where further research would support actions taken.</td></tr>
<tr><td>Sustain current action</td><td colspan="2">0</td><td colspan="4"></td></tr>
<tr><td>Watching brief</td><td colspan="2">10</td><td colspan="4">Need to establish monitoring process to ensure actions are effective</td></tr>
<tr><td>Adaptation urgency</td><td colspan="2">80</td><td>Confidence</td><td colspan="3">High agreement, limited evidence</td></tr>
<tr><td>Consequence</td><td>Now</td><td>Major</td><td>2050</td><td>Major</td><td>2100</td><td>Major</td></tr>
</table>

4.4.8 H8 Risks to Māori and European cultural heritage sites due to ongoing sea level rise, extreme weather events and increasing fire weather

Risk summary

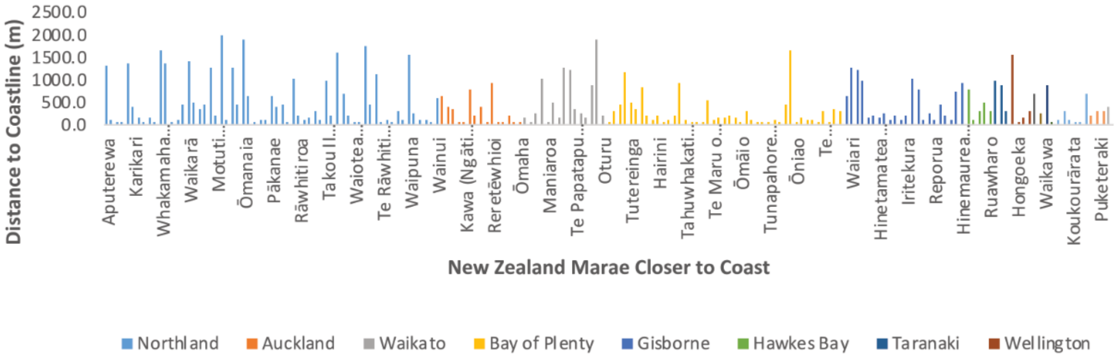
New Zealand's cultural heritage includes places of significance to Māori, archaeological sites, historic buildings and structures, and cultural landscapes (Parliamentary Commissioner for the Environment, 1996). Heritage, in all its forms, is already exposed and vulnerable to the impacts of climate hazards. Ongoing sea-level rise, more intense extreme weather events, and changes in humidity are expected to have significant implications for cultural heritage (IPCC, 2014a). Exposure to acute and ongoing, gradual change hazards is projected to increase over time and be greater under RCP8.5 than RCP4.5.

Exposure

Numerous Māori cultural heritage and early colonial period sites are in coastal low-lying areas and exposed to erosion and inundation (Department of Conservation, 2013). Many of these sites, which include pā, marae, urupā (burial grounds) and food-gathering sites, are deeply connected with Māori identity. Ongoing sea-level rise is expected to undermine and destroy the fragile dunes on which a considerable number of Māori heritage sites are located. High-profile cases of urupā being affected by coastal inundation and erosion have been widely reported in the media (for example, New Zealand Herald, 2019a), and the impact of these changes is expected to become more severe in the long term (Ministry for the Environment, 2017b). Many listed archaeological sites and cultural or ancestral material will be exposed to coastal inundation at 1.5 metres of sea-level rise, including 581 Department of Conservation and 69,048 New Zealand Archaeological Association sites, such as pā, rock paintings and urupā (Department of Conservation, 2019b).

According to one analysis, 93 per cent of coastal marae are located in the North Island, 45 per cent are within 200 metres of the coastline and 70 per cent are below 20 metres mean sea-level elevation (Bailey-Winiata, unpublished). Another 18 marae are located within 200 metres of rivers (Bailey-Winiata, unpublished) and subject to flooding (New Zealand Herald, 2018; Stuff, 2017). The distance of coastal marae to the coastline is shown in figure 15.

Figure 15: Distance of New Zealand marae to the coastline (Bailey-Winiata, unpublished)



Fire also poses risks to cultural heritage; to date, it has destroyed about 15 heritage buildings each year (New Zealand Fire Service and New Zealand Historic Places Trust, 2005). Very high and extreme fire danger is projected to increase across much of New Zealand, but regions such as the West Coast and inland Canterbury will experience less danger (see section 2).

Sensitivity

Very limited research has focused on the sensitivity of cultural heritage to climate change (McIntyre-Tamwoy, 2008). Forino et al (2016) understand sensitivity of built structures to be a function of structural condition, the degree to which the materials of the asset can withstand a potential hazard, and the historical damage of the asset. In general, assets with no inherent weaknesses in their structure will be less sensitive to climate change hazards. Certain materials are likely to be more sensitive to particular climate change hazards and risks; however, research in this area is limited. For example, earth structures are likely to be sensitive to flooding or increased rainfall, stone in wetter climates can deteriorate from increased freeze or thaw effects, and timber buildings – including marae and taonga made from wood – may be sensitive to the impacts of pest species.

Adaptive capacity

The adaptive capacity of heritage assets depends on a number of factors, including the nature of the asset, its location and financial resources available for ongoing care, protection and preservation.

Some cultural assets, for example, Māori heritage sites and urupā, are very difficult to relocate, and urupā in coastal locations are already impacted by coastal erosion and extreme weather. The availability of new places and grounds, and the politics associated with agreement on these, affect the capacity to adapt.

Different heritage types have differing levels of resources for protection and adaptation. Formally listed assets, the majority of which are built early European heritage (Short et al, 2019), have greater access to funding and resources. For example, the National Heritage Preservation Incentive Fund distributed 97.7 per cent of its allocation to built heritage, and only 2.3 per cent to wāhi tapu sites (Heritage New Zealand, 2020a). Limited funding and ability to respond to changes in cultural landscapes limits adaptive capacity.

A number of mechanisms support the protection of Māori cultural heritage. For example, the Oranga Marae programme gives whānau and hapū advice and support to develop their marae and achieve goals around protection of cultural heritage sites (Heritage New Zealand, 2020b). However, some wāhi tapu are on private land and have no significant protection or resources for adaptation.

As discussed under risk E6 (section 5.4.6), insurance is key to securing the finances needed to recover from adverse climate change impacts. While it is possible to secure insurance for historic buildings (McClean and Cox, 2007), there is no market for insuring cultural landscapes.

Consequence

New Zealand's cultural heritage tells the story of about 700 years of human exploration and settlement. Many New Zealanders are proud of the richness and uniqueness of Māori and early European heritage. This heritage comprises places of significance to Māori, archaeological sites, historical buildings and structures, and cultural landscapes (Parliamentary Commissioner for the Environment, 1996). The intangible cultural expressions of heritage such as knowledge and skills connect the past and the present, and collectively contribute to the identities of individuals and communities. Many sites of cultural significance to Māori are deeply connected with Māori identity (King et al, 2012). Māori communities collectively hold land as sources of cultural identity and mana, and preservation of such Māori values in the face of major coastal change is a significant challenge (Smith et al, 2017).

Today, as in the past, cultural heritage performs its irreplaceable role as a source of meaning and identity for communities and individuals. Heritage is not a relic of the past; rather, it is instrumental in steering sustainable development and the wellbeing of communities (Jigyasu, 2013). New Zealand's cultural heritage also creates opportunities for inclusive economic development, through attracting investment and promoting local jobs in tourism, conservation, research, education, marketing, food production and arts and crafts (Jigyasu, 2013). Loss of and damage to heritage will diminish these opportunities.

Interacting risks

Risks to cultural heritage are expected to be intensified by many governance risks relating to institutional arrangements (G2), uptake of tools (G1) and coordination mechanisms (G1), and the potential retreat of the insurance sector from certain areas or asset classes (E6). Many risks in the natural environment, particularly those relating to terrestrial ecosystems (N7), coastal ecosystems (N1), migratory species (N5), indigenous forests (N11), and waters such as lakes (N6), wetlands (N4) and riverine ecosystems (N3), are also likely to influence cultural landscapes and heritage. Risks in the built environment relating to flooding of buildings (B2) are expected to affect some heritage sites. Loss of cultural heritage could have adverse consequences for the tourism sector (E4), and potentially the Government's fiscal position (E1), as well as for trust in government (G8), Treaty obligations (G4), mental health and connection to place (H7) and Māori wellbeing (H5, H6).

Confidence: High agreement, medium evidence

There is high level of agreement that climate change poses risks to cultural heritage. Limited evidence is available on the exposure and vulnerability of these assets in New Zealand. Further work is needed to better understand the distribution of risk.

Adaptation

Significant efforts are under way across government to manage risks related to cultural heritage. For example, Heritage New Zealand Pouhere Taonga (HNZPT) is developing a national-level strategy and exploring funding options. It is also working with the New Zealand Archaeological Association to determine the extent of New Zealand's archaeological sites and HNZPT-listed heritage places at risk from climate change-related sea-level rise and erosion. In addition, HNZPT is supporting some marae communities with advice and specialist services around taonga conservation, cultural resilience and Māori cultural practice, and is empowering communities to manage their buildings and cultural practice. The Department of Conservation has included heritage management in a National Adaptation Plan, and some university organisations are working with iwi and hapū to understand and respond to this risk.

Table 43: H8 Risks to Māori and European cultural heritage sites: Urgency profile

<table>
<tr><th colspan="7">H8 Risks to Māori and European cultural heritage sites: Urgency profile</th></tr>
<tr><th>Urgency category</th><th colspan="2">Proportion of urgency</th><th colspan="4">Description of actions</th></tr>
<tr><td>More action needed</td><td colspan="2">20</td><td colspan="4">Explore adaptation options where the location of sites is known.</td></tr>
<tr><td>Research priority</td><td colspan="2">70</td><td colspan="4">Understand where sites are located and how they could be affected.</td></tr>
<tr><td>Sustain current action</td><td colspan="2">0</td><td colspan="4"></td></tr>
<tr><td>Watching brief</td><td colspan="2">10</td><td colspan="4">Action should be monitored.</td></tr>
<tr><td>Adaptation urgency</td><td colspan="2">75</td><td>Confidence</td><td colspan="3">High agreement, medium evidence</td></tr>
<tr><td>Consequence</td><td>Now</td><td>Major</td><td>2050</td><td>Major</td><td>2100</td><td>Major</td></tr>
</table>

4.4.9 HO1 Opportunity for reduction in cold weather-related mortality due to warmer temperatures

In New Zealand, about 1600 more deaths occur in winter than in summer (Davie et al, 2007). New Zealand homes are, on average, colder than the World Health Organization's (WHO) recommended minimum of 18 degrees Celsius. Data collected for housing in Wellington in 2015, for example, found that the mean indoor temperature was around 15 degrees (Rangiwhetu et al, 2018). Many factors influence mortality rates, including temperature, influenza, household crowding, moisture levels and the thermal performance of buildings (Davie et al, 2007). Rising temperatures in New Zealand may reduce winter mortality rates through impacts on household temperatures, crowding and moisture levels, but reductions in cold weather-related mortality are likely to be offset by increased heat-related illness and mortality (H3). Very little research is available to confirm this opportunity.

Table 44: HO1 Opportunity for reduction in cold weather-related mortality due to warmer temperatures: Urgency profile

<table>
<tr><th colspan="7">HO1 Opportunity for reduction in cold weather-related mortality due to warmer temperatures: Opportunity urgency profile</th></tr>
<tr><td>Urgency category</td><td colspan="2">Proportion of urgency</td><td colspan="4">Description of actions</td></tr>
<tr><td>More action needed</td><td colspan="2">0</td><td colspan="4"></td></tr>
<tr><td>Research priority</td><td colspan="2">10</td><td colspan="4">Understand how cold combines with and exacerbates other factors (eg, damp) to cause increased winter deaths, in order to identify how these can be further reduced.</td></tr>
<tr><td>Sustain current action</td><td colspan="2">60</td><td colspan="4">Sustain existing home insulation and heating subsidy programmes and minimum insulation standards in residential rental properties.</td></tr>
<tr><td>Watching brief</td><td colspan="2">30</td><td colspan="4">Watch and monitor.</td></tr>
<tr><td>Adaptation urgency</td><td colspan="2">45</td><td>Confidence</td><td colspan="3">Medium agreement, limited evidence</td></tr>
<tr><td>Consequence</td><td>Now</td><td>Minor</td><td>2050</td><td>Moderate</td><td>2100</td><td>Moderate</td></tr>
</table>

4.5 Gaps in knowledge

There is overwhelming agreement that changing climatic conditions will exacerbate a range of existing threats to and pressures on New Zealanders' skills, knowledge, and physical and mental health. The severity and geographical spread of these impacts are unclear, primarily because of a lack of research in this domain.

Knowledge gaps remain around how climate hazards will impact New Zealanders' mental and physical health. Although literature on how acute climate hazards will impact New Zealanders' physical health exists, limited information is available on the implications of gradual climate hazards. In particular, there is very limited information on how zoonotic diseases and the quality of and access to resources will impact on New Zealanders' physical health. In addition, research is minimal on how climate hazards will affect vulnerable groups, such as Māori. Risks to Māori social, cultural, spiritual and economic wellbeing from both the loss and degradation of lands and waters, and loss and degradation of species and biodiversity, are relatively unknown and require further investigation.

5 Economy domain | Rohe ōhanga

5.1 Domain description

The definition of the economy domain used by the National Climate Change Risk Assessment for Aotearoa New Zealand was:

> “the set and arrangement of related production, distribution, trade and consumption practices that allocate scarce resources.”

It comprises primary industries, tourism, finance and insurance, manufacturing, mining and whakatipu rawa – Māori enterprise. What happens to and within the economy affects people and their livelihoods.[7] Box 6 provides a Māori perspective on this domain and an overview of the significance of the risks in this domain to Māori values and wellbeing.

Box 6: Māori perspective on rohe ōhanga – the economy domain

Rohe ōhanga | economy domain

Rohe ōhanga is a representation of Māori prosperity in modern-day Aotearoa, developed from a long history in local, regional and international trade. Across Aotearoa, the Māori economy is diverse, with a strong focus on primary industries such as forestry, agriculture, fisheries and tourism. Māori are also significant contributors to the workforce in these industries. There has been steady growth in whakatipu rawa – Māori enterprise, commercial businesses owned by Māori authorities that sustain and build a Māori authority’s asset base. These enterprises demonstrate the innovation in the Māori economy, and the dynamic way the economy responds to change.

The risks identified below relate to reduced production and profitability across the rohe ōhanga, which may then have a significant impact on the economic returns to Māori authorities and landowners and Māori working in those businesses. Specific risks have been identified that may result in reductions in revenue from fisheries quota, inherently connected to the rohe taiao (natural environment domain) and the mātāpono (principle) of kaitiakitanga (intergenerational sustainability) and manaakitanga (care and reciprocity). The broader social, economic and cultural impacts of climate change on some Māori communities are also expected to be disproportionately high, due to the remote location and the economic status of certain communities.

5.2 Snapshot of issues and themes

Climate change will impact on the full spectrum of New Zealand’s economy. The public sector, private sector, small and medium enterprises, large multi-national corporations, primary industries, advanced manufacturing, and services provision will all feel the effects of climate change in some way. These effects are likely to stem from the increasing frequency and intensity of climate hazards, such as floods and fires, and from ongoing, gradual changes, such as changes to climate seasonality and increases in average air and ocean temperatures.

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[7] This report was completed before the arrival of the COVID-19 pandemic in New Zealand, and the resulting impacts on people’s livelihoods.

A significant proportion of New Zealand's economy is tied to climate-sensitive industries, including agriculture, forestry and tourism, and the total Māori asset base is even more heavily invested in these sectors. Extreme weather events and the introduction or proliferation of pests and diseases could have significant consequences for these industries.

Climate change will pose risks to the economy as a whole, and for specific aspects of it. The degree to which the economy is affected will depend on many factors, which extend beyond environmental changes. These include:

- how businesses respond to extreme climate events and gradual, ongoing trends
- the actions of New Zealand's trading partners
- advances in technology, and labour market regulations
- population growth and productivity changes
- changes in consumption patterns
- the level of economic growth.

Climate change risks are interconnected and cut across human and non-human systems. How risks move through and are muted, reconfigured, or amplified in our interdependent world poses a challenge to assessing and adapting to risks. The pervasive and cascading effects of climate change are many, and their relationships warrant additional investigation. For example, damage to a highway due to flooding could cut off a key tourist destination and affect the regional economy, or a wildfire could cause loss in forestry as well as increased health costs from smoke inhalation. Section 1.2.2 explores how cascading impacts within and across domains complicate the application and interpretation of climate change risk assessment.

5.3 Summary of climate change risks and opportunities

Table 45: Summary of climate change risks and opportunities in the economy domain

Economy		
	Ratings	
Most significant risks	**Urgency**	**Consequence**
E1 Risks to governments from economic costs associated with lost productivity, disaster relief expenditure and unfunded contingent liabilities due to extreme events and ongoing, gradual changes.	90*	Extreme**
E2 Risks to the financial system from instability due to extreme weather events and ongoing, gradual changes.	83	Major
Other priority risks examined in stage 2		
E3 Risks to land-based primary sector productivity and output due to changing precipitation and water availability, temperature, seasonality, climate extremes and the distribution of invasive species.	81	Major
E4 Risks to tourism from changes to landscapes and ecosystems and impacts on lifeline infrastructure due to extreme weather events and ongoing, gradual changes.	80	Major
E5 Risks to fisheries from changes in the characteristics, productivity and spatial distribution of fish stocks due to changes in ocean temperature and acidification.	80	Major

Economy		
	Ratings	
Most significant risks	**Urgency**	**Consequence**
E6 Risks to the insurability of assets due to ongoing sea-level rise and extreme weather events.	75	Major
E7 Risks to businesses and public organisations from supply chain and distribution network disruptions due to extreme weather events and ongoing, gradual changes.	68	Major
EO1 Opportunities for increased productivity in some primary sectors due to warmer temperatures.	80	n/a
EO2 Opportunity for businesses to provide adaptation-related goods and services.	80	n/a

* Urgency rating refers to the total adaptation and decision urgency rating (between 1 and 100).

** Consequence rating refers to the highest consequence rating assigned to this risk out of all three time periods (now, 2050, 2100). Section 5.4 provides the consequence rating for each time period for all the risks.

5.4 Climate change risks and opportunities

5.4.1 E1 Risks to governments from economic costs associated with lost productivity, disaster relief expenditure and unfunded contingent liabilities due to extreme events and ongoing, gradual changes

Risk summary

The costs of climate change in New Zealand are already significant (Frame et al, 2018) and will only increase over time. Almost all risks detailed in this report impact the economy and the Government's fiscal position, whether by causing a loss in revenue or by requiring additional expenditure to adapt infrastructure, respond to health needs or recover from extreme events. The damages from and costs of adapting to climate change are expected to be a significant and growing financial burden on public authorities, who will be tasked with funding investments in adaptation, providing post-event relief and responding to health impacts.

Exposure

The fiscal position of the public sector and Government is exposed to the consequences of climate change across the domains. The damage caused by climate change-related hazards will impose a growing financial burden on citizens, businesses and public authorities. Central and local government, on behalf of communities, are responsible for managing risks to public goods and assets (including the environment) and creating an institutional, market and regulatory environment that promotes resilience and action (Ministry for the Environment, 2017c).

Research by Frame et al (2018) investigated the scale of the economic impact of climate change-related floods and drought in New Zealand between mid-2007 and mid-2017. They conservatively estimate that flood and drought costs attributable to the influence of human activities on climate are already somewhere around $120 million per decade for insured damages from floods, and $720 million per decade for economic losses associated with droughts. They warn that these costs will "almost certainly" (Frame et al, 2018, p 9) increase over time. Already the annual cost of repairing land transport networks damaged by weather-related events (B6) has more than quadrupled over the past decade (Boston and Lawrence, 2018). The Government may be exposed to compensation for homeowners and commercial buildings in the event of managed retreat from areas exposed to landslides and coastal or river floods.

The New Zealand Treasury also warns that “[i]n the future, we may also see threats to our natural resources (eg, climate change, water quality and natural disasters) as a fiscal pressure” (New Zealand Treasury, 2016, p 6). Ecosystem services provided by the natural environment are significant, and in some cases irreplaceable. Examples of these services include nutrient cycling, soil provision, water and air purification, carbon sequestration, food and resource provision, and cultural services and experiences. Their loss, as well as diminishing the welfare of all New Zealanders, may burden the Government by affecting key sectors of the economy, such as primary industries (E3, E5) and tourism (E4). The impacts of climate change on people also manifest in the economy through declining productivity in hot weather, the direct health risks stemming from disease and exposure to extreme events (H3), and the indirect costs associated with trauma (H1) and exacerbation of persistent inequities (H2).

Sensitivity

New Zealand governments are sensitive to the financial risks from climate change. Already local governments are struggling to finance infrastructure for housing, tourism and regional development, provide safe drinking water and develop infrastructure that is resilient to climate hazards (Department of Internal Affairs, 2017). Some councils are also experiencing constraints on their ability to finance further investment because they are approaching covenanted debt limits (New Zealand Productivity Commission, 2019).

Local government relies on rates for more than 50 per cent of their income, which are generally based on the land, capital or rental value of property in the local government area (Local Government New Zealand, 2019). This situation increases the sensitivity of local governments to climate change-related impacts that influence property values, for example insurance sector retreat (E6). Additionally, rates that are linked to land, capital or rental values may fail to keep pace with the expenditure required to adapt to climate change, particularly those projected to occur under representative concentration pathway (RCP) 8.5.

At central government level, finances are relatively strong but fiscal pressures are projected to increase as an ageing population slows revenue growth and increases expenses (New Zealand Treasury, 2019a).

Adaptive capacity

Local governments currently have varying, but generally limited, adaptive capacity to respond to economic risks. Some councils have indicated that they could meet additional costs through general or targeted rates (James et al, 2019). However, on average, growth in council rates has outstripped common economic indicators, and continuing rates increases may challenge the future affordability of council rates for households (Department of Internal Affairs, 2017). Other councils have disaster relief funds or have already budgeted for increased infrastructure costs. Many councils remain unsure of what the costs would be and how they would meet those costs (James et al, 2019).

Central government has a greater ability to adapt to this risk by preparing for a changed climatic future and funding adaptation efforts to ensure New Zealanders can continue to prosper socially, economically and culturally. Central government sets the domestic regulatory framework in which adaptation is currently considered. Among other roles, it is also responsible for providing robust information on how New Zealand’s environment may change and making this information accessible to other sectors (Ministry for the Environment, 2017c).

Consequence

There have been numerous attempts to calculate the economic cost of climate change. Notably the Stern Review (Stern, 2006) estimated that, without action, climate change may lead to losses equivalent to at least 5 per cent of global gross domestic product (GDP) each year**.** More recently, Hinkel et al (2014) have estimated that if the sea level rises by 1.23 metres by 2100,[8] frequent floods alone would cause losses of over 9 per cent of global GDP each year. A decline in economic output of this magnitude would have significant consequences for the New Zealand Government's ability to deliver services to support communities.

Confidence: High agreement, medium evidence

There is a high level of agreement that climate change is likely to have adverse consequences for the economy; however, agreement on the extent of these costs is limited. Robust evidence shows the economic costs of climate change in other global regions, but very little research has explored this risk in the New Zealand context. A review of recent research related to climate change risks in New Zealand by McKim identified only two pieces of (grey) literature relating to finance (including banking and insurance) and climate change, and concluded that "a general lack of published research in this area, at least in the New Zealand context, is evident" (McKim, 2016, p15).

Adaptation

All levels of government are undertaking actions that indirectly manage public sector fiscal risk. Central government and its departments have many efforts under way, including tax policies, adverse events policies, transport resilience strategies, capacity building, and engagement with other levels of government. These efforts are not necessarily targeted directly at climate risks, but all the same may serve to reduce associated risks. Similarly, local and regional governments have also progressed actions related to infrastructure strategies, adaptation pathway development, establishing community resilience groups, and emergency management. Adaptation to address the other climate change risks listed in this report will also contribute to reducing this risk.

Table 46: E1 Risks to governments from economic costs associated with lost productivity, disaster relief expenditure and unfunded contingent liabilities due to extreme weather events and ongoing, gradual changes: Urgency profile

<table>
<tr><th colspan="7">E1 Risks to governments from economic costs associated with lost productivity, disaster relief expenditure and unfunded contingent liabilities due to extreme weather events and ongoing, gradual changes: Urgency profile</th></tr>
<tr><th>Urgency category</th><th colspan="2">Proportion of urgency</th><th colspan="4">Description of actions</th></tr>
<tr><td>More action needed</td><td colspan="2">70</td><td colspan="4">Planning and budgeting for the growing financial burden is critical at all levels of the public sector. Adequate resourcing between different levels of government is essential.</td></tr>
<tr><td>Research priority</td><td colspan="2">20</td><td colspan="4">Develop credible estimates of future financial impacts of climate change over time across sectors.</td></tr>
<tr><td>Sustain current action</td><td colspan="2">10</td><td colspan="4">Taking adaptation action in other areas will reduce this risk. Continue to monitor climate change risk reduction efforts.</td></tr>
<tr><td>Watching brief</td><td colspan="2">0</td><td colspan="4"></td></tr>
<tr><td>Adaptation urgency</td><td colspan="2">90</td><td>Confidence</td><td colspan="3">High agreement, medium evidence.</td></tr>
<tr><td>Consequence</td><td>Now</td><td>Minor</td><td>2050</td><td>Major</td><td>2100</td><td>Extreme</td></tr>
</table>

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[8] The highest projected global mean sea-level rise across all models and emissions scenarios (95th percentile of MIROC ESM CHEM).

5.4.2 E2 Risks to the financial system from instability due to extreme weather events and ongoing, gradual changes

Risk summary

Financial instability impacts livelihoods, socio-economic inequality and the economy. The fundamental changes projected in the climate system are likely to have severe implications for the stability of the global financial system (Dafermos et al, 2018). New Zealand is exposed to climate change impacts in financial markets globally as well as locally. Climate change-related hazards could severely and abruptly damage the balance sheets of households, corporations, banks and insurers, triggering financial and macro-economic instability (Batten et al, 2016).

Exposure

New Zealand's financial system is highly exposed to climate change through local changes and international markets. The global financial system is composed of an extremely complex network of tightly linked financial institutions and markets. As the global fallout following the implosion of the United States' sub-prime mortgage market in 2008 demonstrated, financial system complexity and interconnectedness can transmit and amplify disruption across the globe. The stability of New Zealand's financial system is therefore influenced by the impacts of climate change-related hazards globally, as well as the behaviour of foreign governments, regulatory bodies and financial institutions (Batten et al, 2016). Any single acute event or series of acute events, such as hurricanes or cyclones, fires or floods, that precipitate rapid asset value reappraisals in major financial hubs like New York, Tokyo, Shanghai, Shenzhen, Hong Kong or London could affect New Zealand's financial system. The pricing of ongoing, gradual onset events, particularly sea-level rise, could also trigger rapid asset value reappraisal and financial system disruption. Vulnerability of supply and distribution systems (E7) may also expose the financial system to disruption (Hong et al, 2019).

Small and medium enterprises (SMEs), which account for 97 per cent of all New Zealand businesses and 29 per cent of employment (New Zealand Foreign Affairs and Trade, nd), are particularly sensitive to climate change-related disruption, so have the potential to be a source of financial system instability.

Both extreme events and ongoing, gradual changes could contribute to financial system instability in New Zealand. Ongoing, gradual changes such as sea-level rise, or change in climatic means, could over time stress businesses, governments, bank balance sheets, and economic activity. Extreme events in areas where valuable assets are concentrated, such as cities, could also lead to disproportionate financial system instability.

Sensitivity

New Zealand's financial system is resilient to a broad range of economic risks (Reserve Bank of New Zealand, 2019). Many factors affect the sensitivity of New Zealand's financial system to climate change impacts, including debt, capitalisation and ability to price risk.

New Zealand's AAA credit rating is justified by its 'very high economic resilience', a strong fiscal position, and effective institutions and policies, which mitigate the country's vulnerability to financial system shocks (Stuff, 2016b). However, a large external or domestic shock, such as a natural disaster, could threaten this current position and result in a credit downgrade that would undermine the banking system by raising the cost of funding (Moody's, 2017). This would be particularly severe if it led to some of New Zealand's many highly indebted households and dairy farms to default (Reserve Bank of New Zealand, 2019).

The Reserve Bank of New Zealand has recognised that the costs of bank failures are higher than previously understood, and has proposed reducing the sensitivity of the banking system by gradually raising bank capital requirements. However, some insurers and non-bank deposit takers have capital buffers that would absorb only relatively small losses, rendering them sensitive to disruption (Reserve Bank of New Zealand, 2019).

The insurance sector is highly sensitive to changes in climate hazards and may have underestimated the impact of climate change on catastrophe risks. For example, reinsurers could be underestimating their exposure to 1-in-10-year and 1-in-250-year catastrophe losses by an average of about 50 per cent (Standard and Poor's, 2014). Catastrophe models, which are used by insurers, reinsurers, governments, capital markets and other financial entities, also tend to rely on historical data and do not necessarily incorporate climate change trends (Lloyd's, 2014).

Adaptive capacity

The Reserve Bank Climate Change Strategy acknowledges the need to consider climate change risk in:

- the setting of monetary policy (policy that controls either monetary supply or the interest rate payable on short-term borrowing)
- the monitoring of financial stability risks and financial markets
- the identification of appropriate prudential requirements (Reserve Bank of New Zealand, 2020).

However, historically low interest rates limit the ability to stimulate the economy in the event of a demand-side shock (Reserve Bank of New Zealand, 2019). Monetary policy instruments are also limited in addressing supply-side shocks.

Actions taken by the financial sector influence the size and allocation of damages from a hazard (Batten et al, 2016). For example, the amount of insurance and credit available for financing building construction in flood-prone areas will determine the size of the eventual financial losses from flooding in these areas, as well as the allocation of these losses. The uncertainty in future greenhouse gas concentrations, corresponding climate change and the reactions of humans to this change hinder accurate and efficient pricing of risk (Aglietta and Espagne, 2016). Importantly, the 'long tails' of probability distributions (unlikely but extreme events) that grow 'thicker' (that is, more likely) with climate change inaction cannot be ruled out as they are crucial for accurate pricing of uncertainty (Weitzman, 2009).

There is an international movement towards disclosure of climate change risks, such as through the Carbon Standards Disclosure Board, the United Nations' Principles for Responsible Investment, the Task Force on Climate-related Financial Disclosures (TCFD) and the Network for Greening the Financial System, of which New Zealand is a member. The intention of this movement is to mobilise mainstream financial flows towards investments that are not exposed to climate risk. To date, TCFD disclosure is minimal and capital flows generally still fail to consider climate risk. Generally the market under-reacts to many types of value-relevant information (Weitzman, 2009) such as industry news, demographic shifts and upstream–downstream relationships (Cohen and Frazzini, 2008; Hong et al, 2007). Research also suggests that stock markets are inefficient in responding to information about drought trends (Hong et al, 2019). The reasons for this lack of response require further research, but may include inattention, home country equity bias or other institutional investor frictions. However, the inability to adequately price climate change risk, whatever the reason, reduces adaptive capacity (Hong et al, 2019). Government proposals to introduce TCFD-aligned disclosures may help reduce sensitivity to this risk by enabling risks to be more accurately priced.

Consequence

Climate change presents a systemic risk to the financial system, with severe impacts on the real economy. Extreme events, such as flooding or fire, along with ongoing, gradual changes, like soil erosion or ongoing sea-level rise, can have a number of impacts. These impacts could be intensified by interactions between the financial system and the non-financial components of the economy, as well as by government policies and regulations.

Financial instability could have a range of economic effects, including increasing income inequality (Domanski and Zabai, 2016) and reinforcing the adverse effects of climate change on economic activity (Dafermos et al, 2018).

Climate change poses a risk to financial systems by disrupting both supply and demand.

- Demand-side disruptions affect consumption, investment and international trade.
- Climate change-induced losses could reduce household wealth and therefore private consumption.
- Business investments could be reduced by uncertainty and damage to physical and financial assets.
- Climate hazards can have significant effects on domestic and international trade (Gassenher et al, 2010; Oh and Reuveny, 2010).
- Supply-side disruptions affect the productive capacity of the economy.

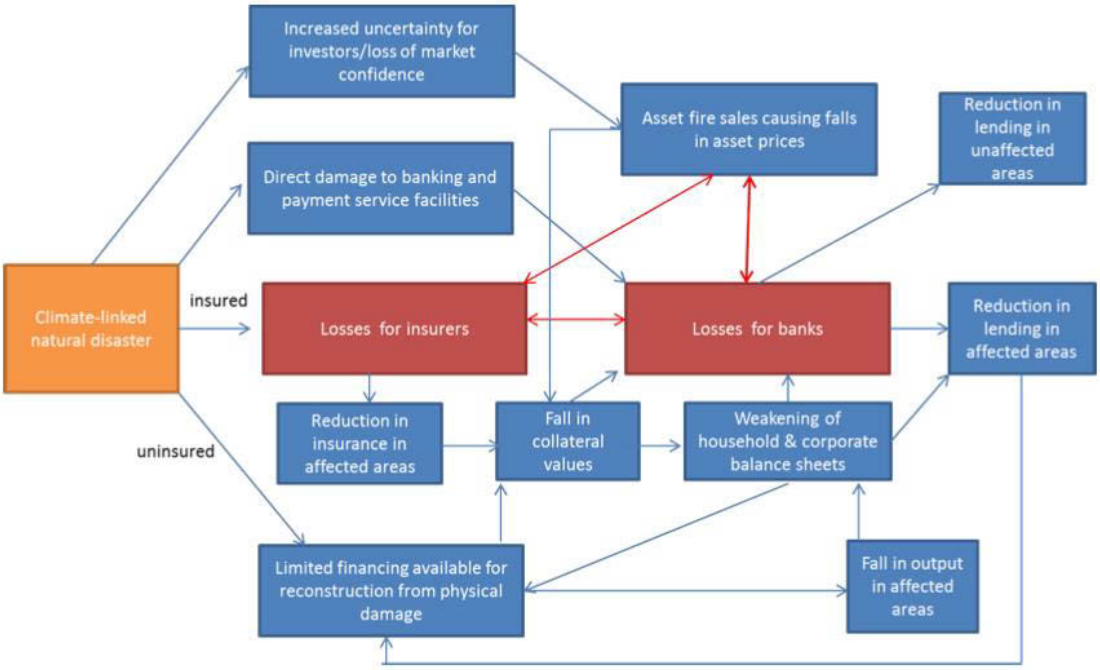
These disruptions could include loss of worker productivity in hot weather, impacts on production facilities and the transport networks, or shortages in commodities reducing the supply of goods.

Climate change has the potential to cause permanent or long-term damage to capital and land (Stern, 2013), and increase the rate of capital depreciation (Fankhauser and Tol, 2005); both effects can reduce profitability and lead to a gradual deterioration in firms' liquidity. Extreme events deteriorate the financial robustness of banks (Klomp, 2014), which in extreme cases results in capital reserves that are insufficient to cover regulatory requirements. This can require a government response, possibly even a bailout, which would adversely affect the public debt-to-output ratio (Dafermos et al, 2018). If banks suffer losses on their capital as a result of a climate hazard and cannot raise new capital immediately, they may reduce lending to both affected and unaffected areas to improve their regulatory capital ratios. This reduction in credit supply could intensify a fall in the value of assets used to secure loans, and further impact on the balance sheets of households and businesses. This could deepen the inevitable economic downturn that follows a climate hazard (Batten et al, 2016).

An extreme event could also undermine business confidence and trigger a sharp sell-off in financial markets, increasing the cost of funding new investments and reducing investment demand. Further, climate change may influence how households allocate capital: they may, in response to declining corporate profitability and increases in risk, reallocate financial wealth from corporate bonds towards term deposits and government securities, which are perceived as less risky. This investment portfolio reallocation can cause a gradual decline in the price of corporate bonds, reducing economic growth from wealth-related consumption and also the ability of firms to fund investment, constraining economic growth (Dafermos et al, 2018). These impacts are expected to become more severe if global warming passes a 2.5-degree Celsius threshold (Dafermos et al, 2018).

Another way climate change can affect the stability of the financial system is through the insurance sector. Increasingly frequent and severe extreme events, such as fires, floods and storm surges, could have a direct effect on the insurers that cover them. If insured losses from an event or a series of events are sufficiently large and concentrated, they could lead to distress or failure of insurance companies, affecting financial stability if they were to disrupt critical insurance services and systemically important financial markets, such as securities lending and funding transactions (French et al, 2015). Large-scale fire sales of assets by distressed insurers could reduce asset prices, adversely affecting the balance sheets of other financial institutions, such as banks. If these risks are uninsured, the deterioration of the balance sheets of affected households and corporates might lead to losses for their lender banks (Campiglio et al, 2018). Some of these relationships are illustrated in figure 16.

Figure 16: **A transmission map from a climate hazard to financial sector losses and the macro-economy (Batten et al, 2016)**



Interacting risks

Financial system instability will have impacts on the Government's fiscal position (E1), other economic sectors (E3, E4, E5) and the ability to fund adaptation (G2).

Emergency government responses may be taken in the context of a major financial system disruption, posing risks to democratic decision-making processes (G8). Financial crises also tend to exacerbate existing inequities (H2) and cause adverse impacts on health (H3).

Confidence: High agreement, medium evidence

There is a reasonably high degree of agreement on the impacts of climate change on financial system stability, and a large and growing body of academic and grey literature supporting this consensus. However, this research area is in its infancy, and few data have been developed for the New Zealand context.

Adaptation

Some adaptation efforts, both current and planned, are explicitly targeting financial system stability in the context of climate change. The Reserve Bank of New Zealand has developed a climate change strategy and undertakes other regulatory actions to support financial system stability. The finance and insurance sectors are working with governments to establish policy frameworks that enable proactive risk reduction, and some banks are starting to factor climate change risk into lending decisions. Adaptation to address other risks in New Zealand will also contribute to reducing this risk.

Table 47: E2 Risks to the financial system from instability due to extreme weather events and ongoing, gradual changes: Urgency profile

<table>
<tr><th colspan="7">E2 Risks to the financial system from instability due to extreme weather events and ongoing, gradual changes: Urgency profile</th></tr>
<tr><td>Urgency category</td><td colspan="2">Proportion of urgency</td><td colspan="4">Description of actions</td></tr>
<tr><td>More action needed</td><td colspan="2">40</td><td colspan="4">Develop a coordinated long-term plan integrating climate risk across relevant sectors.
Build resilience into the financial system, including climate change-related financial disclosure and banking regulations (particularly around lending).
Mobilise climate finance for adaptation.
Build the resilience of New Zealand's SMEs.</td></tr>
<tr><td>Research priority</td><td colspan="2">50</td><td colspan="4">Develop better understanding of the potential disruption over time resulting from shocks due to climate change impacts, and identify and implement mechanisms to reduce the disruption.</td></tr>
<tr><td>Sustain current action</td><td colspan="2">10</td><td colspan="4">The Reserve Bank has research programmes and a climate change strategy, and the Council of Financial Regulators has recently established a climate work stream, which are good foundations to build on.
Existing monetary policy mechanisms have some capacity to manage shocks.</td></tr>
<tr><td>Watching brief</td><td colspan="2">0</td><td colspan="4"></td></tr>
<tr><td>Adaptation urgency</td><td colspan="2">83</td><td>Confidence</td><td colspan="3">High agreement, medium evidence</td></tr>
<tr><td>Consequence</td><td>Now</td><td>Minor</td><td>2050</td><td>Moderate</td><td>2100</td><td>Major</td></tr>
</table>

5.4.3 E3 Risks to land-based primary sector productivity and output due to changing precipitation and water availability, temperature, seasonality, climate extremes and the distribution of invasive species

Risk summary

The primary sector faces risks from both extreme events and ongoing, gradual changes. Climate change will directly impact the quality and quantity of output across many areas, including horticulture (Cradock-Henry, 2017), viticulture (Sturman et al, 2017), and agriculture and forestry (Ausseil et al, 2019; Lake et al, nd; Wakelin et al, 2018). Changes in temperature and seasonality influence maturation (Salinger et al, 2019), length of growing season and the quality (size, shape, taste) of horticulture products (Cradock-Henry, 2017; Salinger, 1987), the distribution of pests and diseases (Wakelin et al, 2018; Watt et al, 2019) and the efficacy of some pest control agents (Gerard et al, 2013). The amount of land suitable for primary industries will decrease as sea levels rise, low-lying coastal areas become inundated, and groundwater is salinised (Lake et al, nd).

The impacts of climate change will increase over time and be greater under RCP8.5 than RCP4.5. Some of these impacts are already being felt by the sector – for example, pressure on the availability of water (Frame et al, 2020).

Exposure

The primary sector is highly exposed to climate change, as most activities depend on climate conditions. Many agricultural, horticultural and forestry varieties grow in narrow climate ranges, and current production distribution reflects historical climate suitability. The magnitude of the primary sector's exposure to climate change is affected by two main processes: the changing climate and associated hazards; and the changes made in the primary sector for non-climatic reasons that may increase or decrease its exposure to climate hazards.

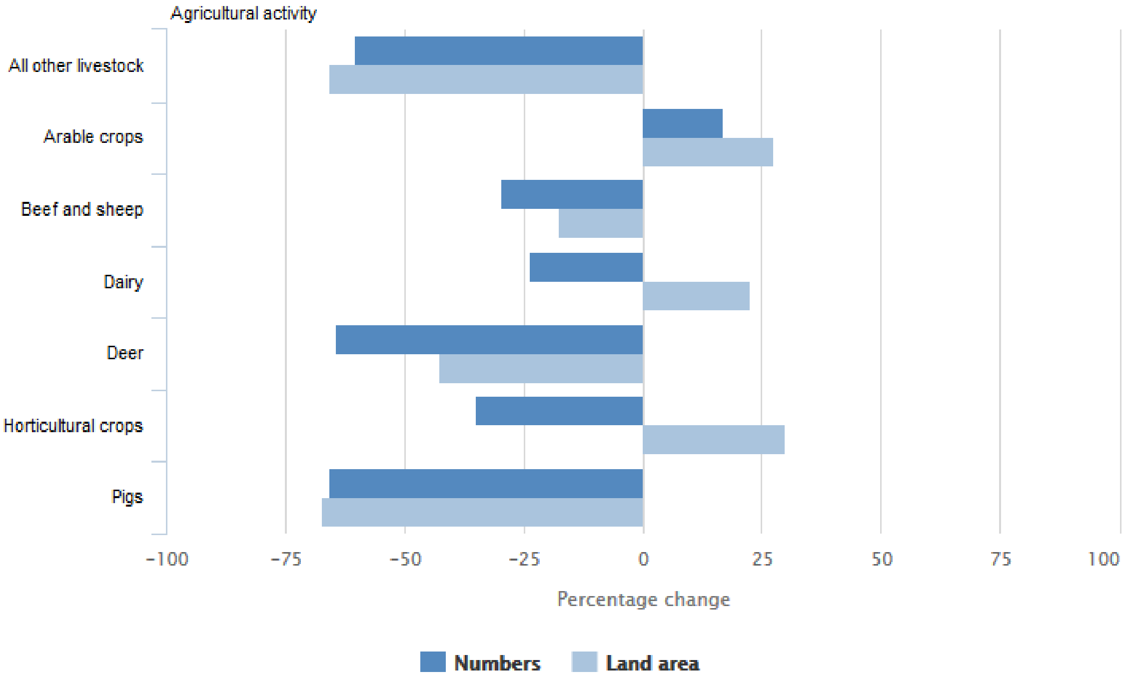
Areas of New Zealand that have historically been suitable for certain types of production may become less suitable over this century (Ausseil et al, 2019). The mean air temperature in New Zealand has increased by 1 degree Celsius since 1909 and is projected to increase by a further 0.8 to 1.1 degrees by 2050 under RCP8.5. This may have spatial implications for growing seasons and harvesting, shifting the locality of certain crops (Salinger, 1987). Fewer frost days can also lead to pest outbreaks (Gerard et al, 2013). Changes in seasonality, trending towards longer summers and shorter winters, will aggravate this.

Precipitation is another key factor for primary production. Under warming of about 2 degrees Celsius from pre-industrial temperatures, a 1-in-20-year drought could occur at least twice as often in eastern parts of New Zealand (New Zealand Climate Change Centre, 2010). Annual precipitation is projected to increase in the west and south of New Zealand and decrease in the north and east by 2050 under RCP8.5 (Ministry for the Environment, 2018). In 2100 under both RCP4.5 and RCP8.5, the largest changes in rainfall will be spatially and seasonally specific. Intense rainfall events can contribute to erosion and the loss of topsoil, so pose an irreversible risk to productivity. Sea-level rise is projected to be 0.79 metres under RCP8.5 by 2100, and coastal flooding exposes low-lying primary sector land to salinisation and inundation (Ministry for the Environment, 2017b).

As well as changes to mean climate variables, which put ongoing stress on primary sector industries, climate extremes can cause significant short-term disruption to production. In 1998, Cyclone Bola resulted in farming and horticulture losses equivalent to $170 million (Ministry for the Environment and Stats NZ, 2018).

Land-use decisions in the primary sector are based on many factors (Journeaux et al, 2017), and the composition of the sector is relatively dynamic. Between 2002 and 2016, for example, the dairying area has increased by 22.6 per cent and the area used for horticultural crops by almost 30 per cent (Stats NZ, 2018). Figure 17 shows the area changes for different land uses between 2002 and 2016.

Figure 17: Change in farm numbers and area between 2002 and 2016 (Stats NZ, 2018)



Climate change is also likely to increase the distribution of pests and diseases in New Zealand (Wakelin et al, 2018; Watt et al, 2019), posing risks to primary production. If New Zealand's pastoral sector becomes more reliant on importing feeds or seeds, then it is likely that it will become more exposed to novel pathogens and invasive species.

Sensitivity

Within the diverse and dynamic primary sector, areas differ significantly in their sensitivity. Horticulture, for example, is very sensitive to water availability at critical times of the growing season (B1), or to intense rain or hail. Pastoral systems are less sensitive to the timing of precipitation, but are sensitive to changes in precipitation (Ausseil et al, 2019) and temperature. In the arable sector, the sensitivity varies between locations and types of crops. Catch crops may be less sensitive due to their growth during late autumn and winter (Ausseil et al, 2019) when rainfall is usually higher, but changing seasonality may affect this. Like most of the primary sector, forestry is sensitive to pests and diseases (Watt et al, 2019), as well as windthrow and fire.

Sensitivity also varies with location (characteristics including soil type and topography) (Ausseil et al, 2019; Cradock-Henry, 2017) and the type of production in each sub-sector. For example, intensive livestock systems may be more susceptible to certain risks, including disease and heat stress, than more extensive systems (Ministry for the Environment and Stats NZ, 2018; Wreford and Topp, 2020). Māori-owned farms mostly engage in mixed sheep–beef farming and forestry (Ministry for the Environment and Stats NZ, 2018). While Māori farmers are likely to be affected in the same way as non-Māori farmers, Māori land can be more isolated from infrastructure, and concentrated in areas with less productive land types (Cottrell et al, 2004). Less productive areas such as Northland and the East Cape region may be affected by more drought and extreme weather events, disproportionately affecting the larger Māori populations who live there (Cottrell et al, 2004).

Higher temperatures can increase the severity and range of disease and pathogens, reduce the efficacy of biological control agents and reduce yields. Dairy cattle are also sensitive to changes in temperature, which can lead to heat stress, facial eczema, mycotoxins, flies, ultra-violet (UV) damage to udder and teats, and eye cancer (Verkerk et al, nd).

Current land-use practices may amplify and perpetuate the impacts of climate change. Changes in the extent and intensity of agricultural practices, for example, result in compaction of soil, decreasing soil productivity, restricting plant growth and impeding water drainage. Conversely, reforestation and efforts to limit erosion can reduce climate change impacts. Beyond climate change, primary land-based economic activities are exposed to risks posed by legislative changes, input and output prices, credit markets, land valuation and operating costs (Cradock-Henry, 2017).

Adaptive capacity

The primary sector in New Zealand as a whole has relatively high adaptive capacity, but this differs between individual farms, locations and sectors. The primary sector is dynamic, and adaptation may mean transformative shifts between production types and locations, so that in the longer term, the sector may look quite different from today (Cradock-Henry et al, 2020).

Primary sector industries are already adopting or considering adaptive measures such as water storage to improve reliability of supply and allow more efficient use, management of soil fertility and grazing, pasture diversity and infrastructure that will withstand climate extremes (New Zealand Climate Change Centre, 2010). Given the autonomous nature of adaptation in this sector, collective adaptation opportunities could be missed (G1). As identified earlier in this section, irrigation supports a range of intensive land uses, improves productivity and reduces risk to agricultural and horticultural activities from low or seasonal rainfall (Ministry for the Environment and Stats NZ, 2018). It also alters the landscape, increases nutrient runoff risk and removes water from groundwater and rivers (Ministry for the Environment and Stats NZ, 2018). Climate change will alter the timing, amount and distribution of the water consented (above environmental limits) and increase demand as temperature and evapotranspiration rise. With changes in future water availability, conflicts between water users are likely to increase, requiring effective governance to plan and manage water use and water supply systems for the full range of community and environmental needs.

Where successful adaptation relies on the individual farmer's capacity to apply new management strategies and be innovative and flexible, other socio-economic conditions and factors are also critical. Age, access to capital, social networks, access to technology, perceptions and attitude towards risk will all influence the sector's adaptive capacity (Cradock-Henry, 2017). Some sectors, including dairy, are also relatively path-dependent due to high levels of investment in infrastructure. These factors interact with adaptation timeframes, and whether farmers are likely to employ short-term reactive strategies or long-term proactive strategies.

Under future climate change scenarios, autonomously led adaptation may be insufficient and less efficient, requiring collective communication, engagement and education. Good governance and networks can also provide a platform for sharing information and experiences, providing a mechanism for moving beyond the existing barriers noted above (Wreford et al, 2017). Many individual or regional adaptations may also be limited by structural or institutional barriers, including access to processing facilities or markets, the provision of multi-use water infrastructure, and legislative barriers.

Consequence

The land-based primary sector contributed almost 4 per cent of New Zealand's GDP and just over half of the country's export earnings in 2016 (New Zealand Treasury, 2016). Māori GDP is still dominated by the primary sector, contributing $1.8 billion in 2013 (Ministry for the Environment and Stats NZ, 2018). Climate change threatens the viability of parts of this industry, with major disruptions to production across the agricultural, horticultural and forestry sectors. Extreme weather events, such as flooding or wildfire, can cause extensive damage and disrupt market access (E7), while changing seasonality and climate suitability will require farmers to adopt new management practices. Consequences will vary across production type and region but, without effective adaptation, are likely to involve considerable disruption and economic losses. Interdependencies in the primary sector value chains increase the risks of adverse consequence.

The wider New Zealand economy has already experienced the effects of climate change. Drought costs attributable to anthropogenic influence on climate have been estimated at $720 million (Frame et al, 2020). A Reserve Bank study reports that the 2013 drought reduced GDP by 0.3 to 0.6 per cent, increased world dairy prices by 10 per cent, and lowered the exchange rate by 3 per cent (Kamber et al, 2013). In a future where droughts are more frequent and intense, and combined with interacting hazards, these costs will become more significant.

A changed climate may increase the geographic ranges of pests and weeds already established in New Zealand, and make the environment more suitable for incursions of organisms not currently present. Nimmo-Bell (2009) estimated that plant and animal pests cost New Zealand's primary industries over $2.5 billion per annum in productivity losses and pest management activities. As an example to illustrate the costs involved, invertebrate pests are estimated to cost the pastoral sector between $1.7 and $2.3 billion each year currently (Ferguson et al, 2019) and climate change is likely to increase this. Climate change may also impact the ecology of existing biological control agents used to supress pests and weeds in New Zealand, reducing their efficacy and contributing to loss of production.

Changes in weather systems, including temperature conditions and water availability, will affect plant growth and have implications for yields in primary productivity such as pastures and horticulture (Ministry for the Environment and Stats NZ, 2018). Productivity may be further undermined by erosion and the attendant loss of soil. For example, the rapid erosion of low hill country after a drought or fire, followed by extreme rainfall, could permanently impact the landscape's ability to support primary industries.

The Māori economy is focused on primary production industries, such as dairy, horticulture (especially kiwifruit) and forestry. Reduced production and profitability would have a significant impact on economic return to Māori landowners and Māori working in those businesses.

In addition, the risks to forests from climate change (Watt et al, 2019) may directly undermine New Zealand's ability to meet its international emissions reduction obligations under the Paris Agreement, as well as its domestic targets under the Climate Change Response (Zero Carbon) Amendment Act 2019.

Interacting risks

Land-based primary sector output and productivity depends on the natural environment and is exposed to the risk of increased exotic or invasive species (N2). The changing dynamics of the agriculture industry and the many stressors are likely to pose a risk to mental health, identity, autonomy and sense of belonging (H7) and to worsen inequities (H2). Conflict over resource access such as water may lead to disruption and a loss of trust in government (H4). Future disruptions to the electricity system (B8), water security (B1) and transport networks (B6) expose land-based sector productivity to supply chain disruption (E7), compounding economic risks. Efforts to reduce these risks will support access to markets and processing facilities.

Confidence: High agreement, medium evidence

There is a high level of agreement that climate variability – including increasing temperatures, changes in precipitation patterns, changing seasonality, extreme weather events, drought, changing pests and diseases and ongoing sea-level rise – will expose the land-based primary sector to economic risk. Further research is needed to identify barriers and dependencies (across scales and sectors), and the timing of impacts. There are gaps in understanding of how extreme event frequency could affect system productivity and how climate risk interacts with other drivers; economic analysis of impact costs, and the costs and benefits of adaptation, is also limited. The largest gaps in evidence, however, relate to adaptation implementation (Cradock-Henry et al, 2019).

Adaptation

The land-based primary sector is currently involved in many diverse adaptation efforts. These include:

- legislative reform such as the Biosecurity Act Review
- research such as the Sustainable Land Management and Climate Change (SLMACC), Deep South research programmes and other research by industry bodies such as DairyNZ
- the development of tools such as the five-step Adaptation Toolbox, and sector-specific tools such as for the kiwifruit industry
- support for Māori agribusinesses through Te Puni Kōkiri.

Investment continues in the development of breeds and species that are more resilient to the impacts and implications of climate change. Agreements such as *He Waka Eke Noa* (New Zealand Government, 2019) also support adaptation efforts. Evidence indicates some farmers and growers are proactively adapting to climate change; however, such actions are not universal and, in the absence of coordination, autonomous adaptation could be maladaptive.

Table 48: E3 Risks to land-based primary sector productivity and output due to changing precipitation and water availability, temperature, seasonality, climate extremes and the distribution of invasive species: Urgency profile

E3 Risks to land-based primary sector productivity and output due to changing precipitation and water availability, temperature, seasonality, climate extremes and the distribution of invasive species: Urgency profile		
Urgency category	**Proportion of urgency**	**Description of actions**
More action needed	50	Although some autonomous individual or sector action is occurring, there is a need for greater Government action to ensure individual short-term actions are not maladaptive. Government also has a role in removing structural or institutional barriers to adaptation, providing knowledge and supporting adaptation with public good outcomes.
Research priority	25	Risks are relatively well understood, but additional research is needed into invasive species, social barriers to adaptation, and the interaction of climate risk with other drivers.

Sustain current action	25		Some degree of individual and sectoral adaptation, but hindered by a range of barriers.			
Watching brief	0					
Adaptation urgency	81		**Confidence**	High agreement, medium evidence		
Consequence	Now	Minor	2050	Moderate	2100	Major

5.4.4 E4 Risks to tourism from changes to landscapes and ecosystems and impacts on lifeline infrastructure due to extreme weather events and ongoing, gradual changes

Risk summary

Natural environments have supported New Zealand's tourism industry but these environments, and the infrastructure that allows us to access and enjoy them, are at risk from climate change hazards. Changes to the number of snow days and peak snow elevation may impact skiing and snow activities (Hopkins, 2013), and, along with warmer temperatures, may result in glacier retreat (Espiner and Becken, 2014). Ongoing sea-level rise and other climate hazards may cause damage to infrastructure including rail, roads and airports that provide accessibility for tourism (Paulik et al, 2019b). Furthermore, an increase in sea level can alter coastal ecosystems that attract visitors. Because many tourist activities are affected by weather, climate change that exacerbates precipitation, wind and other extreme weather events has the potential for negative impact. An interplay of climate factors that degrade wildlife ecosystems may disrupt tourism ventures that centre on wildlife activities such as birdwatching tours (Kutzner, 2019). Changes in climate pose a risk to present-day tourism activities such as skiing and snow activities, and access to iconic destinations. The risk to the tourism industry is expected to intensify over time in the projected climate scenarios.

Exposure

Natural attractions in New Zealand are central to the tourism sector (Orchiston and Espiner, 2017). As a result, the tourism sector is exposed to a range of extreme events[9] as well as ongoing, gradual changes, particularly related to changes in natural snow coverage (Hopkins, 2013), extreme weather events and sea-level rise, as described in more detail below (see also section 2).

- Snow: Projected changes under RCP8.5 indicate that by 2090, snow days per year are expected to reduce by 30 days or more, with the largest reductions in the South Island high country (higher altitudes) and inland basins (Ministry for the Environment, 2018). Although not analysed for an RCP8.5 pathway, snow duration is negatively correlated with elevation for RCP4.5, where a decrease in snow duration and peak snow elevation is anticipated. This could negatively impact the ski industry, particularly for ski fields at lower elevations, such as Queenstown (Hopkins, 2013).
- Extreme weather events: An increase in extreme wind in the South Island and in the southern half of the North Island is projected for both 2050 and 2100 under RCP8.5. An increase in rainfall is projected for all zones, but is greatest for zones 1, 3 and 6. In addition, the intensity of tropical cyclones is projected to increase, as well as extreme rainfall events in zones 1–4 (Pearce et al, 2018). In December 2019 slips and washouts to

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[9] This report was completed before the arrival of the COVID-19 pandemic in New Zealand, and the resulting impacts on the tourism sector.

road infrastructure due to heavy rainfall and extreme winds (B6) resulted in the isolation of every major settlement along the West Coast between Hokitika and Haast, reducing tourism to this region during peak tourist season.

- Sea-level rise: Under RCP8.5, by 2100 the greatest sea-level rise expected is 0.79 metres, which can result in salinisation of coastal wetlands and groundwater (Ministry for the Environment, 2017a) (N1). For all regions, exposure to extreme storm tides may also increase. Coastal flooding exposes key infrastructure such as rail, roads and airports to disruption (B6). Thirteen airports have been identified as exposed (B7), including Auckland and Wellington, which provide key international links for the tourism sector (Paulik et al, 2019b).

Sensitivity

Tourism activities related to natural attractions employ about 300,000 people directly and generate a direct contribution to GDP of 5.8 per cent and an additional 4.0 per cent coming through industries supporting tourism (Stats NZ, 2019b). These activities are sensitive to extreme weather events, such as intense snowfall, wind and rainfall. These extreme events can be problematic for transport accessibility, as well as resulting in activity cancellation, closure of walking and access tracks, and damage to infrastructure such as accommodation and the electricity grid (Espiner and Becken, 2014). Weather-related damage can pose a significant cost to tourism providers both directly and indirectly through, for example, insurance costs (Becken et al, 2010). The direct dependence on the environment, combined with the relationship of exposures, heightens the sensitivity of New Zealand’s tourism sector to climate change impacts.

Adaptive capacity

Tourism stakeholders have already begun to diversify tourism products and services to adapt to changes to the natural assets on which they depend. In the ‘Glacier Country’, this includes adding hot pools, several bush walks and a Kiwi house (Espiner and Becken, 2014). For tourism ventures, wildlife activity diversification is shifting the focus of tours and broadening the focus to a wider range of species (Kutzner, 2019). Diversification helps retain visitors in regions for longer, particularly during extreme weather events (Becken et al, 2010). Already, however, maladaptive responses are emerging, such as offering scenic flights to view retreating glaciers that are no longer accessible on foot.

There are many tourism stakeholders, so networks and cross-communication are fundamental to enhance adaptive capacity (Kutzner, 2019). The small but cohesive character of local communities, and the relationships between key stakeholders, are likely to strengthen adaptive capacity (Espiner and Becken, 2014). However, a framework is needed for a coordinated response, establishing a strategy and approach to adaptation, and working across sectors and levels of government. This is fundamental to closing existing network gaps (Kutzner, 2019). Adaptation responses still fundamentally rely on the environment (like snowmaking in the ski industry), and focus on incremental changes to existing systems rather than longer-term transformative changes. Despite inherent resilience in local communities, current levels of adaptation may not be enough for the impacts of climatic hazards.

Consequence

Climate change is expected to have negative implications for tourism and recreation, particularly operations that depend on natural assets. As described above, reductions in snowfall or the ability to operate snowmaking equipment could reduce the net number of days suitable for skiing. Coastal erosion and ongoing sea-level rise could impact the viability of some coastal tourism, and extreme events could increase the risk of damage to important tourism infrastructure such as huts and tracks, as well as isolating key tourist destinations through disruptions to roads (B6). Changes to natural ecosystems such as the extinction of species may impact wildlife tourism ventures (see section 3 on the natural environment domain). The effects of climate change are already being realised in the tourism industry, although direct correlation is not always acknowledged (Hopkins, 2013).

The cost to tourism of climate change impacts is likely to be high. It is estimated that billions of dollars of assets will be affected by ongoing sea-level rise, while the cost of extreme weather events to the land transport network alone in the past 10 years has increased from $20 million to $90 million per year (Ministry for the Environment, 2017c). These costs may be compounded by the impacts on tourism that relies on the transport network and infrastructure assets, highlighting the interdependencies across domains. It is likely that with an increase in frequency and intensity of extreme weather events, cumulative costs will increase, challenging coping capacity.

Interacting risks

Tourism is highly susceptible to feedbacks and changes in natural, social and economic systems. Changes to the natural environments, such as coastal ecosystems (N1), species (N2), migratory, coastal and riverbed nesting birds (N5) and lake ecosystems (N6), may impact on tourism industries. Recreational use of sub-alpine ecosystems is also likely to be negatively impacted by increasing temperatures (N9). Loss of, or damage to, cultural heritage (H8) could have adverse consequences for the tourism sector.

Impacts on airports (B7) and linear transport networks (B6) will hinder the movement of people, with adverse consequences for the tourism industry.

Confidence: High agreement, medium evidence

There is overall a high level of agreement that climate change hazards such as extreme weather events, rising sea levels and changes in natural snow will expose the tourism sector to economic risk. While there is agreement that a changing climate is having an impact on the products and services provided by the tourism sector, an evidence gap remains in understanding the economic resilience of the tourism sector. Further research is needed to understand the future vulnerability of the sector to climate change impacts, and ensure that adaptation, not maladaptation, occurs.

Adaptation

Various levels of government and many departments, including the Department of Conservation (DOC), the Ministry of Business, Innovation and Employment (MBIE) and other bodies such as Tourism New Zealand, are taking steps to reduce this risk. This work includes the DOC climate change adaptation action plan, and MBIE and Tourism New Zealand research into tourism demand. At the local government level, policies, plans and tourism strategies, although not necessarily focused on climate change, will have co-benefits in addressing this risk. Evidence indicates autonomous adaptation is under way, such as ski fields diversifying into mountain biking.

Table 49: E4 Risks to tourism from changes to landscapes and ecosystems and impacts on lifeline infrastructure: Urgency profile

<table>
<tr><th colspan="7">E4 Risks to tourism from changes to landscapes and ecosystems and impacts on lifeline infrastructure: Urgency profile</th></tr>
<tr><th>Urgency category</th><th colspan="2">Proportion of urgency</th><th colspan="4">Description of actions</th></tr>
<tr><td>More action needed</td><td colspan="2">40</td><td colspan="4">Clear direction from Government for long-term plans for tourism under climate change (integrate climate change risk into tourism strategy). Action at Government level to ensure autonomous individual action by tourism actors is not maladaptive.</td></tr>
<tr><td>Research priority</td><td colspan="2">40</td><td colspan="4">Understanding of how key tourist regions will be affected by climate risks; develop plans to adapt to the risk.</td></tr>
<tr><td>Sustain current action</td><td colspan="2">20</td><td colspan="4">Risks will be further reduced as risks to the built environment domain (lifelines infrastructure) and the natural environment domain are reduced.</td></tr>
<tr><td>Watching brief</td><td colspan="2">0</td><td colspan="4"></td></tr>
<tr><td>Adaptation urgency</td><td colspan="2">80</td><td>Confidence</td><td colspan="3">High agreement, medium evidence</td></tr>
<tr><td>Consequence</td><td>Now</td><td>Minor</td><td>2050</td><td>Moderate</td><td>2100</td><td>Major</td></tr>
</table>

5.4.5 E5 Risks to fisheries from changes in the characteristics, productivity and spatial distribution of fish stocks due to changes in ocean temperature and acidification

Risk summary

Primary production in coastal waters may be vulnerable to climate change-driven ocean warming, acidification and sedimentation (Royal Society | Te Apārangi, 2016). Fish physiology is directly linked to temperature, so increasing sea surface temperatures under both RCP4.5 and RCP8.5 may alter growth, metabolism, reproductive success and food consumption (Ficke et al, 2007). This is most likely to occur at a species level, disrupting and creating additional pressures for aquatic communities (Ficke et al, 2007). Increasing ocean acidification also may have a negative impact on carbonate-forming species, including molluscs such as pāua, cockles and flat oysters that provide significant economic value (Law et al, 2017a; Rouse et al, 2017), although the evidence on this is mixed (Cornwall and Hurd, 2016; Cross et al, 2016). Ongoing sea-level rise and ocean acidification will continue to increase gradually under both RCPs. The transmission of some diseases is temperature dependent, increasing in prevalence at higher temperatures and with a faster transmission rate (Sweet et al, 2016). Other stressors from human activity such as disturbance of habitat associated with commercial fishing and over-exploitation can have significant impacts on productivity (Parsons et al, 2014).

Exposure

Commercial fisheries are reliant on the productivity and spatial distribution of fish species and ecosystems, leaving them exposed to changes in fish stock abundance, composition and behaviour. Changes in ocean temperature and ocean acidification will affect habitat, species growth and reproduction rates, impacting abundance, composition and behaviour.

Under RCP8.5 the mean sea surface temperature is projected to increase by 1 degree Celsius by 2040 and 2.5 degrees by 2090 (Climate Change Adaptation Technical Working Group, 2017). The Tasman Sea is projected to experience the largest temperature change, with an expected warming exceeding 3.1 degrees by 2100; the southern waters will experience the lowest warming (Law et al, 2017b). Marine heatwaves are already exacerbating changes, and sea surface temperature was up to 6 degrees above average in 2016/17 in some areas (Salinger 2019; Sutton and Bowen, 2019).

Changes in habitat will lead to a change in the distribution of species, and this has already been observed in New Zealand's marine systems (Law et al, 2017b). The reproductive success, growth and survival of fish species will depend on its thermal tolerance and ability to adapt, but is likely to result in geographic shifts of ecosystems, and an increasing dominance of warm-water species (Ficke et al, 2007; Law et al, 2017b).

The effects of ocean acidification on primary productivity, nutrient availability and chlorophyll, as well as on fish behaviour and calcifying species, are uncertain. Evidence is mixed, and varies between species (Avignon et al, 2020; Chan et al, 2016; Cross et al, 2016; Hildebrandt et al, 2016; Law et al, 2017a; Long et al, 2017; Parsons et al, 2014). Projections indicate that surface pH will continue a gradual decline across New Zealand's marine environment under RCP8.5 (Law et al, 2017a).

Sensitivity

The vulnerability of fisheries, and of the ecosystems that support them, will be determined by their tolerance to changes in sea surface temperatures and ocean acidification. How increasing temperatures impact on growth, metabolism and reproductive success will depend on the thermal tolerance of individual species, so it is difficult to determine just how vulnerable New Zealand fisheries are. Recruitment, which involves the process of adding individuals to a population based on either their birth or their maturation, is correlated with sea surface temperature for several New Zealand fish species, including gemfish, southern blue whiting and snapper (Beentjes and Renwick, 2001). Increases in sea surface temperature are likely to result in spatial changes for these species; fish populations that are particularly sensitive to an increase may become less abundant, change location or experience range contractions (Ficke et al, 2007). New Zealand's crustacean species, and any other species with carbonate shells, may also be sensitive to ocean acidification because their shell composition is the most vulnerable to dissolution under lower pH conditions (Law et al, 2017a).

Fisheries are also sensitive to the indirect effects of climate change such as availability of food and habitat (Dunn et al, 2009). For example, a decline in phytoplankton due to increasing temperatures beyond optimum temperature thresholds can result in a decrease in fisheries productivity (Ficke et al, 2007; Thomas et al, 2012). Climate change effects may also be more pronounced for short-lived species and those approaching the limits of their thermal and acidity ranges in New Zealand waters (Dunn et al, 2009). Furthermore, fish populations that provide recreational value in geographically isolated systems such as lakes and springs are highly sensitive to changes in climate, as they are limited by physical barriers to migration (Ficke et al, 2007).

Adaptive capacity

Adaptive capacity at the individual level and the ability of the industry to modify its practices and investments in part depend on governance frameworks and regulation (Royal Society | Te Apārangi, 2016). The quota management system (QMS) provides the framework for maintaining fisheries at a sustainable level within the exclusive economic zone (EEZ) and territorial sea, and New Zealand's fisheries management system allows for flexibility in responding to the changes. Good governance will be central for building adaptive capacity and developing clear adaptation plans and may mitigate potential maladaptive pathways.

Awareness of the effects of climate change is critical to adaptive capacity and is evident in New Zealand, as demonstrated by new research programmes, monitoring and workshops being held to learn from international experiences (Pinkerton, 2017). However, the industry's response to climate change and its ability to plan may be affected by the:

> "many interacting factors that affect fishery performance, including overfishing, management-driven change, market demands (size, season), natural fluctuations in population dynamics, inter-annual variation in biophysical environment, interactions with other species, habitat loss and finally climate change." (Pecl et al, 2019, p 1503)

Consequence

Commercial fisheries contribute about 0.7 per cent to New Zealand's GDP, produce the fifth-largest export commodity by value, and are responsible for 0.7 per cent of New Zealand employment (Williams et al, 2017).

By 2100, net primary productivity is projected to decline by 1.2 per cent under RCP4.5 and by 4.5 per cent under RCP8.5 (Tait et al, 2016). Ocean warming will affect fish stock productivity and species distribution, impacting on fish stock abundance in New Zealand's EEZ.

The effect of ocean acidification on finfish species is unconfirmed, but could be significant. Two examples of species at risk from ocean acidification include the snapper and the green-lipped mussel. The snapper has been a food source for Māori, provides significant value to commercial fisheries and is highly sought-after among recreational fishers (Parsons et al, 2014). Increased acidity has been demonstrated to alter behaviour of larval fish and decrease survival, reducing future recruitment (Parsons et al, 2014). The green-lipped mussel, which is a significant export, is also highly sensitive to increasing acidification due to its shell composition (Law et al, 2017a). The decline of these and other species would have a negative effect on the economy and the marine ecosystem.

Māori ownership, management and use of commercial and non-commercial fisheries in New Zealand is significant, accounting for almost 50 per cent of the national fisheries quota. Reductions in revenue from quota leasing would decrease the ability of Māori to fund social and cultural development initiatives.

Interacting risks

Dependence on the natural environment as an economic resource exposes commercial fisheries to several other risks. This includes risks to marine ecosystems (N7) and coastal ecosystems and their productivity (N1, N8), as well as to carbonate-based hard-shelled species (N10) that contribute to the economy and are important for ecosystem resilience.

Governance also poses a risk where uptake of decision support tools is insufficient (G1), uncoordinated actions occur that can result in maladaptation (G1) and knowledge to inform adaptation pathways is inadequate (G5). Disruptions to the electricity system (B8) and transport networks (B6) due to extreme weather events and sea-level rise also expose the industry to supply chain disruption (E7) and compounding economic risks.

Given that Māori have ownership of almost 50 per cent of the fisheries quota, and given the cultural significance of the marine ecosystem, impacts on fisheries will affect Māori social, economic, cultural capital and spiritual wellbeing (H6). There is also potential for conflict, disruption and loss of trust in government where access to and availability of resources change (H4).

Confidence: High agreement, limited evidence

There is an overall high level of agreement that climate-driven changes such as ocean acidification and increased sea surface temperatures will expose fisheries to economic risk. While there is agreement that fisheries are vulnerable to a changing climate, gaps in research remain, especially around the vulnerability of whole ecosystems and species in particular taxa.

Table 50: E5 Risks to fisheries from changes in the characteristics, productivity and spatial distribution of fish stocks: Urgency profile

<table>
<tr><th colspan="7">E5 Risks to fisheries from changes in the characteristics, productivity and spatial distribution of fish stocks: Urgency profile</th></tr>
<tr><th>Urgency category</th><th colspan="2">Proportion of urgency</th><th colspan="4">Description of actions</th></tr>
<tr><td>More action needed</td><td colspan="2">40</td><td colspan="4">Assessment and potential development of adaptive mechanisms in the QMS in response to the dynamic nature of fish stocks under climate change; action to ensure that autonomous action by commercial fisheries is not maladaptive.</td></tr>
<tr><td>Research priority</td><td colspan="2">40</td><td colspan="4">Understanding and supporting Māori wellbeing; the effect of ocean acidification on productivity; the way fish stocks may change in future; and potential mechanisms to ensure the fisheries management system is fit for purpose into the future.</td></tr>
<tr><td>Sustain current action</td><td colspan="2">20</td><td colspan="4">Some autonomous adaptation by commercial fisheries (see above to avoid maladaptation); continue current fisheries and marine reform programmes.</td></tr>
<tr><td>Watching brief</td><td colspan="2"></td><td colspan="4"></td></tr>
<tr><td>Adaptation urgency</td><td colspan="2">80</td><td>Confidence</td><td colspan="3">High agreement, limited evidence</td></tr>
<tr><td>Consequence</td><td>Now</td><td>Minor</td><td>2050</td><td>Moderate</td><td>2100</td><td>Major</td></tr>
</table>

5.4.6 E6: Risks to the insurability of assets due to ongoing sea-level rise and extreme weather events

Risk summary

Projected changes in the frequency and intensity of the acute hazards people and organisations insure against, such as flood, fire, storm-surge, landslide, hailstorm and tsunami, are causing the insurance industry to change premiums, develop new insurance offerings and adjust availability. These changes are likely to affect many insurance markets; most significantly, the home insurance market. Changes to insurance offerings could result in additional hardship following extreme events and have significant flow-on effects for New Zealand society including loss of peace of mind, displacement of communities, changes in business investment and household consumption, fiscal risks to the Government, and financial system instability.

Exposure

Mainstream insurers increasingly see climate change as a material risk to their business. Through their pricing and terms and conditions, they play a key role in communicating and raising awareness about climate change risks and help society spread the cost of losses; however, they cannot be expected to insure all risks (Mills, 2009). The insurance sector is intrinsically vulnerable to climate change; when a risk becomes uneconomic or sufficiently probable, as in the case of coastal, flood and fire risks, the insurer can decide that an area is ‘uninsurable’ and withdraw insurance altogether (Storey et al, 2015).

Insurers may retreat from an area of New Zealand following a climate event, either in that location or in another New Zealand location. Because most of New Zealand’s insurance providers are international, retreat may also be hastened by another country’s experiences, which convince them that risk profiles have changed because of sea-level rise or other climatic changes (Storey et al, 2015).

Climate hazards such as drought, fire, flooding and ongoing sea-level rise have the potential to expose asset holders to insurance withdrawal. Most of New Zealand is projected to experience an increase of more than 150 per cent in very high or extreme fire days by 2100 under RCP8.5 (Ministry for the Environment, 2018). This increase may change insurance costs for assets located in rural areas or in the rural–urban interface, which are relatively more exposed to fire risk (Australian Financial Review, 2020; Shrimali, 2019). Much of New Zealand’s population lives in coastal areas, as reflected in a coastal bias in claims under the Earthquake Commission (Fleming et al, nd). Analysis indicates that the Northland, Bay of Plenty, Nelson and Tasman regions have the highest proportions of people and properties affected by extreme weather, and that, as well as coastal bias, properties on steeper land are more likely to be associated with landslip, flood and storm claims than properties on flatter land (Fleming et al, nd).

Urban sprawl and population growth in areas of high exposure, such as along the coast, on floodplains and on the fringes of forestland, expose many more people and assets to climate change risks. The exposure of asset holders to this risk is greater under RCP8.5 than RCP4.5, and is likely to increase over the century.

Sensitivity

Some asset classes and population groups are more sensitive to insurance sector responses to climate change. Long-lived assets in areas of known exposure will be highly sensitive, as they will continue to be exposed to repeated events over the asset’s useful life and unable to use insurance to help recover following events. Owners and managers of heritage sites are also likely to be sensitive to insurance sector responses, which will compound challenges with securing insurance they already face.

Profitable businesses and wealthy asset owners will be able to absorb higher insurance premiums, but lower-income asset owners and small businesses will be sensitive to changes in these premiums.

Adaptive capacity

Changes to market signals through insurance costs may encourage autonomous adaptation, and households and businesses may change behaviour in response. Businesses, for example, may choose to mitigate risks on site through elevating buildings or moving assets to lower risk locations; but such actions may be unaffordable for smaller businesses. Some households may be able to relocate to a less risky zone, but others be unable to move for diverse reasons (see, for example, Māori concerns related to place-based attachment and identity (H5) in section 4.4.5). These households may be unable to secure adequate insurance for their properties. Property developers and existing homeowners may also seek to block information about risk being shared with potential homebuyers, locking in future exposure.

The current flat-rate Earthquake Commission premium nationwide helps spread the risk of more hazardous locations across all policyholders, supporting insurance penetration and affordability. However, it mutes the price signal, which can be an effective motivator of autonomous adaptation (Storey et al, 2015).

As climate projections become more granular, insurers will be able to price insurance at a finer scale (recognising that greater granularity does not decrease uncertainty). This may minimise the risk of broad swathes of communities being priced in the same way, or support development of new insurance products. It is unlikely that new entrants will come into the insurance market, as the highly detailed information needed to accurately price risk acts as a barrier to entry, particularly in small markets (White, 2011).

Reducing this risk is critically dependent on governance arrangements, such as tools that support decision-making under uncertainty (G1), coordination among decision-makers (G1) and the ability for the central government to compensate property owners who are forced to relocate (G2). Alternative structures, such as multi-sector partnerships between the public, private and civic sectors, are increasingly seen as critical initiatives to improve risk management (Crick et al, 2018). An example in practice is the United Kingdom's Flood Re scheme, between the government and private insurers, which aims to make flood cover more available and affordable (Flood Re, 2020).

Consequence

Insurance is a risk transfer tool used to improve adverse financial consequences that follow on from unlikely disasters. If an insurer retreats from an area where assets and asset owners are still exposed to the risk, recovery will be delayed and hugely costly for asset owners. The reduced insurance coverage could in turn reduce asset values in affected areas (and potentially also unaffected areas that face similar risks), which could tighten the borrowing constraints of households and corporates. Even if losses are largely insured and financing for reconstruction is immediately available, a severe weather-related catastrophe could affect the banking sector and the real economy (flow of goods and services) in the medium term (Batten et al, 2016).

Insurance contracts are generally renewed on an annual basis. Because insurance is a requirement for residential mortgages in New Zealand, and failing to maintain insurance can trigger default, insurance withdrawal could cause home loan defaults because of the maturity mismatches between residential insurance and mortgages. Lenders may be left in technical default, experience material losses, or change behaviour to require more equity and higher interest rates for properties at risk of insurance retreat (Lawrence et al, 2016).
Local authorities and their insurers could find themselves holding unexpected liabilities if future courts rule that councils are liable for resource consents provided to homes threatened by climate change.

Interacting risks

Very human risks relate to insurance retreat. Insurance contributes to peace of mind and plays a key role in helping policyholders recover from losses (Mills, 2005). Loss of insurance could therefore impact on mental health and wellbeing (H7). Even for those who are insured, the processes following an event, such as managing insurance claims, can be a further source of trauma (Ohl and Tapsell, 2000; Thrush et al, 2005). If loss of insurance does not allow the policyholder to recover following a hazard event or encourages them to move away from the area prior to an event, many people will have the negative experiences associated with loss of place and community cohesion (H1). Unavailability or unaffordability of insurance cover will reshape the distribution of vulnerable groups, exacerbating existing inequities or creating new ones (H2).

Confidence: High agreement, low evidence

There is a high degree of agreement that climate change will change asset insurability. Target research on asset insurability in New Zealand has been limited, although the international body of literature and attention to the topic are growing.

Adaptation

A number of adaptation efforts are under way or planned. These are currently directed at increasing knowledge about this risk. In particular, research is directed towards determining liability for costs in the instance of insurance retreat. Efforts to reduce the risk, through land-use planning that accounts for dynamism and sea-level rise, are being made in some regions of New Zealand. Some insurance providers, such as IAG, are also exploring risk-based pricing mechanisms.

Table 51: E6: Risks to the insurability of assets: Urgency profile

<table>
<tr><th colspan="7">E6: Risks to the insurability of assets: Urgency profile</th></tr>
<tr><th>Urgency category</th><th colspan="2">Proportion of urgency</th><th colspan="4">Description of actions</th></tr>
<tr><td>More action needed</td><td colspan="2">40</td><td colspan="4">Improve the policy guidance and clarity around the Earthquake Commission and climate change risks. Incorporate increasing climate risk in land-use planning. Work on increasing public awareness of the issues and support private adaptation.
Investigate options and develop national plans, including alternative mechanisms and partnerships, to support asset owners in the case of insurance retreat.</td></tr>
<tr><td>Research priority</td><td colspan="2">40</td><td colspan="4">Better understanding of insurance retreat thresholds. Develop knowledge and processes on managing retreat on a large scale.</td></tr>
<tr><td>Sustain current action</td><td colspan="2">0</td><td colspan="4"></td></tr>
<tr><td>Watching brief</td><td colspan="2">20</td><td colspan="4">Monitor developments in insurance markets around the world.</td></tr>
<tr><td>Adaptation urgency</td><td colspan="2">75</td><td></td><td colspan="3">High agreement, low evidence</td></tr>
<tr><td>Consequence</td><td>Now</td><td>Insignificant</td><td>2050</td><td>Moderate</td><td>2100</td><td>Major</td></tr>
</table>

5.4.7 E7 Risks to businesses and public organisations from supply chain and distribution network disruptions due to extreme weather events and ongoing, gradual changes

Risk summary

Supply chains comprise local and global networks of infrastructure, people, information, materials and capital, so are subject to climate change-related disruption at a number of scales and in many geographies. Local, regional, national and international supply chains are likely to be adversely impacted by acute hazards such as flooding, fire or landslides, and gradual changes such as sea-level rise, changes in seasonality, drought and erosion. Adverse weather and transport network disruption (B6) are increasingly cited as reasons for supply chain disruption (Business Continuity Institute, 2019).

Due to its geographical separation from global markets, New Zealand is particularly prone to supply and distribution disruption (Basnet et al, 2006). Supply chain disruptions can lead to losses in productivity, share price movements, damage to brand and reputation, loss of customers and increased regulatory scrutiny. The sensitivity and vulnerability of supply chains are influenced by many factors, including the resilience of key physical infrastructures, industry profitability, the material characteristics of products, and regulatory frameworks. Because of this, their sensitivity and vulnerability differ between geographies, economic sectors and the actors in each sector. Supply chains are already vulnerable to climate change-related hazards, and exposure of supply chains to hazards is likely to be greater under RCP8.5 than RCP4.5, and to increase over time.

Exposure

The geographical reach and complexity of production and consumption systems create different degrees of exposure to climate change-related hazards occurring locally, regionally or internationally. Organisations with localised supply chains may be unaffected by events occurring in other regions, while other organisations are exposed to disruption from international events. For example, Woolworths, which operates Countdown supermarkets and is New Zealand’s largest private sector employer, has noted the “devastating effects” that climate change is having on farmers in New Zealand, and the disruption caused by the floods in Townsville in 2019 (Woolworths Group, 2019). Supply chains can therefore be considered highly exposed to climate change-related disruption, although exposure will differ on a case-by-case basis.

Supply chains for all sectors are likely to be affected; the mining sector, as one example, is vulnerable and exposed to changing precipitation patterns and water availability. Water scarcity may increase operational costs, reduce output or lead to increased competition for water between local communities and the operation’s sites (B1), while heavy rains over shorter periods could cause flooding of sites (B2). These same floods or flooding in a different area could affect transport infrastructures, delaying or increasing the costs of product delivery (B6).

New Zealand’s small pharmaceuticals sector may be affected by loss of biodiversity, an input to production, which is projected to decline in diversity and abundance as a result of long-term changes to climate (N7). Many other sectors, such as the industrial sector, are vulnerable to extreme weather events and rising sea levels, which could cause production facilities to shut down and increase the cost of raw materials (B2). Supply chains and distribution networks are already exposed to adverse weather. Exposure will increase under both RCP4.5 and RCP8.5.

Sensitivity

Trends in the global economy have increased the sensitivity of supply chains to climate change-related disruptions. For example, the centralisation of inventories over the past 40 years has increased the sensitivity of supply chains to extreme weather events in that location, such as flooding or storms (Dasaklis and Pappis, 2013). Supply chains have also, in general, become leaner, longer and more complex in response to technological change, globalisation and market competition, which can increase exposure and sensitivity to climate change hazards; although complexity can also enhance resilience (Lim-Camacho et al, 2017). The inventories that once buffered supply chain shocks have disappeared, making them more fragile and prone to disruption by acute events. Due to its geographic separation from global markets, New Zealand is particularly prone to supply and distribution disruption (Dasaklis and Pappis, 2013).

Many factors influence a sector or industry's sensitivity to supply chain disruption. These include industry profitability, access to alternative markets and suppliers, the material characteristics of products, and regulatory frameworks. A highly profitable industry is more likely to survive disruption, and alternative markets and suppliers can ensure that production processes can continue, and buyers can be reached. The case study below (box 7) highlights how alternative markets and material characteristics (in this instance, perishability) influence the sensitivity of a sector to supply chain disruption in a distant but important market.

Box 7: Supply chain disruption in the New Zealand agricultural sector

The COVID-19 pandemic demonstrates how events in other markets impact on New Zealand's agricultural sector. The following consequences are a result of the outbreak (New Zealand Herald, 2020) at the time of writing this report in March 2020.

- The impacts on dairy shipments to China from New Zealand are limited because most shipped exports (powders, infant milk formula) have a good shelf life and are sold for consumption at home, although disruption of logistics is a key risk. Cheese, while having a good shelf life, is mainly used in food service and so more exposed to any downturn in food service.
- Supply chain disruption has made distribution of red meat imports more difficult, decreasing China's short-term import demand. The trend for Chinese consumers to eat out less often is also expected to decrease demand for imported red meat.
- New Zealand exporters can redirect lamb exports into other markets where demand remains solid, although at a discounted price, which will put downward pressure on prices.
- More than 70 per cent of New Zealand mutton exports go to China. Other markets are limited, potentially creating a slowdown in mutton processing until supply chain distribution issues are resolved.
- Labour shortages due to travel restrictions and factory shutdowns are expected to reduce Chinese import demand for wool in the short term.
- The cherry industry had air-freighted most of its crop for the season to China before the virus hit. If it had not been fortunate enough to do so, the COVID-19 disruption would have had considerably worse impacts for the industry.

Adaptive capacity

The resilience of infrastructure networks, such as roads, rail, airports and ports, influence supply chain vulnerability. Complex supply chains that have a lot of nodes and links are more resilient to disruption (Lim-Camacho et al, 2017). It is possible for individual businesses and organisations to manage the risk of disruption to their supply chain through:

- design of new supply chain networks, which could consider facility location, product design, sourcing, transportation, and distribution and network configuration
- routing and scheduling programmes, inventory planning and control, material requirements planning, and production scheduling (Dasaklis and Pappis, 2013).

However, it is challenging for many businesses to build detailed information on how supply chains and distribution channels may be affected by climate change-related disruptions.

While empirical research on supply chain management in New Zealand is scarce, information sharing appears to be reactive rather than planned and is seen as an exchange of 'basic information' rather than an 'exchange of knowledge'. Developments are somewhat encouraging, with 88 per cent of respondents in a recent survey by Donovan et al (2017) stating that they regularly solve problems jointly with their suppliers. However, only 58 per cent of respondents include key suppliers in their strategic planning or goal-setting activities (Donovan et al, 2017). This suggests that while organisations set up contracts with their strategic partners, they do not integrate them into the organisation's strategic planning, nor do they include those partners in long-term planning. Research suggests that several factors influence information sharing in supply chains, including the:

- number of buyers requesting information
- commitment of buyers to use information in their future procurement decisions
- profitability of an industry
- existence of greenhouse gas emissions regulations (Jira and Toffel, 2013).

The degree to which climate change will exacerbate this risk depends on the magnitude of change, the effectiveness of adaptation actions taken by other businesses, and infrastructure networks' resilience to climate change (B1, B2, B6, B8).

Resilient infrastructure is crucial in enabling businesses to minimise climate change disruptions to their operations. Some organisations (generally larger businesses) have a higher capacity to understand and manage risks from climate change, such as through collaborating with their suppliers. The actions these organisations take can have positive wider effects, by building capacity and increasing the resilience of supply chain partners. Further research is needed to identify and assess climate change risks to key nodes in the supply and distribution network (G5), and additional funding is needed to future-proof existing infrastructure (G2).

Consequence

Supply chain disruptions can lead to losses in productivity, share price movements, damage to brand and reputation, loss of customers, and increased regulatory scrutiny. For businesses, these changes are likely to result in unfulfilled orders and breach of delivery contracts, in turn leading to loss of revenue and reputational damage. Climate change also adds uncertainty to supply chain networks, especially for globalised ones operating across continents. Supply chains are also likely to incur higher insurance costs due to their exposure to climate change.

Interacting risks

The impacts of supply chain disruption can flow through to other sectors, such as tourism (E4), where key transport networks on the West Coast are frequently disrupted, as well as the primary sector (E3) and fisheries (E5). Frequent supply chain disruptions could contribute to financial system instability (E2) and raise risks to the Government's fiscal position (E1).

Confidence: High agreement, medium evidence

While a large volume of international peer-reviewed evidence suggests that climate change has the potential to disrupt supply chains, New Zealand-specific research is very limited. The evidence that exists is generally theoretical, although many empirical studies have focused on supply chain disruption from non-climate change-related events.

Adaptation

Managing supply chain risks requires adaptation action by governments, which can address market failures, and by organisations and businesses, which have a strong internal incentive to manage this risk. The New Zealand Transport Agency has a number of actions in progress, including a resilience project to ensure the highway network can withstand disruption, and it is developing guidelines to assess coastal risks. The Ministry for Primary Industries is also working with the Rural Support Trust to support impacted rural communities. It is likely that major companies have their own supply chain risk management strategies; however, many private sector organisations have not yet considered changing climate change risk profiles.

Table 52: E7 Risks to businesses and public organisations from supply chain and distribution network disruptions: Urgency profile

<table>
<tr><th colspan="7">E7 Risks to businesses and public organisations from supply chain and distribution network disruptions: Urgency profile</th></tr>
<tr><td>Urgency category</td><td colspan="2">Proportion of urgency</td><td colspan="4">Description of actions</td></tr>
<tr><td>More action needed</td><td colspan="2">20</td><td colspan="4">Encourage market and supply chain diversification, particularly among SMEs. Efforts needed to reduce lifeline infrastructure risks.</td></tr>
<tr><td>Research priority</td><td colspan="2">40</td><td colspan="4">Build evidence base to identify critical nodes of potential disruption (internationally or nationally) for key sectors.
Develop greater understanding of managing risk through market and supply chain diversification.</td></tr>
<tr><td>Sustain current action</td><td colspan="2">30</td><td colspan="4">Large businesses are already acting to manage supply chains (clear incentive). Links to action in the built environment domain (section 6).</td></tr>
<tr><td>Watching brief</td><td colspan="2">10</td><td colspan="4">Monitor developments.</td></tr>
<tr><td>Adaptation urgency</td><td colspan="2">68</td><td>Confidence</td><td colspan="3">High agreement, medium evidence</td></tr>
<tr><td>Consequence</td><td>Now</td><td>Minor</td><td>2050</td><td>Moderate</td><td>2100</td><td>Major</td></tr>
</table>

5.4.8 EO1 Opportunities for increased productivity in some primary sectors due to warmer temperatures

Initial benefits to agriculture and forestry are predicted in the western and southern parts of New Zealand and in areas close to major rivers due to a longer growing season, less frost and increased rainfall. The following are some specific opportunities NIWA (2007) has identified.

- Kiwifruit: Warmer summer temperatures are likely to result in more areas of the South Island becoming suitable for kiwifruit cultivation, although this is likely to be offset by some existing areas becoming less productive.
- Apples: Apples are likely to flower and reach maturity earlier, with increased fruit size, especially after 2050.
- Grapes: Central Otago is currently the southern margin for cool-climate wine production in New Zealand. Wine grapes in this region will benefit greatly from warmer, drier conditions (Ministry for Primary Industries, 2018).
- Horticulture: In general, new species may become viable.
- Plantation forestry: Growth rates (mainly pine, *Pinus radiata*) are likely to increase in response to elevated carbon dioxide levels and wetter conditions in the south and west of New Zealand. Increasing temperatures can also stimulate decomposition of soil organic

matter and mineralise more nitrogen to further boost the nutritional status of trees (Watt et al, 2019). This may also have negative consequences, however, as fast-growing timber can have implications for strength.

- Pasture: Seasonal pasture growth may increase under some scenarios and in some areas. Seasonal average growth rates show consistent, large increases in winter and spring, as expected under warmer conditions and an extended growing season.
- Fisheries: An increase in primary productivity in shallower surface layers is likely in southern New Zealand waters.

Opportunities will depend on water availability, skills extension, adoption of new technologies, and biosecurity practices. Production yields may increase for certain species due to better growing environments. Higher average temperatures are associated with faster maturation, leading to an earlier harvest; higher carbon dioxide concentrations will also increase crop growth rates (Reisinger et al, 2010). However, these scenarios assume a system where nutrients and water supply are not limited, so do not consider complicating factors such as pests, extreme events and competition for dwindling resources (Wreford et al, 2010).

Increasing crop yields would involve an increased demand for water supply, creating a greater reliance on irrigation systems. A change in mean average temperature may also allow the range of existing species to extend, and the introduction of new types of crops. As noted for kiwifruit above, this expansion may be offset by some existing areas becoming less productive. There may also be an opportunity for diversification into new areas or species of mahinga kai (food provisioning). Further research is needed to better understand the relationships between temperature, water availability and carbon dioxide fertilisation.

Table 53: EO1 Opportunities for increased productivity in some primary sectors: Opportunity urgency profile

EO1 Opportunities for increased productivity in some primary sectors: Opportunity urgency profile			
Urgency category	**Proportion of urgency**	**Description of actions**	
More action needed	60	A regulatory framework and guidance will be required to ensure that autonomous adaptations are not maladaptive.	
Research priority	20	How to underpin private sector autonomous adaptation.	
Sustain current action			
Watching brief	20	Watch and monitor.	
Adaptation urgency	80	**Confidence**	Medium agreement, medium evidence

5.4.9 EO2 Opportunity for businesses to provide adaptation-related goods and services

Climate change is widely recognised as a significant risk to economic activity and businesses. As discussed in section 5.4.1 (E1), climate change could reduce global GDP by trillions of dollars (Channell et al, 2015) and average global incomes by a quarter. Like any disruptive force though, some businesses will benefit from new markets and opportunities. These include opportunities for organisations that provide adaptation-related goods and services, such as insurance, adaptation finance, farming technologies and engineering services. The finance sector may be able to develop new products and expand existing products such as green bonds into the adaptation space.

Table 54: EO2 Opportunity for businesses to provide adaptation-related goods and services: Opportunity urgency profile

<table>
<tr><th colspan="4">EO2 Opportunity for businesses to provide adaptation-related goods and services: Opportunity urgency profile</th></tr>
<tr><th>Urgency category</th><th>Proportion of urgency</th><th colspan="2">Description of actions</th></tr>
<tr><td>More action needed</td><td>60</td><td colspan="2">A regulatory framework and guidance will be needed to ensure that autonomous adaptations are not maladaptive.</td></tr>
<tr><td>Research priority</td><td>20</td><td colspan="2">How autonomous adaptation can deliver co-benefits for emissions reduction.</td></tr>
<tr><td>Sustain current action</td><td></td><td colspan="2"></td></tr>
<tr><td>Watching brief</td><td>20</td><td colspan="2">Watch and monitor.</td></tr>
<tr><td>Adaptation urgency</td><td>80</td><td>Confidence</td><td>Medium agreement, medium evidence</td></tr>
</table>

5.5 Gaps in knowledge

The economy domain has gaps in knowledge, information and data that would benefit from further research to understand and address the priority risks and opportunities. At present there is some understanding of how certain sectors in the New Zealand's economy (including primary industries and tourism) might be affected by climate change; even in these sectors though, significant knowledge gaps remain.

The land-based primary sector would benefit from further research into how autonomous adaptation can best be supported. There are also gaps in understanding of how changed frequency of extreme events could affect production systems and how the sector can prepare for this disruption. Commercial fisheries suffer from a general lack of research, including around the vulnerability of both particular species and entire ecosystems.

Further research is needed to understand the future vulnerability and economic resilience of the tourism sector in relation to climate change impacts and how to support effective adaptation and avoid maladaptation.

It is unclear how climate change impacts might flow into and through New Zealand's financial system. Very limited evidence is available on how climate change will impact the banking and insurance sectors, on which the New Zealand economy depends. There is no consistent data collection system across New Zealand on insurance sector retreat; data in general is collected by councils in an ad hoc manner. A key knowledge gap relates to the exposure of housing stock to insurance sector retreat (Storey et al, 2015).

6 Built environment domain | Rohe tūranga tangata

6.1 Domain description

The built environment domain refers to the set and configuration of physical infrastructure, transport and buildings. It consists of buildings and housing, energy, the three waters (drinking, storm and waste), transport, He Whare Āhuru He Oranga Tāngata (the Māori Housing Strategy), urban spaces, waste management and flood management.

Box 8 provides a Māori perspective on this domain and an overview of the significance of domain risks to Māori values and wellbeing.

Box 8: Māori perspective on rohe tūranga tangata – the built environment domain

Rohe tūranga tangata | built environment domain

Te rohe tūranga tangata (the built environment) includes infrastructure and built indigenous places that enable Māori to connect with and reinforce a sense of place and identity. The risks outlined in this section include those related to built structures intrinsically linked to whakapapa (genealogy) such as kāinga (homes), wharenui and marae (meeting houses and grounds), and urupā (burial grounds). These are important places for the expression of whanaungatanga (kinship) and manaaki (hospitality) for Māori, and as a consequence there is a direct connection to the rohe tangata (human domain). Because many of these built structures are located in Aotearoa's coastal areas, some are at risk of being damaged or destroyed, yet their inherent connection to place makes relocation of these structures and places challenging.

The risks to infrastructure also identified below relate to landfill failure, linear infrastructure and wai (water). These include risks to water security, supply and wastewater. Wainuiātea, the great expanse of water, connects Māori to the origins of creation, to Ranginui (sky father) and Papatūānuku (earth mother). Risks that may affect the mauri (life force and essence) of water, or access to it, are of critical concern and linked to the whakapapa connection of Māori. The consequences for Māori of the water risks identified include the contamination and diminishing mauri of bodies of water, and potential effects on the ability of Māori to participate in cultural practices such as gathering of food (māhinga kai).

6.2 Snapshot of issues and themes

Achieving climate resilience in the built environment is essential for the continued wellbeing and prosperity of New Zealanders. The built environment, comprising buildings and infrastructure, provides the services essential for society and the economy to function.

Climate change will impact on buildings across New Zealand, including residential housing, commercial buildings and public buildings such as schools and hospitals. Critical infrastructure, such as transport, water, electricity and waste systems, is also at risk.

Climate change is also likely to result in increased costs to manage and maintain urban infrastructure, facilities and amenities, and an overall reduction in levels of service for communities. Impacts associated with disruption to infrastructure not only will apply directly to assets themselves, but also will have cascading consequences for communities and activities.

Climate hazards likely to impact on the built environment include higher temperatures (hot days and heatwaves), changes in rainfall and wind patterns, sea-level rise, extreme weather events (heavy rainfall and strong winds), drought and fire weather. Climate change will also exacerbate natural hazards already being felt across many communities, including inland and coastal flooding, storm surges, rising groundwater, erosion, landslides and increased liquefaction susceptibility. Recent publications have quantified the exposure of sectors of New Zealand's built environment, highlighting the potential for climate change to have significant impacts, potentially on infrastructure worth billions of dollars (Local Government New Zealand, 2019; Parliamentary Commissioner for the Environment, 2015).

Many of New Zealand's major urban areas are located either on the coast or on river floodplains. The impact of coastal and inland flooding is well documented for New Zealand and presents a current and increasing risk for the built environment.

Groundwater rise (influenced by sea-level rise) is an emerging risk to the built environment, impacting on buildings and infrastructure and increasing salinity in water supplies.

Drought severity will increase in most regions of New Zealand and is considered a significant risk. In addition to reducing water availability, drought and increased temperatures can result in higher water demand, exacerbating supply issues.

While understanding of the built environment's exposure to sea-level rise and associated coastal hazards is relatively strong, less evidence is available to support understanding of inland flooding, drought and wildfire. Further research is also needed to understand the sensitivity of the specific built environment sectors, particularly airports, ports and landfills, to climate change impacts.

6.3 Summary of climate change risks and opportunities

Table 55: Summary of climate change risks and opportunities in the built environment domain

Built environment		
	Ratings	
Most significant risks	**Urgency**	**Consequence**
B1 Risk to potable water supplies (availability and quality) due to changes in rainfall, temperature, drought, extreme weather events and ongoing sea-level rise.	93*	Extreme**
B2 Risks to buildings due to extreme weather events, drought, increased fire weather and ongoing sea-level rise.	90	Extreme
Other priority risks examined in stage 2		
B3 Risks to landfills and contaminated sites due to extreme weather events and ongoing sea-level rise.	85	Major
B4 Risk to wastewater and stormwater systems (and levels of service) due to extreme weather events and ongoing sea-level rise.	85	Extreme

Built environment		
	Ratings	
Most significant risks	Urgency	Consequence
B5 Risks to ports and associated infrastructure due to extreme weather events and ongoing sea-level rise.	70	Major
B6 Risks to linear transport networks due to changes in temperature, extreme weather events and ongoing sea-level rise.	60	Extreme
B7 Risk to airports due to changes in temperature, wind, extreme weather events and ongoing sea-level rise.	55	Extreme
B8 Risks to electricity infrastructure due to changes in temperature, rainfall, snow, extreme weather events, wind and increased fire weather.	55	Extreme
BO1 Opportunity for reduction in winter heating demand due to warmer temperatures.	65	n/a

* Urgency rating refers to the total adaptation and decision urgency rating (between 1 and 100).

** Consequence rating refers to the highest consequence rating assigned to this risk out of all three time periods (now, 2050, 2100). Section 6.4 provides the consequence rating for each time period for all the risks.

6.4 Climate change risks and opportunities

6.4.1 B1 Risk to potable water supplies (availability and quality) due to changes in rainfall, temperature, drought, extreme weather events and ongoing sea-level rise

Risk summary

All towns, cities and sectors rely on a safe and secure water supply. Many water supplies in New Zealand are currently at risk from drought, changes in mean annual rainfall, extreme weather events (including heavy rainfall) and sea-level rise. Climate change is likely to increase these risks.

Drought severity will also increase in most regions of New Zealand due to climate change. As well as reducing water availability, drought and increased temperatures can result in higher demand levels, exacerbating supply issues. Population growth is expected to increase, which will add pressure to water supplies. High-growth regions include Auckland, Bay of Plenty, Northland, Waikato, Greater Wellington, Hawke's Bay and Otago.

Sea-level rise (leading to salinity stress) and increases in heavy rainfall (leading to potential flooding and sedimentation of water sources) are already affecting the quality of water supplies around New Zealand. These impacts are likely to increase in the future with climate change.

Māori see water as the essence of all life, making impacts on water a significant cultural issue. Some Māori communities also rely on non-reticulated water systems, making them vulnerable to drought and water contamination.

Exposure

Potable water supplies are exposed to drought, changes in mean annual rainfall, heavy rainfall, ongoing sea-level rise and salinity stress, which can impact on water availability and quality.

Climate change projections show that drought severity will increase in most regions of New Zealand except for Taranaki-Manawatu, the West Coast and Southland. Droughts are likely to increase in frequency and intensity in already drought-prone areas (Ministry for the Environment, 2018). While some areas of New Zealand will experience an overall reduction in water availability annually, other areas may experience a lack of water during specific times of need or seasonally. Since 2014, 44 to 66 per cent of councils have implemented water restrictions each year (Water New Zealand, 2015, 2016, 2017, 2018). This range represents a significant proportion and is likely to increase due to climate change without intervention. Recent drought events have had significant recorded impacts on water supplies around New Zealand. In 2010, for example, Northland experienced the worst drought in 60 years, when its record-low rainfall levels resulted in significant water supply shortages for rural and urban populations (Northland Regional Council, 2011). Wellington likewise experienced drought in 2013, coming close to running out of drinking water (Harrington et al, 2016). During the 2019/20 summer, Northland experienced its driest summer on record, resulting in significant water shortages throughout the region. Waikato and Auckland also experienced serious shortages at this time (RNZ, 2020b).

Heavy rainfall can lead to contamination of water supplies that rely on freshwater rivers and lakes. In March 2017, Auckland experienced three extreme-intensity, short-duration events (the 'Tasman Tempest'), which resulted in significant sedimentation of water reservoirs and contamination of a number of the dams supporting Auckland's water supply (Urich et al, 2017).

New Zealand has nearly 150 mapped aquifers, which provide roughly one-third of its daily supply. Many of these are located along the coast (Pattle Delamore Partners Ltd, 2011). As sea levels rise, coastal aquifers will become increasingly vulnerable to saltwater contamination. Salinisation of coastal aquifers is already occurring in Northland, Auckland, Waikato, Bay of Plenty, Taranaki, Wellington, Tasman, Marlborough, Canterbury and Dunedin (Pattle Delamore Partners Ltd, 2011). Salinity stress and wider groundwater changes will increase the pressure on water security, impacting both the availability and quality of water (Thorburn et al, 2013).

Sensitivity

Water supplies are sensitive to climate change impacts due to the design, condition and location of water supply infrastructure, and changes in water availability and demand patterns.

Periods of drought and high temperature create water shortages through reduced rainfall and increased evapotranspiration. At the same time, people respond to the conditions by using more water for outdoor purposes, increasing both average and peak water demand further exacerbating the water shortage

Water demand, both average and peak, can be affected by increasing temperatures, during periods of drought and high temperature as people use more water for outdoor use. This exacerbates water shortages, due to already reduced water availability, as a result of reduced rainfall and increased evapotranspiration. (Local Government New Zealand, 2019; Paulik et al, 2019a, 2019b; Hendy et al, 2018; Thorburn et al, 2013). A significant number of towns in New Zealand do not have water meters, or are only partially metered. This makes managing water demand in these towns difficult (Water New Zealand, 2018).

Increased temperatures and drought can also result in algal blooms, which can contaminate drinking water sources (Ministry for the Environment and Stats NZ, 2020).

Water supplies are generally more sensitive in areas where there is a single source of water, as opposed to those where a number of sources are available, such as Auckland, which has access to storage dams in the Hunua and Waitakere Ranges, the Onehunga Aquifer, and the Waikato River (Watercare, nd).

Rural water supplies are also sensitive to climate change hazards, particularly where reticulated systems are limited or absent (Woodward et al, 2001). Rural and Māori communities, and those with inadequate resources to either import water or pay for private treatment facilities, will be more sensitive to increasing drought conditions (Woodward et al, 2001).

The potential for water insecurity to adversely impact communities that already have social inequities or health issues is not well understood in New Zealand. The Government inquiry into the Havelock North campylobacteriosis outbreak in 2016 outlined this, and noted:

> “unlike in areas where consumers can make their own assessment of risk, drinking water risks are effectively imposed on all consumers by suppliers. The consumer base will include many people who are vulnerable for various reasons, including old age, youth, and those who are immunocompromised or suffering from ill health’ (Department of Internal Affairs, 2017).”

Adaptive capacity

In terms of water availability, the adaptive capacity of systems will largely depend on the ability to maintain or enhance supplies and storage, and to manage and reduce per capita demand levels. Overseas experience has shown that demand levels can be reduced through targeted interventions, such as water efficiency, metering, pricing, and behaviour change (Tortajada and Joshi, 2013).

In New Zealand, water is largely supplied to cities and towns by individual local authorities (city or district councils) or, less often, by council-controlled organisations. Given the currently fragmented nature of water supply management, improvements in adaptive capacity may continue to be ad hoc around New Zealand. However, central government is currently undertaking a Three Waters Review (Department of Internal Affairs, 2018) and is establishing a new regulatory body (to be called Taumata Arowai) that will administer and enforce a new drinking water regulatory system, including by managing risks to sources of drinking water. These initiatives may deliver much-needed oversight and consistency in adapting to climate change risks.

Adaptive capacity is considered lower in smaller communities, where infrastructure is already under pressure due to low levels of investment. Climate change impacts will exacerbate these pressures. The costs to upgrade water and wastewater infrastructure around New Zealand to meet current drinking water standards have been estimated at about $8 billion (BECA, 2019; GHD et al, 2019).

Consequence

Given the importance of water supplies for communities and business, consequences from impaired supply can be significant and could arise from a range of climate hazards.

The Auckland ‘Tasman Tempest’ event impacted water supply in Auckland and affected thousands of people across the city. The event caused very poor raw water quality and compromised treatment facilities. As a result, throughput was significantly reduced.

Watercare called for voluntary water savings of 20 litres per day for residential customers. It embarked on a targeted engagement campaign with all large commercial users to inform them of issues and encourage voluntary reductions and contingency planning. Through these actions, severe commercial losses and impacts on public health were avoided.

As mentioned, recent droughts have resulted in significant water shortages through Waikato, Auckland and Northland, resulting in numerous water reduction advisories and waiting lists for water tank refills of up to five weeks (RNZ, 2020b). Water reductions are generally staged, with initial restrictions placed on public outdoor use (public parks, sports fields), followed by private outdoor use (gardens), and finally more restrictive measures targeted at residential and commercial use. The increasing levels of restriction will have corresponding levels of consequences for community health and wellbeing, and for business operations.

Droughts can also lead to more favourable conditions for the development of algal blooms (influenced by high water temperatures, long residence times and high nutrient concentrations) and a decrease in water quality, particularly in non-reticulated systems (van Vliet and Zwolsman, 2008), as well as within reticulated systems where treatment may be inadequate. This can lead to significant health impacts. While not directly climate change-related, the contamination event at Havelock North illustrates the potentially severe social consequences of water supply contamination (Department of Internal Affairs, 2017).

Interacting risks

Changes in water availability from drought and reduced rainfall will have significant consequences for all domains. This may include increases in diseases due to water-borne pathogens or as a result of lack of hygiene in a water shortage (H3) (Hendy et al, 2018). More frequent watering bans and higher water prices (or the imposition of water prices) and wide-scale drinking water shortages could compound existing inequities, and create new ones (H2). Rivers, lakes and streams (and associated ecosystems) may be impacted by increased pressure from human use (N3, N6). Mitigating impacts on rivers, lakes and streams could also help reduce the risks to potable water supplies in some areas (N3, N6). The management of water resources could be further challenged by inadequate institutional arrangements, including uncoordinated and inconsistent governance between and within levels and agencies of government and private property owners, and the possibility of maladaptive actions (G1, G2). A reduction in capacity of amenity spaces will impact on human health and wellbeing.

Confidence: High agreement, medium evidence

Overall, there is a high level of agreement that climate change will impact on urban and rural water security. Strong evidence is available on hazard exposure to water systems. In general, evidence on the vulnerabilities of water security to climate change is also strong, but further research is needed to understand community vulnerability to changes in water quality.

Adaptation

Adaptation varies among councils and water supply authorities. Auckland’s Watercare has developed a climate change strategy that includes a focus on climate resilience for its network. All authorities actively monitor water availability, demand and water quality, and most have prepared demand management plans and drought management plans.

Table 56: B1 Risk to potable water supplies (availability and quality): Urgency profile

<table>
<tr><th colspan="7">B1 Risk to potable water supplies (availability and quality): Urgency profile</th></tr>
<tr><th>Urgency category</th><th colspan="2">Proportion of urgency</th><th colspan="4">Description of actions</th></tr>
<tr><td>More action needed</td><td colspan="2">70</td><td colspan="4">Urgent action is needed to best manage urban and rural water security now and for the near future, given this current and pressing risk.</td></tr>
<tr><td>Research priority</td><td colspan="2">30</td><td colspan="4">Urgent research focus is needed to address the considerable knowledge gap on the impacts of drought on water supply, availability, quality and demand for New Zealand.</td></tr>
<tr><td>Sustain current action</td><td colspan="2"></td><td colspan="4"></td></tr>
<tr><td>Watching brief</td><td colspan="2">0</td><td colspan="4"></td></tr>
<tr><td>Adaptation urgency</td><td colspan="2">93</td><td>Confidence</td><td colspan="3">High agreement, medium evidence</td></tr>
<tr><td>Consequence</td><td>Now</td><td>Major</td><td>2050</td><td>Extreme</td><td>2100</td><td>Extreme</td></tr>
</table>

6.4.2 B2 Risks to buildings due to extreme weather events, drought, increased fire weather and ongoing sea-level rise

Risk summary

A significant number of buildings in New Zealand (residential, non-residential and cultural heritage) are at risk from climate change, predominantly through extreme weather events, drought, increased fire weather and sea-level rise. Buildings are also at risk of impacts from natural hazards such as inland flooding, coastal flooding, landslides, groundwater rise and wildfire, all of which are projected to increase in frequency and severity over time with climate change.

These risks could result in temporary disruption, damage and destruction of buildings and potentially require relocation from at-risk locations in the future. The failure of drainage systems in urban areas (due to capacities being exceeded) and the potential overtopping and breach of stopbanks and other flood defences could also have a significant impact on buildings. The increased risk of flood defence failure is poorly understood, but the associated consequences are likely to be significant.

The ability to adapt existing buildings in a cost-effective manner is limited, as buildings are generally designed to be long-standing permanent structures served by complex infrastructure systems. Those with suspended timber floors are considered to have higher adaptive capacity than buildings that have concrete floor slabs, because the former can sometimes be relocated. Similarly, new buildings can be located away from risk areas or be designed to accommodate projected changes to the climate.

For Māori, this risk may affect connectivity to whenua, the foundation of tūrangawaewae. This includes direct impacts of climate hazards and natural hazards on Māori land, communities and cultural buildings (including marae), along with impacts from potential adaptation responses such as relocation of buildings (IPCC, 2014b; King et al, 2010; Stephenson et al, 2018). See also section 3.4.5 (H5) for more discussion around risk to cultural assets.

Exposure

Buildings are exposed to inland flooding, sea-level rise (and associated groundwater rise), coastal flooding, extreme weather events, wildfires and drought. These hazards can lead to disruption to communities and temporarily or permanently damage buildings. Extreme weather events (strong winds and heavy rainfall) and wildfires can lead to significant and permanent damage and destruction of buildings. The number of buildings exposed is projected to increase under representative concentration pathway (RCP) 4.5 and RCP8.5, with greater exposure under RCP8.5.

In New Zealand many communities live on the coast, and buildings face significant exposure to coastal flooding and erosion, which will be exacerbated by sea-level rise. Currently over 72,000 people and 49,700 buildings are exposed to coastal flooding.[10] For example, in 2015, 800 homes were flooded in South Dunedin from a high tide that coincided with an extreme rainfall event. This event gave rise to over $28 million in insurance claims (Insurance Council of New Zealand, 2017; Stephenson et al, 2018). Exposure of buildings to coastal flooding will increase this century under both RCP4.5 and RCP8.5. Under RCP8.5, by 2100 about 117,900 buildings across New Zealand are projected to be exposed to coastal flooding (Paulik et al, 2019b).

Exposure to inland flooding is high at present, with about 675,000 people across New Zealand living in flood hazard areas and an estimated 411,500 buildings already exposed to inland flooding.[11] Overtopping and breaching of stopbanks and flood defences, and failure of pumped stormwater systems, are already resulting in significant exposure. For example, in April 2017, Cyclone Debbie hit the Bay of Plenty coast, bringing significant rainfall and flooding the Rangitāiki River. This resulted in breaching of the ageing Rangitāiki stopbank and catastrophic flooding of Edgecumbe, with $72 million in insurance claims from damaged and destroyed housing (Rangitāiki River Scheme Review Panel, 2017; Stephenson et al, 2018). A full evacuation of Edgecumbe's 2000 residents was ordered and was maintained for eight days (Stephenson et al, 2018). Communities protected by flood defences could be more exposed to increased flooding, as flood defence schemes have a finite design capacity and often no secondary stormwater systems. Future exposure of buildings is likely to increase under RCP4.5, with greater exposure projected under RCP8.5.

Extreme weather events (strong wind and heavy rainfall) currently affect buildings across New Zealand. The data on insurance payments from severe weather events show the magnitude of loss from storms in New Zealand has increased over the past decade (Insurance Council of New Zealand, 2020). The future exposure of buildings and people to extreme weather events across New Zealand is likely to increase under both RCP4.5 and RCP8.5 (Ministry for the Environment, 2018).

Groundwater rise is poorly understood in New Zealand. However, it is recognised as an emerging issue in many coastal communities. For example, the suburb of South Dunedin (about 4800 homes) is known to have high groundwater levels that are influenced by tides. This combination contributes to surface flooding following heavy rain events, especially in winter when groundwater is naturally closer to the ground surface (Otago Regional Council, 2016).

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[10] Paulik et al (2019b) undertook a high-level study on New Zealand's exposure to 1 per cent annual exceedance probability (AEP) coastal flood inundation under present-day and future higher sea levels.

[11] Paulik et al (2019a) undertook a high-level study to attempt to enumerate New Zealand's asset exposure in inland (fluvial and pluvial) floodplains. In the absence of a national flood hazard map, exposed areas were identified by creating a 'composite' flood hazard area map from modelled and historical flood hazard maps and flood-prone soil maps. The analysis provides a representative sample of built assets exposed on New Zealand's fluvial and pluvial floodplains. Notably the analysis cannot be attributed to a particular return-period flood event currently nor in the future with climate change.

Erosion, including landslides, is a frequent occurrence in New Zealand. Climate change may accelerate the processes causing erosion, through extreme rainfall and sea-level rise, resulting in increased exposure of buildings (Basher et al, 2012; Rosser et al, 2017). Buildings may also be increasingly exposed to soils with higher liquefaction susceptibility, because of groundwater rise in coastal plains and reclaimed areas (Ministry for the Environment, 2017b; Quilter et al, 2015). Drought may increasingly affect expansive soils, which can cause soils to dry and shrink (BRANZ, 2008).

New Zealand has a history of wildfires, and exposure is projected to increase due to climate change (Pearce et al, 2018). Buildings will be exposed to wildfire through direct impacts on structures, as well as because of the characteristics of vegetation surrounding buildings. Under RCP4.5 and RCP8.5, it is likely that exposure to wildfire, particularly in rural areas, will increase throughout this century (Pearce et al, 2018).

Sensitivity

Buildings around New Zealand are currently sensitive to coastal inundation, flooding, extreme weather events, fire weather, and soil changes and movements such as liquefaction, landslides and soil shrinkage and swelling. Sensitivity to climate and natural hazards is driven by a range of factors including the design, age and condition of buildings.

New Zealand’s building stock is largely made up of wooden and masonry houses, and houses with reinforced concrete frames (Uma et al, 2008). The average age of residential dwellings in New Zealand is about 50 years (Jaques et al, 2015). Dwelling condition is directly related to dwelling age, and therefore informs sensitivity to damage, with older buildings (including cultural heritage buildings) likely to experience a greater level of damage (Buckett et al, 2010).

Many buildings in New Zealand are sensitive to floods, which can result in structural damage, particularly where inundation reaches or exceeds the elevation of the floor (Reese and Ramsay, 2010). The level of damage floods cause to buildings depends on a number of factors, the most important of which are the flood characteristics (water depth, water velocity, inundation duration) and the building characteristics (including type of structure, and material) (Reese and Ramsay, 2010). Groundwater rise could also impact on buildings, which would lead to the risk of rising damp and impaired stormwater drainage (Tauranga City Council, 2019). Buildings in areas of high groundwater may have prolonged exposure to floodwaters, with resulting higher levels of damage.

Historically, extreme weather events have caused significant damage, disruption and financial cost throughout New Zealand (Cenek et al, 2019). While limited information is available in New Zealand on the sensitivity of buildings to wind- and weather-related damages, a number of events have resulted in significant damage over the past decade (Cenek et al, 2019). For example, in April 2014, ex-Tropical Cyclone Ita struck the West Coast of the South Island, resulting in more than 60 houses in Greymouth losing roofs (Cenek et al, 2019).

Prolonged periods of extreme rain can also damage buildings through increased moisture penetration in walls and damper conditions indoors, degrading building interiors (Department of Building and Housing, 2006). This has been associated with health consequences for building occupants (Department of Building and Housing, 2006). Extreme wind can exacerbate the impact of rainfall on buildings by increasing moisture penetration and can result in destruction of buildings, including roofing being blown off, broken windows, and other flying debris (Department of Building and Housing, 2006).

Knowledge of stopbank design, age and condition (which informs sensitivity to damage from flood events) remains sparse across New Zealand. This is compounded by a lack of consistency between formal and informal stopbanks (Crawford-Flett et al, 2018), which reduces the effectiveness of monitoring and maintenance.

Many types of buildings in New Zealand are also sensitive to wildfires. The level of sensitivity depends on a number of factors, which include the:

- density per hectare of buildings
- size and shape of groups of buildings
- type and amount of vegetation close by
- distance between structures
- width and layout of roads and reserves
- climate zone
- materials used in structures (Opie et al, 2014).

Buildings in New Zealand can also be sensitive to liquefaction. The Christchurch earthquake sequence showed this sensitivity is driven by a range of factors, including land characteristics (soil type), groundwater levels, and the design of the buildings themselves (Ministry of Business, Innovation and Employment, 2017).

Buildings are sensitive to landslides, which are caused by a number of factors including rainfall, soil stability, structural building type (including foundations) and intensity of land development (Guillard-Goncalves et al, 2016; Lin et al, 2017). They are also sensitive to drought-induced soil movements, which can cause certain types of soil to dry and shrink (Corti et al, 2011). As buildings shift and subside, this can result in structural damage to foundations and cracked walls and ceilings (Kovats and Osborn, 2016).

Adaptive capacity

Existing residential and commercial buildings inherently have a low level of adaptive capacity. Buildings are built as long-standing permanent structures and are served by complex, centralised infrastructure systems that require large capital and ongoing operational expenditures. Buildings with a concrete floor slab construction are more difficult to relocate and repair, and therefore would have lower adaptive capacity than older buildings with a suspended timber floor.

New buildings and settlements can be built with a much higher level of adaptive capacity, to be tolerant to a wider range of climate and weather extremes. Many good local and international examples are evident. For example, the Urban Growth Partnership (UGA) approach to spatial planning includes climate resilience and protecting and enhancing the natural environment as an overarching objective. The UGA is a partnership between central government agencies, local government and iwi, and is focused on urban growth areas around New Zealand.

Improving adaptive capacity would require funding, which has financial implications for households, communities, local government and central government. Further research is needed to determine how financial institutions and government authorities can support the financing of adaptation measures. Ultimately, enhancing adaptive capacity will require strong leadership, governance, funding mechanisms and community engagement.

Consequence

Climate change impacts on buildings will have significant economic, social, cultural and public health consequences. Major floods can have financial impacts on individuals and households, such as potentially reducing house and land prices. These impacts could be compounded by insurance retreat from high-risk areas in New Zealand.

The consequences for coastal communities, such as Haumoana, Granity, Waitara and Urenui, which currently have homes that are being undermined or swamped by wave action, will increase due to climate change. Other low-lying settlements in New Zealand could also face increased social and economic impacts; for example, South Dunedin, Edgecumbe, Lower Hutt and Petone are already prone to major flooding (Stephenson et al, 2018). These consequences are far reaching across all domains.

The impact of flooding, sea-level rise, and extreme weather on buildings could also result in loss of access to valued places, and impact on physical and mental health, identity and sense of belonging (Stephenson et al, 2018). Many communities have existing social and economic vulnerabilities, including poor health, lack of social connections, and financial distress. These vulnerabilities can reduce the capacity of people and communities to recover following shocks, such as the damage caused from floods and extreme weather events. This may lead to increasingly severe consequences over time (Stephenson et al, 2018).

Increased moisture in buildings due to extreme weather events and flooding could also result in poor public health outcomes, and have a range of economic and social consequences. At present, mould is visible to some extent in an estimated half of all houses in New Zealand, with a slightly higher prevalence in rental properties (White et al, 2017a). Mould is a key indicator of overall indoor air quality and is potentially harmful to the health of household occupants (Chang-Richards et al, 2018).

The failure of flood management and protection schemes could also lead to extreme consequences, given the large number of people living in areas where flood management schemes are in place.

Interacting risks

There are interacting risks to buildings due to transport connections (B6) and essential community infrastructure (B1, B4, B8), as the impacts from climate change on these supporting infrastructures could directly affect the utility of buildings and the viability of communities.

Climate change risks to buildings will also have significant flow-on effects for people, the economy and governance. The risk to residential housing could exacerbate existing inequities (H2) and impact on social cohesion and community welfare (H1). Climate change risks to buildings (B2) may affect cultural heritage sites (H8). Impacts on residential and non-residential buildings could cause cascading economic risks, such as public sector fiscal risks from the growing financial burden and unfunded contingent liabilities (E1), risks to financial system stability and economic development (E2), and risks to the insurance sector (E6). The exposure and sensitivity of buildings to climate hazards could be further compounded by inadequate institutional arrangements, including uncoordinated and inconsistent governance between and within levels and agencies of government and private property owners (G2). There could also be maladaptive actions, such as supporting property owners with adaptation in high-risk locations that could create moral hazard problems (G1). Finally, hardening coastal environments (for example, sea walls) to defend settlements against erosion and flooding can lead to coastal squeeze and impacts on coastal ecosystems (N1).

Confidence: High agreement, medium evidence

There is a high level of agreement that buildings are exposed and sensitive to climate and natural hazards. Further research is needed to understand the level of exposure of buildings due to climate change, particularly those defended by flood schemes (including stopbanks). Overall, the research on sensitivity is robust, with considerable evidence in New Zealand and globally on the sensitivity of buildings to present-day natural hazard impacts.

Adaptation

A number of initiatives are under way at the community, local government and central government levels to progress adaptation for buildings and broader settlements. There are currently community (council-funded) coastal restoration projects through Coast Care and the Coastal Restoration Trust of New Zealand, and community resilience groups are also being established by the Ministry for the Environment to build community resilience to flood risk.

Regional councils in New Zealand monitor and manage flood protection schemes (including stopbanks) and many are actively assessing these in relation to climate change. More broadly, most regional and district councils regularly undertake hazard planning, which includes mapping and monitoring flood risk, improving consent requirements around river and coastal flooding and, in some cases, developing rules to allow for relocatable houses.

Central government also has a number of planned and ongoing initiatives, including a project led by the Ministry of Business, Innovation and Employment to review available evidence on how the building regulatory system could be used to support the Government's climate change objectives. Heritage New Zealand Pouhere Taonga is also supporting marae communities to manage their own buildings and cultural practice, through advice and specialist services.

Table 57: B2 Risks to buildings: Urgency profile

<table>
<tr><th colspan="7">B2 Risks to buildings: Urgency profile</th></tr>
<tr><th>Urgency category</th><th colspan="2">Proportion of urgency</th><th colspan="4">Description of actions</th></tr>
<tr><td>More action needed</td><td colspan="2">60</td><td colspan="4">More action is needed to tackle this current and pressing risk affecting buildings in coastal and flood-prone areas. This risk will increase with time and requires an urgent, joined-up and effective response across all levels of government.</td></tr>
<tr><td>Research priority</td><td colspan="2">40</td><td colspan="4">Further knowledge is needed on a number of hazards, including a nationally consistent approach to flood hazard and associated exposure assessments.</td></tr>
<tr><td>Sustain current action</td><td colspan="2">0</td><td colspan="4">While a small subset of this risk, current actions are deemed adequate for fire weather and extreme weather events over the next five years.</td></tr>
<tr><td>Watching brief</td><td colspan="2"></td><td colspan="4"></td></tr>
<tr><td>Adaptation urgency</td><td colspan="2">90</td><td>Confidence</td><td colspan="3">High agreement, medium evidence</td></tr>
<tr><td>Consequence</td><td>Now</td><td>Major</td><td>2050</td><td>Extreme</td><td>2100</td><td>Extreme 2150</td></tr>
</table>

6.4.3 B3 Risks to landfills and contaminated sites due to extreme weather events and ongoing sea-level rise

Risk summary

Active and closed landfills and contaminated sites across New Zealand are currently at risk from extreme weather events and sea-level rise, and from the associated coastal and inland flooding, erosion and rising groundwater. All these hazards are projected to increase in frequency and severity over time due to climate change.

Closed landfills, including legacy landfills (historical, often informal and non-engineered), are likely to be more exposed, as more recently constructed landfills are situated in areas of lower risk to natural hazards (Ministry for the Environment, 2001). Landfills and contaminated sites can be sensitive to erosion, damage and contaminant washout as a result of flooding and extreme weather events. The failure of these sites can mobilise pollutants, with potentially cascading consequences for public health, ecosystems and the economy.

While modern landfills are subject to strict resource consent conditions and monitoring requirements to reduce the risk of failures, understanding of the location and characteristics (including design, extent and type of waste) of closed landfills is limited. Improved understanding of closed landfills will allow authorities to better understand sensitivity and to monitor and manage landfills and contaminated sites that are at risk.

The adaptive capacity of landfills and contaminated sites is likely to vary considerably around New Zealand due to gaps in the understanding of sites and funding availability, which differs between regions.

For Māori, the potential pollution and contamination of food-gathering areas (mahinga kai) from landfill damage, and effects on taonga species are likely to have significant consequences for Māori cultural practices and the wider Māori economy. Risks to landfills and contaminated sites are moderate at present and are likely to increase into the future due to climate change.

Exposure

While no detailed analysis has been undertaken, councils around New Zealand have reported that exposure of landfills to climate hazards is a major issue (Beehive, 2019). Landfills are likely to be exposed to extreme weather events and sea-level rise, along with associated coastal and inland flooding, erosion and rising groundwater. This exposure is projected to increase with climate change. Determining the specific exposure of landfill sites to climate hazards is hindered by a lack of information on the location of numerous closed landfills and contaminated sites (Beehive, 2019).

In general, climate change will increase the exposure of landfills and contaminated sites to inland flooding across New Zealand. For example, in 2019 heavy rainfall washed out the decommissioned Hector landfill near Fox Glacier; as a result, massive amounts of rubbish and contaminated materials were washed down the river and deposited along more than 100 kilometres of the West Coast coastline (Westland District Council, 2019).

Many landfills and contaminated sites are also likely to be exposed to sea-level rise. High-level analysis suggests that about 112 active and closed landfills are located around New Zealand, within 0.5 metres of the mean high water spring (MHWS) level (Local Government New

Zealand, 2019b).[12] As discussed above, the location of many closed landfills around New Zealand is unknown, and further assessments are required to better understand the exposure of landfills and contaminated sites to sea-level rise under RCP4.5 and RCP8.5 (Local Government New Zealand, 2019b).

In general, closed landfills and contaminated sites may be more exposed than modern sites to flooding, due to requirements to situate recently constructed landfills in areas of lower risk to natural hazards (Ministry for the Environment, 2001).

Sensitivity

Detailed investigations have not yet been done to understand the current sensitivity of landfills and contaminated sites to climate change in New Zealand. Sensitivity will differ based on factors such as design characteristics, maintenance and geography. The focus here is on high-level information on the likely sensitivity of landfills.

In general, landfills and contaminated sites are sensitive to extreme weather, sea-level rise, and associated inland and coastal flooding, which can erode cover material, and cause side slope failure and contaminant washout (United States Environmental Protection Agency, 2014). Landfills can be sensitive to flooding, resulting in pollution events due to leachate escape or release of solid waste (Beaven et al, 2020; United States Environmental Protection Agency, 2014).[13]

While modern landfills in New Zealand must be designed to high standards to contain leachate, international research has found it is likely that leachate will eventually escape from all landfills, even modern ones with impermeable and low permeability liners (Brand et al, 2018; WasteMINZ, 2018).

Adaptive capacity

The adaptive capacity of landfills and contaminated sites is generally low, given that they are located in ground, with limited ability to relocate. Governance-related constraints, such as ownership and funding, also result in a lower level of adaptive capacity because land ownership and resource consents are tied to specific funding streams, limiting capacity to adapt.

Adaptive capacity is further reduced by gaps in understanding of landfill locations in New Zealand. Older (legacy) landfills are often discovered during natural hazard events (Stuff, 2019b), and adaptation is not possible ahead of discovery. Therefore, the adaptive capacity for legacy landfills is likely to be low, with significant effort and cost required to defend or relocate them.

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[12] The MHWS level is used as the dividing line between land and sea under both the Resource Management Act 1991 and Marine and Coastal Area (Takutai Moana) Act 2011. MHWS can be defined in many ways, but is traditionally calculated as the long-term average of the highest high tide ('spring tide') that occurs after every new and full moon (NIWA, 2007).

[13] Leachate is the fluid percolating through the landfills and is generated from liquids present in the waste and from outside water, including rainwater, percolating though the waste (Jayawardhana et al, 2016).

Consequence

In New Zealand, recent events at the Hector landfill near Fox Glacier on the West Coast of the South Island demonstrate the potential environmental and economic consequences of landfill and contaminated site failure (Stuff, 2019b).

The failure of landfills and contaminated sites across New Zealand may mobilise pollutants (such as dissolved nitrogen and heavy metals) and solid waste, including glass, metal, plastics and asbestos (Brand et al, 2018). The consequences of this mobilisation could be substantial, possibly including impacts on sensitive ecosystems, groundwater and surface water contamination, reputational damage, declining health outcomes, and negative impacts on economic sectors such as tourism (Brand et al, 2018). These events can take significant time and cost to clean up. Māori could also experience specific consequences, due to pollution of areas of food-gathering (mahinga kai) and impact on taonga species.

Interacting risks

Climate change risks to landfills and contaminated sites will interact with a range of risks in the natural environment, economy, governance and human domains. The natural environment, including freshwater, marine and terrestrial species and ecosystems, could be at risk due to increases in the mobilisation of pollutants and solid waste to areas surrounding landfills (Brand et al, 2018). Economic risks from reduced tourism demand (E4) could also arise through waste contaminating sensitive environments, including aquaculture and fisheries if marine contamination occurs (E5).

Another risk is that adaptation actions are inadequately financed, which could increase the public sector financial burden due to climate change impacts (E1). Potential human risks could include impacts on public health from water contamination and exposure to pollutants, such as asbestos (H3). Further impacts could be on social wellbeing from contamination of recreational sites, and reduction of Māori cultural capital and spiritual wellbeing (H5, H6). Inadequate governance of landfills and contaminated sites. While local and central government agencies are currently undertaking actions to mitigate the risk climate change poses to landfills and contaminated sites, there is a risk that these responses are uncoordinated and insufficient (G2).

Confidence: High agreement, low evidence

There is a high agreement that landfills and contaminated sites are exposed and sensitive to climate hazards and natural hazards. There is a lack of evidence on the location of landfills, and limited understanding of exposure, vulnerability and consequence for sites across New Zealand. This presents a substantial risk that requires further research (Beehive, 2019).

Adaptation

A nationwide assessment, implemented by the Department of Conservation, the Ministry for the Environment and local authorities, is identifying landfills and contaminated sites vulnerable to the impacts of floods and climate change. Assessments are also being carried out at the regional level to identify at-risk landfills and contaminated sites.

Table 58: B3 Risks to landfills and contaminated sites: Urgency profile

<table>
<tr><th colspan="7">B3 Risks to landfills and contaminated sites: Urgency profile</th></tr>
<tr><td>Urgency category</td><td colspan="2">Proportion of urgency</td><td colspan="4">Description of actions</td></tr>
<tr><td>More action needed</td><td colspan="2">40</td><td colspan="4">A central government approach is needed to enable adaptation action for high-risk landfills within the next five years.</td></tr>
<tr><td>Research priority</td><td colspan="2">60</td><td colspan="4">Fill the knowledge gap around existing locations of landfills and the associated risk across New Zealand.</td></tr>
<tr><td>Sustain current action</td><td colspan="2">0</td><td colspan="4"></td></tr>
<tr><td>Watching brief</td><td colspan="2">0</td><td colspan="4"></td></tr>
<tr><td>Adaptation urgency</td><td colspan="2">85</td><td>Confidence</td><td colspan="3">High agreement, low evidence</td></tr>
<tr><td>Consequence</td><td>Now</td><td>Moderate</td><td>2050</td><td>Major</td><td>2100</td><td>Major</td></tr>
</table>

6.4.4 B4 Risk to wastewater and stormwater systems (and levels of service) due to extreme weather events and ongoing sea level rise

Risk summary

Wastewater and stormwater infrastructure are currently at risk from extreme weather events (including heavy rainfall), ongoing sea-level rise and drought. They are also at risk from associated natural hazards such as inland flooding, coastal flooding, coastal erosion, and groundwater rise, all of which are projected to increase in frequency and severity due to climate change.

These risks could result in a range of direct and indirect impacts, including increases in wastewater overflow events to waterways and harbours, and reductions in service levels for stormwater pipe networks due to increased intensities and volumes of rainfall. Further impacts could include mobilisation of urban pollutants, leading to contamination of downstream environments, and cascading consequences on communities and ecosystems from contamination. There is also a direct risk to infrastructure located near the coast, such as low-gradient pipe networks and wastewater treatment plants, from coastal flooding and erosion. These impacts will likely affect both urban and rural settlements throughout New Zealand. Both drought and raised groundwater levels can lead to a range of impacts on buried pipelines (subsidence and cracking), and impact on the functioning of wastewater systems.

The adaptive capacity of wastewater and stormwater systems varies based on a range of factors that include funding, age and the condition of infrastructure. Large wastewater treatment plants will, in general, have a relatively low level of adaptive capacity, whereas networks typically have a higher level of adaptive capacity. In New Zealand, there are a range of climate-resilient approaches for networks that are considered best practice. Many councils and water authorities are aware of these practices, and in some cases have begun to implement them.

For Māori, water is seen as the essence of all life, and the potential for these impacts (such as contamination) to lead to a reduction in mauri (life force) of bodies of water is likely to be of concern.

Exposure

Wastewater and stormwater systems in New Zealand are exposed to extreme weather events, sea-level rise and drought, and this is projected to increase this century under both RCP4.5 and RCP8.5. These climate hazards can lead to inland and coastal flooding, as well as coastal erosion.

At present, over 12,600 kilometres of wastewater and stormwater pipes are estimated to be exposed to inland flooding throughout New Zealand, with approximately 6912 kilometres of wastewater pipes and 5720 kilometres of stormwater pipes also exposed (Paulik et al, 2019a). The greatest exposure is in Auckland, Wellington and Canterbury (Paulik et al, 2019a). The exposure of wastewater and stormwater pipes to inland flooding may not necessarily imply damage or reduction in levels of service. The exposure analysis currently available provides initial information from which further assessments can be targeted to better understand risk and prioritise adaptation.

Significant lengths of wastewater and stormwater infrastructure are also exposed to coastal flooding across a number of regions (Paulik et al, 2019b). At present-day mean sea level, 760 kilometres of stormwater pipes and 1020 kilometres of wastewater pipes are exposed to a 1 per cent annual exceedance probability (AEP) coastal flood (Paulik et al, 2019b). It is estimated that the Canterbury, Wellington, Bay of Plenty and Hawke’s Bay regions have the highest lengths of wastewater and stormwater pipes exposed to coastal flooding (Paulik et al, 2019b). Exposure of wastewater and stormwater infrastructure is projected to increase under both RCP4.5 and RCP8.5. Under RCP8.5 at 2100, about 1632 kilometres of stormwater pipes and 2431 kilometres of wastewater pipes are projected to be exposed (Paulik et al, 2019b).

In areas where groundwater is tidally influenced, stormwater and wastewater systems will be exposed to ongoing sea-level rise. Groundwater levels are poorly understood in New Zealand, as few data are available; however, a number of areas are known to have high groundwater levels, including Tauranga, Christchurch and Dunedin (Tauranga City Council, 2019).

There are a number of low-lying wastewater treatment plants around New Zealand. These will be significantly exposed to coastal flooding (due to sea-level rise and storm surges), coastal erosion and rising groundwater. Many of the country’s largest treatment plants (by treatment volume) are close to the coast and discharge to riverine, coastal or harbour environments (Hughes et al, 2019).

Wastewater and stormwater infrastructure is exposed to extreme weather events and associated heavy rainfall. In general, stormwater infrastructure is not designed for the projected increase in flows and volumes due to climate change (White et al, 2017b). In addition, extreme rainfall can infiltrate wastewater systems and result in wastewater overflows entering receiving environments. This occurs regularly in a number of cities and towns, including Auckland, where wastewater discharges to Auckland beaches in storm events (White et al, 2017b).

At present, New Zealand is yet to experience drought that is long enough to impact wastewater and stormwater systems (White et al, 2017b). Drought severity is projected to increase due to climate change under both RCP4.5 and RCP8.5, and so exposure of these systems is also likely to increase.

Sensitivity

Most urban areas in New Zealand have ageing networks that need significant investment to continue to provide acceptable levels of service (National Infrastructure Unit, 2015). Older infrastructure is more sensitive to climate change impacts, in terms of both physical damage and operational performance (White et al, 2017b).

The infiltration of groundwater into storm and wastewater systems due to sea-level rise will lead to increased flow volumes and salinity, which has potential to affect the performance of wastewater and stormwater systems. Saltwater can accelerate corrosion of pipe, pump and treatment systems, and potentially reduce treatment plant performance (Hughes et al, 2019).

Severe droughts can impact buried pipelines through land subsidence and cracking. Droughts can also impact wastewater systems by reducing inflows (intensified by potential water restrictions), resulting in solids building up in pipes, and more concentrated wastewater flows. This results in oxygen-poor environments that encourage the growth of anaerobic bacteria in wastewater systems, leading to deterioration of concrete and steel pipes (Chappelle et al, 2019).

Often the discharge points of stormwater and wastewater systems are at the lowest elevation of populated areas, making them particularly sensitive to coastal erosion and inundation (White et al, 2017b).

The nature of the system will also determine its ability to cope with and adapt to climate change. Smaller systems, especially in densely populated areas, will be more sensitive to increased rainfall and extreme weather compared with larger systems with spare treatment capacity (Hughes et al, 2019).

Adaptive capacity

In general, the adaptive capacity of wastewater and stormwater systems is considered low. Most towns have ageing networks that are in poor condition and undersized compared with required design standards (for example, to cope with increasing rainfall). Although retrofit is possible, this will be costly and many councils are financially constrained.

Where councils have begun to implement best-practice approaches (such as water-sensitive design approaches to manage stormwater), adaptive capacity will be higher. Systems that follow these approaches are more tolerant of extremes. Notably, current design standards vary around New Zealand, as do the capability and resourcing capacity of councils, contractors and designers to implement changes (Hughes et al, 2019), impacting the adaptive capacity of the broader wastewater and stormwater industry.

Wastewater treatment plants also have a low adaptive capacity. Their location is constrained by the networks that serve them. Both rising seas and groundwater levels place pressure on these important assets, and drive a need for strategies to defend and accommodate the hazard in the short term, allowing time for adaptive approaches to be deployed.

Consequence

Significant lengths of wastewater and stormwater networks across New Zealand are exposed and sensitive to climate hazards. This could result in significant disruptions and cascading consequences to communities, which will increase over time (Paulik et al, 2019a, 2019b).

Inland and coastal flooding will lead to increases in inflow and infiltration of surface and groundwater into wastewater systems and treatment plants. This will increase the frequency of uncontrolled wastewater discharges, and instances of untreated human and industrial waste, toxic material and debris being discharged into receiving environments (American Progress, 2014; Watercare, 2020). Communities located near enclosed harbours or estuaries will potentially be at the highest risk from public health impacts and loss of amenity value (Hughes et al, 2019). As wastewater treatment plants are not designed to remove high concentrations of salts, salinity impacts from rising groundwater may require more advanced treatment processes (Chappelle et al, 2019; Lechevallier, 2014).

Similarly, the increased frequency and magnitude of flood events associated with climate change could have significant impacts on stormwater systems. As well as the physical damage, the capacity of systems could be overwhelmed, resulting in reduced levels of service, disruption to communities, and the mobilisation of contaminants into receiving environments (Hughes et al, 2019). Further, the failure of stormwater systems could have further flooding impacts, including on transportation infrastructure (White et al, 2017b). The consequences will be worse in low-lying areas with low-gradient systems. Sea-level rise and associated groundwater rise could more severely impact these systems, exacerbating flooding within communities.

Severe drought can have a range of physical and operational impacts on wastewater and stormwater pipelines. Wastewater impacts can adversely affect the receiving environment through poorly treated wastewater being discharged, with significant consequences for ecosystems and communities that rely on those environments. With increasing frequency and severity of droughts, there may be cracking and ground subsidence, along with other operational impacts, resulting in the need for extra maintenance to protect service levels (White et al, 2017b).

The potential consequences for Māori are significant. These include the contamination and consequential reduced mauri (life force) of bodies of water (Manning et al, 2015), and diminished ability of Māori to participate in cultural practices such as gathering of food (mahinga kai). Māori communities have a strong connection to their ancestral lands and water bodies, to which a large aspect of their identity is tied (Smith et al, 2017). Other implications may include deterioration of mana whenua and the ability to exercise customary rights and undertake kaitiaki activities.

Interacting risks

Climate change impacts on wastewater and stormwater systems are likely to affect all other domains significantly. Hughes et al (2019) identify a wide range of social, cultural, economic and environmental implications that can arise from climate change impacts on stormwater and wastewater systems. These include community disruption (H1), losses of amenity (H1) (which can be ongoing and recurring) and the effects on people’s lives, which can lead to adverse mental and physical health outcomes (H3, H7). Environmental implications include reduced health of waterways and associated freshwater and marine ecosystems from increased wastewater overflows or discharge of stormwater contaminants. Such events can have a multitude of effects on aquatic ecosystems (N3, N6, N7). Economic implications include direct costs of replacing or repairing damaged assets, the cost of action taken to adapt (which could include managed retreat) and economic losses from business disruption and increasing insurance costs (E1, E6).

Adaptation

Adaptation varies between councils and water supply authorities that manage stormwater and wastewater systems. Auckland's Watercare, for example, has developed a climate change strategy that includes a focus on climate resilience for its wastewater network.

Most councils consider climate change when designing or retrofitting new systems; however, there is acknowledged inconsistency in approaches around New Zealand.

Confidence: High agreement, medium evidence

Overall, there is a high level of agreement that wastewater and stormwater infrastructure is exposed and sensitive to climate change. There is medium strength of evidence on exposure due to sea-level rise currently and into the future, and the general sensitivity of infrastructure to climate change impacts. However, further research is needed to determine exposure of infrastructure to flooding, groundwater rise and drought.

Table 59: B4 Risk to wastewater and stormwater systems (and levels of service): Urgency profile

<table>
<tr><th colspan="7">B4 Risk to wastewater and stormwater systems (and levels of service): Urgency profile</th></tr>
<tr><th>Urgency category</th><th colspan="2">Proportion of urgency</th><th colspan="4">Description of actions</th></tr>
<tr><td>More action needed</td><td colspan="2">50</td><td colspan="4">Urgent consideration on infrastructure provision for the current and future issues associated with changing rainfall patterns on the three waters network.</td></tr>
<tr><td>Research priority</td><td colspan="2">40</td><td colspan="4">Urgent need to develop knowledge, guidance and legislation to support resilient design approaches across all regions and levels of government in New Zealand.</td></tr>
<tr><td>Sustain current action</td><td colspan="2">10</td><td colspan="4">Maintain current focus in major centres on improvements to urban water quality over the next five years.</td></tr>
<tr><td>Watching brief</td><td colspan="2">0</td><td colspan="4"></td></tr>
<tr><td>Adaptation urgency</td><td colspan="2">85</td><td>Confidence</td><td colspan="3">High agreement, medium evidence</td></tr>
<tr><td>Consequence</td><td>Now</td><td>Major</td><td>2050</td><td>Extreme</td><td>2100</td><td>Extreme</td></tr>
</table>

6.4.5 B5 Risks to ports and associated infrastructure due to extreme weather events and ongoing sea-level rise

Risk summary

Ports in New Zealand are currently at low risk from extreme weather events and ongoing sea-level rise. These risks are likely to increase in the future due to climate change, particularly as they relate to associated natural hazards such as coastal flooding, strong winds and extreme weather events. In future these risks have the potential to impact on port infrastructure and their operational capability. Associated infrastructure, such as petroleum storage in coastal areas, could also be at risk.

The exposure of ports and associated infrastructure will be influenced by factors such as geographic setting, wharf heights, tidal ranges, channel depths, and operating ranges for cranes and machinery. The sensitivity of ports and infrastructure is driven by their operational characteristics, and the design, condition and age of structures, buildings and equipment. Internationally, there is good understanding of the general sensitivity of ports; however, detailed understanding of sensitivity in relation to New Zealand ports is limited.

The adaptive capacity of port infrastructure will vary considerably around New Zealand. It depends on factors such as port design, road and rail access, management and governance, and the availability of funding for delivering adaptation actions.

Exposure

Ports and associated infrastructure are likely to be exposed to future extreme weather events (including strong winds, storms and ex-tropical cyclones), sea-level rise, and associated coastal and inland flooding. Quantitative data on specific port exposure around New Zealand are limited, and further assessments are needed to better understand the exposure of ports and infrastructure both current and under RCP4.5 and RCP8.5 projections (Local Government New Zealand, 2019).

Exposure will differ for each port, and be influenced by factors such as geographic setting, wharf heights, tidal ranges, channel depths, and operating ranges for cranes and machinery. For ports in low-lying areas (such as Greymouth, Westport, Whanganui and possibly Gisborne), sea-level rise may result in permanent inundation over time, (Gardiner et al, 2008); further detailed analysis is required to better understand this.

Associated infrastructure, such as petroleum infrastructure, will also be exposed to future extreme weather events, sea-level rise, and associated flood hazards; further assessments are needed to determine the scale and extent of this.

Sensitivity

The sensitivity of ports and associated infrastructure is driven by the physical and operational characteristics of specific ports, and the design, condition and age of structures, buildings and equipment.

Sea-level rise under RCP4.5 or RCP8.5 could result in extreme storm tides (including higher storm surges), exceeding wharf levels. This would affect operation of berth facilities, particularly impacting roll-on roll-off vessels such as the Cook Strait ferries (Gardiner et al, 2008). Internationally, ports and associated infrastructure (such as connecting coastal roads and rail lines) have been found to be sensitive to the impacts of transient or permanent flooding from sea-level rise, storm surges and waves (Astariotis, 2018). While the operational capability of ports is predicted to be adversely impacted in most cases, sea-level rise may provide opportunities for ports to berth ships with deeper draught.

Flooding could potentially impact on the ability of New Zealand ports to operate (Gardiner et al, 2008). Vessel navigation may be interrupted and delayed during flood conditions, especially for ports near rivers, due to debris being carried in flood waters causing damage to vessels and port infrastructure (Gardiner et al, 2008). Surface flooding could damage port buildings, roads and railways, affecting access and the transfer of cargo (Gardiner et al, 2008). Associated infrastructure, such as petroleum storage infrastructure, can also be affected by flooding. Large storage tanks can ‘float’, creating the potential for hazardous spills and contamination of surrounding environments (United States Department of Energy, 2015).

The operation of ports could also be sensitive to extreme weather events and associated strong winds and heavy rainfall. Strong winds can damage port buildings, crane infrastructure, containers, and associated equipment, and could cause operational delays due to ship handling difficulties and impacts on manoeuvring, berthing and loading operations (Gardiner et al, 2008; Astariotis, 2018; Scott et al, 2013). More significant weather events could damage navigational infrastructure, such as aids to navigation (ATONs), and increase the risk of serious maritime incidents. This increases the risk of vessel casualties, impacting marine pollution and the need for vessel salvage (Gardiner et al, 2008).

Heavy rainfall could directly affect port operations through reduced navigation visibility and surface water flooding (Gardiner et al, 2008). Storm surges may also cause overtopping and damage of breakwaters, and additional wave penetration and seiching are likely to cause excessive ship movement at berth, and possibly damage ship and wharf structures and interrupt loading operations (Gardiner et al, 2008).

Adaptive capacity

The adaptive capacity of port infrastructure will vary considerably around New Zealand. Climate change impacts and rising sea levels are unlikely to require existing ports to be totally relocated. However, the ability to adapt to climate change will depend on the port design, road and rail access, management and governance of each port, and the availability of funding for delivering adaptation actions.

Assets likely to be affected by climate change include port facilities such as cranes and gantries, which will need to be assessed for changing operational requirements. Storage facilities may need to be changed or upgraded to accommodate more extreme events and changes in temperature, and changes made to drainage to manage increased flooding of the facilities. On the marine side, modifications or enhancement to existing breakwater systems will need to be considered, as well as upgrades of wharves and berths to cater for expected sea-level rise projections, and any increase in exposure to extreme events.

Assessments of required changes in technology, logistics, training, planning and management of port operations can also increase adaptive capacity of the facility. Working in partnership with local government, investors and supply chain providers to meet changing needs and requirements can enable connected logistic hubs to be more resilient to the impacts of climate change.

Connecting infrastructure (such as road and rail), however, will have a lower level of adaptive capacity than ports. Yet ports will continue to rely on these links continuing to function, which port authorities have limited control over. Road and rail access may need to be modified, and modal shifts considered to improve resilience by introducing elements of redundancy.

Consequence

Ports are critical infrastructure. They facilitate billions of dollars of trade both internationally and nationally, and act as vital lifelines in a natural hazard event (New Zealand Lifelines Council, 2017).

Associated infrastructure is often critical at a regional or national level. For example, New Zealand is highly reliant on petroleum infrastructure at ports for the storage and distribution of petroleum around New Zealand. This directly supports economic activity, public service delivery, and transportation. By mid-century, the impact of climate change on associated petroleum infrastructure may be of less importance, as New Zealand may be less reliant on petroleum as an energy source, through increased electrification of transport systems and industry.

Information on the impact of climate change on ports and associated infrastructure is limited for New Zealand. However, given the importance of this infrastructure and locational constraints, the risk to ports and infrastructure from climate change will increase over time.

Interacting risks

Ports and their associated infrastructure are nationally significant assets, and climate change could cause complex interacting and cascading risks to them, with significant economic and social implications. These will interact with risks in the economy and governance domains, including risks to the disruption to supply chains (E7) and emergency management response capability (G6). There may also be risks to marine environments, because ongoing modifications to the marine environment (for example, dredging) are needed to maintain operations under a future climate (N1, N8). Increased temperatures can affect the types of organisms that live on a ship's hull, increasing the risk of invasive organisms. Serious maritime incidents and damage to ports and associated infrastructure could also lead to marine pollution and impacts on marine ecosystems (N8).

Confidence: High agreement, low evidence

There is a high level of agreement that ports and associated infrastructure are exposed and sensitive to climate hazards and associated flood hazards. In general, the strength of evidence is low for the sensitivity and exposure of ports, and potential interdependencies and cascading impacts. Further research is needed to build knowledge of the climate risks faced by ports at present and in the future under RCP4.5 and RCP8.5 projections.

Adaptation

Ports of Auckland have conducted assessments of climate risk. However, engagement undertaken for the National Climate Change Risk Assessment for Aotearoa New Zealand (NCCRA) revealed no further information on adaptation actions planned or under way in relation to this risk.

Table 60: B5 Risks to ports and associated infrastructure: Urgency profile

<table>
<tr><th colspan="7">B5 Risks to ports and associated infrastructure: Urgency profile</th></tr>
<tr><th>Urgency category</th><th colspan="2">Proportion of urgency</th><th colspan="4">Description of actions</th></tr>
<tr><td>More action needed</td><td colspan="2">10</td><td colspan="4">Central government to lead an integrated approach to understanding climate change risk for ports, and associated adaptation planning.</td></tr>
<tr><td>Research priority</td><td colspan="2">60</td><td colspan="4">Strategic view for all New Zealand ports to establish a nationally consistent approach to identifying risks associated with climate change, including interdependencies and cascading impacts.</td></tr>
<tr><td>Sustain current action</td><td colspan="2">30</td><td colspan="4">Organisations to continue their ongoing operational responses to manage current and future risk associated with climate change.</td></tr>
<tr><td>Watching brief</td><td colspan="2"></td><td colspan="4"></td></tr>
<tr><td>Adaptation urgency</td><td colspan="2">70</td><td>Confidence</td><td colspan="3">High agreement, low evidence</td></tr>
<tr><td>Consequence</td><td>Now</td><td>Minor</td><td>2050</td><td>Moderate</td><td>2100</td><td>Major</td></tr>
</table>

6.4.6 B6 Risks to linear transport networks due to changes in temperature, extreme weather events and ongoing sea-level rise

Risk summary

New Zealand's road and rail networks, or 'linear transport networks', are at risk from increases in temperature, extreme weather events, drought and sea-level rise. They are also exposed to risks from associated natural hazards such as inland flooding, coastal flooding, coastal erosion, landslides and groundwater rise, all of which are projected to increase in frequency and severity due to climate change. These impacts could cause widespread disruptions to New Zealand's transport network in the future.

Road and rail networks allow people and goods to move across New Zealand. These networks provide connectivity for communities, as well as access to critical (lifeline) utilities such as airports, ports, and power or water infrastructure. Climate change could cause temporary disruption, and temporary or permanent damage to networks, and potentially require relocation from at-risk locations.

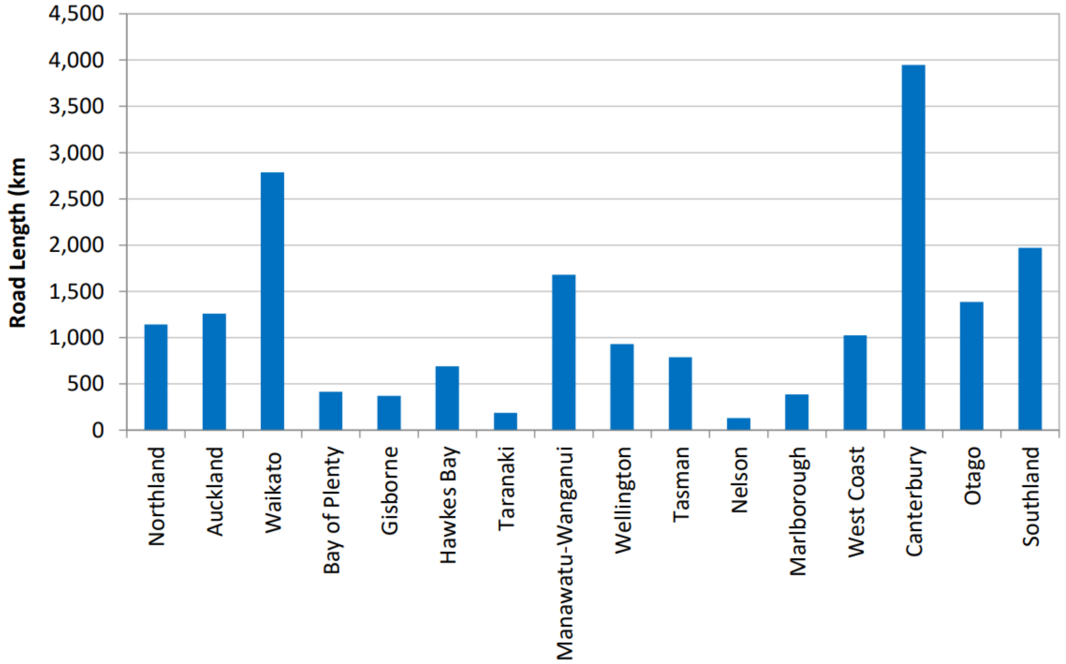
There is limited ability to adapt existing infrastructure in a cost-effective manner, due to the inherent design constraints of roads and rail. For instance, road and rail are generally fixed, have long design lives, and provide essential services that are costly to interrupt. However, new infrastructure can be relocated away from risk areas or designed to accommodate projected changes to the climate.

Given the location of many Māori communities in coastal regions and adjacent to rivers, access roads to marae are often exposed to flooding, coastal processes and landslides. Damage to the transport network could cut off marae and wider Māori communities increasingly frequently.

Exposure

Transport networks are exposed to increases in temperature (heatwaves, hot days and drought), extreme weather events (heavy rainfall, storm events) and ongoing sea-level rise (exacerbating coastal flooding and erosion).

Figure 18: Regional-level road network exposure to inland flood hazard (Paulik et al, 2019a)



At present, more than 19,000 km of road, or about 20 per cent of New Zealand's road network, is located in inland flood hazard areas (Paulik et al, 2019a). As figure 18 shows, Canterbury has the greatest exposure, with over 3900 kilometres exposed, followed by Waikato with more than 2500 kilometres and Southland with just under 2000 kilometres exposed. Over 1500 kilometres of railway is currently exposed to inland flood hazards around New Zealand (Paulik et al, 2019a). Railway network exposure exceeds 200 kilometres in the Manawatu–Whanganui and West Coast regions, and 150 kilometres in the Auckland, Waikato, Northland and Canterbury regions (Paulik et al, 2019a). Exposure of transport networks to flooding is likely to increase under both RCP4.5 and RCP8.5, although only limited assessments of future flood risk due to climate change have been done.

Road and rail networks are also highly exposed to coastal flooding (Paulik et al, 2019b). New Zealand has about 1400 kilometres of roads currently exposed to coastal flooding. The Waikato region has 342 kilometres of roads exposed, followed by the Bay of Plenty at 234 kilometres and Canterbury at 243 kilometres (Paulik et al, 2019b). About 87 kilometres of rail networks are exposed at present, of which Otago has 25 kilometres and Auckland 10 kilometres of commuter rail services (Paulik et al, 2019b). Exposure of transport networks to coastal flooding is projected to increase under both RCP4.5 and RCP8.5. Under RCP8.5 at 2100, about 2710 kilometres of roads and 180 kilometres of rail networks are projected to be exposed (Paulik et al, 2019b).

Road and rail networks around New Zealand are potentially exposed to higher temperatures and drought – leading to potential land subsidence, degradation of asphalt and buckling of rail lines. Between 2004 and 2008, Gardiner et al (2009) recorded 78 events throughout the national rail network of tracks buckling due to heat. Road and rail networks in the north are at greater risk from climate change, as temperatures and hot days are projected to be higher in these locations. Exposure to higher temperatures will increase under both RCP4.5 and RCP8.5, with higher exposure projected under RCP8.5.

Groundwater rise is poorly understood in New Zealand. However, it is recognised as an emerging issue in a number of coastal areas, and as having potential to particularly impact on roads.

Sensitivity

The sensitivity of linear transport networks to extreme weather events depends on the physical condition of the assets, local ground conditions, and design of the infrastructure itself (Gardiner et al, 2009). Transport networks are sensitive to frequent inland or coastal flood events. These events can result in short-term disruption and closure while the road or rail route is impassable, and larger events can lead to damage (for example, scour, erosion or washout) (New Zealand Lifelines Council, 2017). Large rainfall events can also lead to landslides. Recent events have demonstrated they can cause substantial damage to road and rail networks.

The transport network is currently sensitive to these hazards, as numerous examples of road and rail disruption, damage and closure demonstrate. The 2019 Canterbury floods resulted in damage and closures to state highways connecting North and South Canterbury after the Rangitata River burst its banks. King tide flooding of State Highway 1 north of the Auckland Harbour Bridge has occurred a number of times in the past five years, resulting in inundation and lane closures (Auckland Transport, 2018). The sensitivity of the rail and road networks to inland flooding is partly related to inadequacies in culverts and drainage systems (Rushbrook and Wilson, 2007).

Increased temperatures can cause damage and disruption to both the rail and road network, with extreme heat causing buckling of rail lines and degradation of asphalt road surfaces. All railway networks are sensitive to increased air temperature, which can buckle tracks and cause signalling system overheating and outages (Gardiner et al, 2009). These impacts already occur regularly, with the result that, for example, Metlink in Wellington has placed permanent temperature monitoring equipment across its network (Wellington.Scoop, 2019). High temperatures have resulted in signalling system overheating and outages in Petone (Wellington) in 2019, and have derailed a goods train in National Park in 2016 due to track buckling (Wellington.Scoop, 2019; Stuff, 2016a). Higher temperatures can also damage and degrade road networks, with pavement surfaces melting on hot days (Gardiner et al, 2008).

High groundwater can damage road formations, lead to shrink–swell issues when combined with drought conditions, and increase liquefaction susceptibility.

Adaptive capacity

Many factors affect the adaptive capacity of linear transport infrastructure, including availability of funding, asset renewal cycles, and the fragmentation of ownership (across the New Zealand Transport Authority, KiwiRail and territorial authorities). Because of this wide range of influences, adaptive capacity varies considerably.

The length of road available per person in New Zealand is one of the highest in the world, which could constrain funding. Because local government is responsible for maintaining local roads, regions could differ in their adaptive capacity because of funding constraints faced by territorial authorities and regional councils.

Transport assets also have long life cycles. It is easier to adapt assets for climate change when they are scheduled for renewal; in contrast, recently constructed infrastructure that does not already consider climate change will be more costly to adapt.

Another issue is the lack of consistent approaches (such as design standards and decision support tools) to account for climate change. This inconsistency reduces the adaptive capacity of the road and rail systems. Adoption of improved, consistent methods and approaches will improve risk reduction for transport infrastructure, through appropriate siting of infrastructure, using suitable standards and designing for uncertainty, redundancy and flexibility.

Consequence

Extreme weather events, ongoing sea-level rise and increased temperatures could damage and disrupt linear transport networks. These networks provide a critical service to all communities in New Zealand and are essential to the economy.

Road networks provide critical access to lifeline utilities (power, water, gas, telecommunications, health care) and other essential services. Any disruption to transport can lead to significant cascading consequences.

Co-location of transport networks is common across New Zealand, exposing many road and rail networks to common hazards, with limited alternative routing. The New Zealand Transport Authority has assessed the resilience of the transport network, including weighting for suitable detour routes given their importance of overall resilience. For example, the West Coast highway in the South Island (State Highway 6) has no alternative route along much of its length. Climate change hazards and associated flooding and erosion could lead to widespread, and potentially long-term, service disruption.

Interacting risks

Impacts on the transport network are exacerbated by a range of institutional and governance factors. These include a lack of alignment and integration within and between the transport sector organisations and relevant legislation (G2). There is also limited application of methods to prioritise investment and access funding for adaptation (G1, G5). Damage and outage to the land transport network can also impact on other critical services such as airports (B7), three-waters (B1, B4) and ports (B5), as well as on communities (B2) and emergency services. These risks could potentially have social and cultural impacts, including physical and mental health impacts, reduced social cohesion, and reduced ability to access cultural sites such as marae (H3, H4, H5, H7, H8, B2). These ultimately can lead to cascading economic impacts across all sectors at local, regional and national levels, including tourism (E4), the primary sector (E3), fisheries (E5) and broader business impacts (E7).

Confidence: High agreement, medium evidence

There is a high level of agreement that transport networks are exposed and sensitive to climate hazards. There is strong evidence on the scale of present exposure, but further research is needed to determine future exposure due to climate change (in particular for flood hazards). The evidence on the sensitivity of roads to present-day natural hazards is robust.

Adaptation

A number of local and central government adaptation efforts are under way to reduce climate risks to linear transport networks. The New Zealand Transport Authority is currently developing a business case for a national resilience programme (including climate hazards), as well as a national coastal exposure assessment, which will inform a climate change adaptation plan. Most regional councils regularly map flood and coastal hazards to inform planning. Some territorial authorities are beginning to build adaptation planning into long-term plans.

Table 61: B6 Risks to linear transport networks: Urgency profile

<table>
<tr><th colspan="7">B6 Risks to linear transport networks: Urgency profile</th></tr>
<tr><th>Urgency category</th><th colspan="2">Proportion of urgency</th><th colspan="4">Description of actions</th></tr>
<tr><td>More action needed</td><td colspan="2">20</td><td colspan="4">For coastal inundation, more action is needed across the road and rail networks to best understand future steps. For effective action, consideration around funding and legislative constraints will be required to reduce current and future risks.</td></tr>
<tr><td>Research priority</td><td colspan="2"></td><td colspan="4"></td></tr>
<tr><td>Sustain current action</td><td colspan="2">80</td><td colspan="4">Current action in understanding and managing the majority of flood risk for the linear transport network is adequate currently and into the near future.</td></tr>
<tr><td>Watching brief</td><td colspan="2"></td><td colspan="4"></td></tr>
<tr><td>Adaptation urgency</td><td colspan="2">60</td><td>Confidence</td><td colspan="3">High agreement, medium evidence</td></tr>
<tr><td>Consequence</td><td>Now</td><td>Major</td><td>2050</td><td>Major</td><td>2100</td><td>Extreme</td></tr>
</table>

6.4.7 B7 Risk to airports due to changes in temperature, wind, extreme weather events and ongoing sea-level rise

Risk summary

New Zealand’s airports are at risk from projected changes in temperature, wind, extreme weather events and sea levels due to climate change. Airports are also at risk from associated natural hazards such as inland flooding, coastal flooding and coastal erosion. These hazards are projected to increase in frequency and severity over time.

Airports provide a vital link during business as usual and emergencies, and are specifically defined and listed as lifeline utilities in Schedule 1 of the Civil Defence Emergency Management Act 2002. Climate change could result in damage to airport infrastructure and assets, as well as operational impacts from extreme weather events and flooding. Increased numbers of hot days could also affect aircraft take-off performance and damage runway pavements. Because airports are networked to surrounding infrastructure, such as access roads and other domestic and international airports, the potential for cascading impacts and associated consequences for New Zealand is higher.

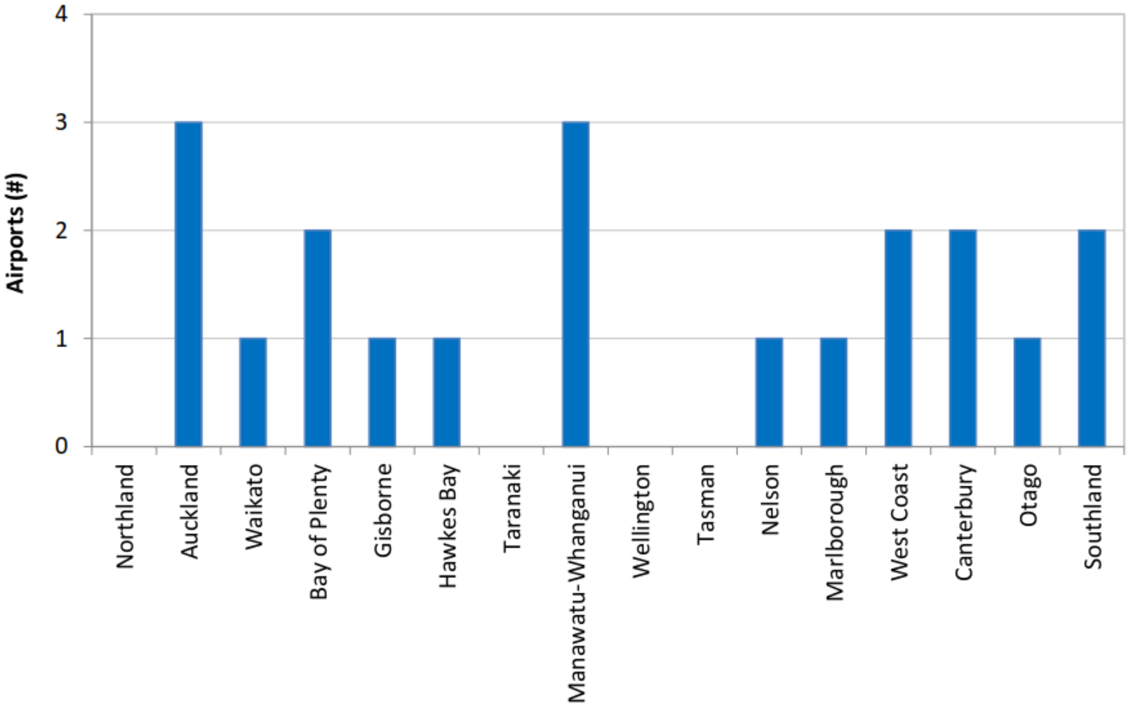
The adaptive capacity of airports varies. Some airports are investing in plans to address key risks, whereas others face a lack of finance as a major hurdle, limiting their adaptive capacity.

Exposure

Airports are exposed to increases in temperature, wind, extreme weather events (heavy rainfall leading to inland flooding) and ongoing sea-level rise (exacerbating coastal flooding and erosion). The airport components exposed are the airfield (including the runway, taxiway and apron), terminals, navigation and ground equipment, and airport and aircraft operations (including aircraft take-off and landing, loading and unloading). Exposure of all components is likely to increase by 2050 and 2100 under both RCP4.5 and RCP8.5.

Figure 19 presents current exposure to inland flooding (Paulik et al, 2019a). This shows New Zealand currently has around 20 airports exposed to inland flood hazard areas, including Auckland and Christchurch international airports (Paulik et al, 2019a). This exposure of airports to flooding is likely to increase under both RCP4.5 and RCP8.5, although few assessments of future flood risk due to climate change have been done.

Figure 19: Regional airport exposure within the flood hazard area (Paulik et al, 2019a)



Airports are also exposed to sea-level rise and associated coastal flooding. At present-day mean sea level, there are 13 airports with land exposed to coastal flooding (Paulik et al, 2019b). This includes Auckland and Wellington international airports, and major domestic airports in Tauranga, Hawke's Bay, Nelson and Dunedin (Paulik et al, 2019b). Coastal erosion, exacerbated by sea-level rise and extreme weather events, has been raised as an issue by representatives from major airports in New Zealand during consultation for the NCCRA. Exposure of airports to coastal flooding is likely to increase at 2050 and 2100 under RCP4.5 and RCP8.5, with an estimated 14 airports exposed in 2100 under RCP8.5 (Paulik et al, 2019b).

The exposure of airports to strong winds is projected to increase, which could damage airport ground equipment and affect operations (Ministry for the Environment, 2018; National Academies of Sciences, Engineering, and Medicine, 2012). Airports are also exposed to extreme heat, which can affect runway pavements and aircraft take-off performance, and the number of hot days is projected to increase under RCP4.5 and RCP8.5 (Ministry for the Environment, 2018).

Sensitivity

Airport infrastructure, equipment and operations are sensitive to increased temperature, wind, extreme weather events and ongoing sea-level rise, as well as associated natural hazards. The sensitivity of airports is driven by a number of factors, including the condition and design of airport assets and infrastructure and operational requirements.

Airports are sensitive to flooding, which can damage airport buildings, runways and other infrastructure (Burbidge, 2016; National Academies of Sciences, Engineering, and Medicine, 2019). Current aerodrome surface drainage capacity may be sensitive to increased flooding, which could result in disruptions and delays to airport operations (Burbidge, 2016). Ground transport links to airports may also be at risk from inundation (Burbidge, 2016). Navigation equipment at and below ground level is particularly sensitive to the impacts of inland and coastal flooding (National Academies of Sciences, Engineering, and Medicine, 2012). Flood hazards may lead to permanent inundation of infrastructure and capacity loss unless preventative measures are taken, such as constructing coastal defences (National Academies of Sciences, Engineering, and Medicine, 2012).

Airports in New Zealand are currently sensitive to extreme weather events and increased storminess. Strong winds can impact runway usage and capacity, result in difficulties for planes taking off and landing safely, and delay ground operations and maintenance (National Academies of Sciences, Engineering, and Medicine, 2012). Thunderstorms can also affect airport operations due to lightning damage to airport equipment and power systems, and they can delay and disrupt ground operations (National Academies of Sciences, Engineering, and Medicine, 2012; Otago Daily Times, 2019a).

Airports are sensitive to long-term changes in wind direction. As runways are designed based on prevailing winds, if those winds changed airports might need to use crosswind runways more often or to relocate runways. For some airports, such adjustments may require significant investment (Burbidge, 2016; National Academies of Sciences, Engineering, and Medicine, 2012).

Airports are also sensitive to pavement deformation and damage due to extreme temperatures (National Academies of Sciences, Engineering, and Medicine, 2012). This is currently impacting on runway pavements, such as when the Auckland Airport runway was closed for emergency repairs in February 2020 (RNZ, 2020a). Higher temperatures can also affect airport operations by impacting on aircraft take-off performance (Coffel et al, 2017). Take-off performance is particularly affected in airports with short runways and high temperatures, or those at high elevations (Coffel et al, 2017).

Adaptive capacity

Adaptation of airport buildings, infrastructure and assets through relocation, redesign, flood defences or changing drainage capacity is technically feasible, but likely to require significant capital investment (Burbidge, 2016). Climate change mitigation responses (and other impacts on demand for air travel) could also affect adaptive capacity and the ability of airports to finance adaptation actions.

Reducing risks to airports also depends on strengthening supporting infrastructure, such as road and power networks, which airport authorities generally do not have control over. If major changes to airport infrastructure are required, current governance arrangements in New Zealand could affect the adaptive capacity of airports. For example, the relocation of a runway may involve significant and complex consenting requirements under the Resource Management Act 1991.

Consequence

Operational impacts of flooding on airports can include flight delays, temporary apron or runway closure, and reduced access to airports (National Academies of Sciences, Engineering, and Medicine, 2012, 2019). This is a nationally significant risk, as airports are central to the movement of people and goods and support the functioning of New Zealand’s economy; they are gateways for tourism, commerce and business. The three major airports (Auckland, Christchurch and Wellington) together represent around 34 million passenger trips per year on average,[14] which amounts to about 80 per cent of total New Zealand passenger trips (Airways, 2019). Airports maintain connectivity for regions across New Zealand and provide crucial transport links during emergencies. Airports are specifically defined and listed as lifeline utilities in the Civil Defence Emergency Management Act 2002.

Interacting risks

Climate change risks to airports could result in complex interacting risks with significant economic impacts, including risks to supply chains (E7) and the tourism sector (E4). Regional airports service much of New Zealand and can have national significance in an emergency (G6). For example, Hokitika Airport could become critical as a transport link for the West Coast if the region is isolated by road (New Zealand Lifelines Council, 2017).

Confidence: High agreement, low evidence

There is a high level of agreement that airports are both exposed and sensitive to climate change. There is relatively strong evidence for the exposure of airports to sea-level rise and coastal flooding, but evidence is lacking for future flood risk under RCP4.5 and RCP8.5. Research globally has examined the sensitivity of airports and airport operations to natural hazards; however, little New Zealand-specific research is available.

Adaptation

A number of airport authorities (and their local government owners) are carrying out risk assessments and adaptation planning. Some airports are looking at elevating navigation equipment and power assets to reduce exposure, and a number are planning for future engineering solutions and considering relocation of assets where needed.[15]

Table 62: B7 Risk to airports: Urgency profile

<table>
<tr><th colspan="7">B7 Risk to airports: Urgency profile</th></tr>
<tr><th>Urgency category</th><th colspan="2">Proportion of urgency</th><th colspan="4">Description of actions</th></tr>
<tr><td>More action needed</td><td colspan="2"></td><td colspan="4"></td></tr>
<tr><td>Research priority</td><td colspan="2">20</td><td colspan="4">Research into specific hazard impacts on airports is needed, given they are classed as critical infrastructure. This includes further understanding of any barriers to future adaptations needed for climate change in existing environmental legislation.</td></tr>
<tr><td>Sustain current action</td><td colspan="2">80</td><td colspan="4">Knowledge development and associated adaptation planning for climate change are occurring and should continue in organisations.</td></tr>
<tr><td>Watching brief</td><td colspan="2"></td><td colspan="4"></td></tr>
<tr><td>Adaptation urgency</td><td colspan="2">55</td><td>Confidence</td><td colspan="3">High agreement, low evidence</td></tr>
<tr><td>Consequence</td><td>Now</td><td>Major</td><td>2050</td><td>Major</td><td>2100</td><td>Extreme</td></tr>
</table>

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[14] This report was completed before the arrival of the COVID-19 pandemic in New Zealand, and the resulting impacts on air travel.

[15] Meeting between risk assessment team and airport representatives, 9 March 2020.

6.4.8 B8 Risks to electricity infrastructure due to changes in temperature, rainfall, snow, extreme weather events, wind and increased fire weather

Risk summary

Climate change presents a range of risks for electricity infrastructure in New Zealand. These risks are predominantly associated with changes in temperature, rainfall, snow, extreme weather events, wind and fire weather. Electricity infrastructure is also at risk from natural hazards such as inland and coastal flooding.

For generation infrastructure, present-day risks are low, with limited changes in risk projected into the future. New Zealand's heavy reliance on renewable electricity sources (particularly hydro and wind) means it has significant exposure to climate variability. Specific risks include potential changes in water flows (resulting from changes in rainfall and snowmelt) and in wind patterns, affecting security of supply and associated generation capacity. Climate change could also affect demand for electricity through increased cooling demand in summer and reduced heating demand in winter. This will cascade impacts into physical infrastructure, which could require upgrades to adjust for changing demand peaks.

Transmission and distribution infrastructure is currently at risk of disruption and damage from climate change hazards, including extreme weather and fire weather, and this risk will increase into the future. Climate change risks to electricity transmission and distribution infrastructure could have significant potential consequences for New Zealand's energy security if they are not well managed.

Electricity generation in New Zealand has a moderate level of adaptive capacity, as diverse distributed generation sources are connected to the national grid. A number of electricity generation companies are actively assessing, modelling and planning for risks associated with a changing climate. The results of this work should provide for more informed decisions that account for uncertainty wherever possible, enhancing adaptive capacity. Transmission and distribution infrastructure has a lower level of adaptive capacity, given that many of the networks are already operating at capacity.

Māori face potential flow-on effects from increased electricity demand in summer at the expense of ecological or cultural values (Interim Climate Change Committee, 2019).

Exposure

Elements of New Zealand's electricity generation, transmission and distribution network are exposed to changes in temperature, rainfall, snow, extreme weather events, wind and fire weather. Exposure is expected to increase under both RCP4.5 and RCP8.5 over this century.

Electricity generation

New Zealand's generation infrastructure is exposed to changes in rainfall and snowmelt, which will affect inflows to dams supplying hydro-electric generators, reducing generating capacity. Similarly, changing wind patterns will affect generation from wind sources. Managing volatility in both water inflows and wind patterns is already a key challenge for New Zealand's electricity providers (Meridian Energy Limited, 2019).

Water storage for hydro-electric power generation is dominated by a few key reservoirs in the South Island and Lake Taupō in the North Island (Renwick et al, 2010). Generation is driven by a combination of rainfall and snowmelt, with snowmelt providing on average 50 per cent of spring and summer inflows into New Zealand's main hydro-electric storage reservoir in the Waitaki catchment (McKerchar et al, 1998). Modelling has indicated little change in total yearly inflow to hydro lakes by 2050, but seasonal changes are projected for the South Island, with summer inflows reducing and winter inflows increasing (Interim Climate Change Committee, 2019). North Island inflows are not expected to change by 2050 (Interim Climate Change Committee, 2019).

New Zealand's current wind energy resource is predominantly from westerly winds. Climate change could increase these westerly wind flows, particularly during winter and spring (Electricity Authority, 2018), potentially increasing generation capacity.

Generation infrastructure is also exposed to potential changes in electricity demand from climate change (for example, warmer winters meaning less demand for heating, or warmer summers meaning increased demand for cooling) (Interim Climate Change Committee, 2019; Meridian Energy Limited, 2019; Ministry of Business, Innovation and Employment, 2019).

Transmission and distribution infrastructure

Transmission and distribution infrastructure around New Zealand is exposed to extreme weather events, wildfire and associated natural hazards including inland and coastal flooding.

Extreme weather events, including extreme wind and rain, and coastal flooding from storm events and ex-tropical cyclones, currently affect the electricity network throughout New Zealand (Orion New Zealand Limited, 2019; Paulik et al, 2019b). Over the long term, the exposure of electricity networks to extreme weather events is likely to increase under both RCP4.5 and RCP8.5 (Ministry for the Environment, 2018).

Transmission and distribution infrastructure is currently exposed to wildfire in hotspots throughout New Zealand, and exposure is projected to increase this century (Pearce, 2019; Pearce et al, 2018). Fire exposure could also increase due to wildfires starting from electricity networks, particularly in rural areas. With more uncertainty over projected fire weather, it is difficult to identify the changing level of exposure between RCP4.5 and RCP8.5 out to 2100.

In terms of inland flood exposure, at present there are about 3400 kilometres of transmission lines and 5800 structures in inland flood hazard areas (Paulik et al, 2019a). Canterbury, Waikato and Manawatu–Whanganui have the highest transmission line exposure in these areas (Paulik et al, 2019a). Over the past decade, flooding has affected the electricity network (including pylons and substations) on numerous occasions across New Zealand (Powerco, 2017; Transpower, 2019; Vector Limited, 2017). Inland flood exposure is likely to increase under RCP4.5 and RCP8.5.

Transmission infrastructure is also exposed to coastal flooding at present, including around 120 kilometres of transmission lines, 180 support structures and two substation sites (Paulik et al, 2019b). Exposure of transmission networks to coastal flooding is projected to increase under both RCP4.5 and RCP8.5. Under RCP8.5 at 2100, about 187 kilometres of transmission lines and 305 support structures are projected to be exposed (Paulik et al, 2019b).

Sensitivity

Wind and hydro-electric generators are sensitive to changing water inflows, wind patterns and demand profiles due to climate change. Transmission and distribution infrastructure sensitivity is driven by the age, condition and design of structures.

Generation infrastructure

The sensitivity of generation infrastructure depends on inflows of water into reservoirs and the capacity of the network to respond to changes in demand for electricity (Climate Change Adaptation Technical Working Group, 2017). Although hydro-electricity stations are inherently sensitive to changes in rainfall and snowmelt, at present this is considered a manageable impact and does not pose a significant risk over the short term (Meridian Energy Limited, 2019).

The generation capacity of existing wind farms should increase as a result of climate change, but strong winds could also result in more instances where turbines need to be shut down to avoid damage from strong winds (Electricity Authority, 2018).

Generation infrastructure could also be sensitive to increases in demand and the potential flattening of the annual demand profile (due to increased demand for summertime cooling and irrigation and reduced wintertime heating requirements), although not all studies have reached these conclusions (BusinessNZ Energy Council, 2019; Climate Change Adaptation Technical Working Group, 2017; Electricity Authority, 2018; Transpower, 2018). While it is understood that energy generation is not overly sensitive to changes in peak demand, the electricity grid is vulnerable to increasing demand (Transpower, 2018), as discussed below.

Transmission and distribution infrastructure

Transmission and distribution infrastructure is currently sensitive to extreme weather events, fire weather and associated coastal and inland flooding (Climate Change Adaptation Technical Working Group, 2017).

Extreme weather events can damage the network and interrupt power supply throughout New Zealand (Orion New Zealand Limited, 2019). Transmission and distribution lines can be damaged by wind, including from falling trees and other windborne debris, and lightning (Burillo, 2018; Orion New Zealand Limited, 2019). Heavy rainfall can lead to flooding, landslides, and erosion, which can also damage the electricity network (Burillo, 2018; New Zealand Lifelines Council, 2017; Orion New Zealand Limited, 2019). Landslides can cause damage to overhead lines, and critical transmission lines pass through many areas of slip-prone terrain (New Zealand Lifelines Council, 2017). A recent example comes from the South Island floods in December 2019, when pylons were damaged due to river flooding, causing power outages (Transpower, 2019).

Underground cables tend to be more resilient to flood impacts, but floodwaters can scour bridges and attached cables (New Zealand Lifelines Council, 2017). Widespread flooding can also affect lower-level electrical generating equipment, such as substations, causing extended business interruption losses, although these are subject to high design standards (Burillo, 2018; Lawrence et al, 2016; New Zealand Lifelines Council, 2017).

Rural electricity networks are sensitive to fire weather in New Zealand. Wildfires can damage electricity network infrastructure and render power lines inoperable due to ionised air (Burillo, 2018). Networks are also potentially a source of ignition for fires (Burillo, 2018; Otago Daily Times, 2019b; Stuff, 2020). Ignitions can occur from the failure of distribution and transmission network components (Mitchell, 2013). This includes ignitions from an asset failure, such as transformer or substation failure, and those caused by a contact event, such as trees contacting powerlines (Cainey, 2019).

Adaptive capacity

Electricity generation in New Zealand has a moderate level of adaptive capacity, given there are diverse distributed generation sources connected to the national grid. A number of electricity generation companies are actively assessing, modelling and planning for risks associated with a changing climate. The results of this work should provide for more informed decisions, accounting for uncertainty wherever possible and enhancing adaptive capacity.

Transmission and distribution infrastructure has a lower level of adaptive capacity, given that many of the networks are already operating at capacity, fixed in location and controlled by population locations. Additionally, as distribution infrastructure is managed by numerous individual businesses that make their own investment decisions about resilience levels, and less funding is available, distribution infrastructure is likely to have lower adaptive capacity than transmission infrastructure (Climate Change Adaptation Technical Working Group, 2017).

Consequence

The electricity network is nationally significant infrastructure, needed for powering homes and businesses and delivering public services (Lawrence et al, 2016; New Zealand Lifelines Council, 2017). Failures of generation, transmission or distribution elements can have widespread, severe consequences across all sectors of New Zealand's economy and society.

The most critical components of the transmission and distribution network are those that transmit the largest volume of electricity, have limited redundancy, and supply critical customers. Businesses, public services, and critical national infrastructure rely on a functioning electricity network, and unmanaged climate change impacts could result in increased cost and reduced reliability (New Zealand Lifelines Council, 2017).

While impacts on transmission and distribution infrastructure are manageable at present, climate change is set to increase risks over this century, and this could present significant consequences to New Zealand if not well managed and planned for.

If electricity demand increases significantly, additional infrastructure will be required to provide for this increased demand, with long lead times and much investment needed (Interim Climate Change Committee, 2019; Meridian Energy Limited, 2020; BusinessNZ Energy Council, 2019). Increasing proportions of renewable generation (particularly wind and solar) could result in increasing intermittency in supply, especially when the levels of dams supplying hydro-electric generators are low during dry years (Transpower, 2018; Meridian Energy Limited, 2020).

Interacting risks

Risks to the electricity network will interact with a range of risks in the built environment, economy, natural environment, and human domains. Climate hazards, and associated impacts, could result in power interruptions leading to cascading risks to supply chains and business continuity (E7), the delivery of public services (including emergency services) (G6), and electrified transport systems (B3). The risk of electricity networks igniting fires will have cascading risks across domains, including risks to buildings and people (B2), human health and wellbeing (H3), and terrestrial ecosystems (N7). If demand for electricity increases, there could be increased investment in renewable energy projects. This could result in environmental risks and Māori-specific impacts in relation to ecological or cultural values (H5) (Interim Climate Change Committee, 2019).

Confidence: High agreement, medium evidence

There is high agreement that electricity infrastructure is exposed and sensitive to climate change impacts, with potentially high consequences. There is a strong understanding of the exposure and sensitivity of electricity infrastructure to climate change at present, but further research is needed to build an evidence base for long-term exposure under RCP4.5 and RCP8.5.

Adaptation

Most electricity generation companies are assessing future climate change risks and scenarios to understand potential future demand and how to plan and adapt to potential changes. Transpower are understood to be assessing climate change risk to transmission assets, such as substations, and are also looking at future demand scenarios and management options. Engagement for the NCCRA revealed limited information on adaptation actions planned or underway for distribution infrastructure in relation to this risk.

Table 63: B8 Risks to electricity infrastructure: Urgency profile

<table>
<tr><th colspan="9">B8 Risks to electricity infrastructure: Urgency profile</th></tr>
<tr><th>Urgency category</th><th colspan="2">Proportion of urgency</th><th colspan="6">Description of actions</th></tr>
<tr><td>More action needed</td><td colspan="2"></td><td colspan="6"></td></tr>
<tr><td>Research priority</td><td colspan="2">20</td><td colspan="6">Further knowledge and understanding is needed of physical climate change risks to transmission and distribution networks. Research on impacts of changing demand on generation, transmission and distribution is also a priority.</td></tr>
<tr><td>Sustain current action</td><td colspan="2">80</td><td colspan="6">Existing research has provided good knowledge to risks associated with climate change at an organisational level.</td></tr>
<tr><td>Watching brief</td><td colspan="2"></td><td colspan="6"></td></tr>
<tr><td>Adaptation urgency</td><td colspan="2">55</td><td>Confidence</td><td colspan="5">High agreement, medium evidence</td></tr>
<tr><td>Consequence</td><td>Now</td><td>Moderate</td><td>2050</td><td>Moderate</td><td>2100</td><td>Major</td><td>2150</td><td></td></tr>
</table>

6.4.9 B01 Opportunity for reduction in winter heating demand due to warmer temperatures

Households in New Zealand typically use about 15 per cent of their energy on space heating and 27 per cent on water heating (Electricity Authority, 2018). Energy use in New Zealand is significantly higher in winter (June to August) (Electricity Authority, 2018).

About a quarter of New Zealand households are estimated to be in fuel poverty (Howden-Chapman et al, 2012). Average indoor temperatures are cold by international standards, and occupants regularly report they are cold because they cannot afford to heat their houses (Howden-Chapman et al, 2012).

Fuel poverty is thought to be a factor in New Zealand's high rate of excess winter mortality (16 per cent) and excess winter hospitalisations (8 per cent) (Howden-Chapman et al, 2012). Warmer winters and fewer frosts due to climate change could reduce demand for winter heating (Ministry for the Environment, 2017c). This could lead to lower costs and reduced stress for those who cannot afford electricity. However, the effects of warmer winters on heating demand and fuel poverty are complex to predict, as non-climate factors, such as future energy policy, prices and housing quality, are also important considerations. Further, this reduction could be offset by increased air conditioning use in summer.

Table 64: B01 Opportunity for reduction in winter heating demand: Opportunity urgency profile

<table>
<tr><th colspan="4">B01 Opportunity for reduction in winter heating demand: Opportunity urgency profile</th></tr>
<tr><th>Urgency category</th><th>Proportion of urgency</th><th colspan="2">Description of actions</th></tr>
<tr><td>More action needed</td><td>40</td><td colspan="2">The condition of housing in New Zealand needs to be improved to support better public health outcomes and potential reductions in heating cost.</td></tr>
<tr><td>Research priority</td><td>20</td><td colspan="2">Understanding the benefits from warmer winter temperatures, potential risks from overheating in summer, and how New Zealand’s housing stock should be adapted.</td></tr>
<tr><td>Sustain current action</td><td>0</td><td colspan="2"></td></tr>
<tr><td>Watching brief</td><td>40</td><td colspan="2">Watch and monitor.</td></tr>
<tr><td>Adaptation urgency</td><td>65</td><td>Confidence</td><td>Medium agreement, low evidence</td></tr>
</table>

6.5 Gaps in knowledge

Across the built environment risks, there are substantial knowledge gaps. For some risks, such as the impact of climate change on landfills, airports and ports, there is a substantial knowledge gap across all elements of the risk. This includes a lack of understanding of exposure, vulnerability, and also research around consequence. Recent and historic events have been documented as a proxy for information. For all risks, a lack of consistent hazard information at a national scale, such as flooding from rivers and surface water, results in a knowledge gap for hazard exposure. This is particularly evident when looking to understand climate change scenarios and associated timeframes.

7 Governance domain | Rohe kāwanatanga

7.1 Domain description

Governance is understood as the relationships between, coordination mechanisms for and processes undertaken by the state, market and civil society to address collective issues (Driessen et al, 2012; Lange et al, 2013; Olson, 1965). The governance domain definition used in this risk assessment is the governing architecture and processes of interaction and decision-making that exist in and between governments, economic and social institutions. Governance permeates all aspects of New Zealand, from the Treaty partnership between Māori and the Government (the Crown) to the relationship between local government and communities, from the economy to the built environment to natural ecosystems.

Box provides a Māori perspective on the governance domain and an overview of the significance of the risks in this domain to Māori values and wellbeing.

Box 9: Māori perspective on rohe kāwanatanga – the governance domain

Rohe kāwanatanga – governance

Rohe kāwanatanga reflects the complex arrangement of decision-making between different entities of mana (power, control and authority) within, and interacting with, Māori. This includes partnerships with the Government (the Crown) through Te Tiriti o Waitangi. Cultural considerations such as kawa (protocols) and tikanga (customs and procedures) sit centrally within a Māori governance framework, which also drives taonga tuku iho – the intergenerational approach that considers the aspirations of whānau, hapū and iwi in decision-making.

The priority risks in this domain relate to both ongoing, gradual changes and extreme events resulting from climate change. They include the risk that the Government's response to these risks results in a breach of Te Tiriti ō Waitangi obligations, which would have wide-ranging consequences and may lead to a loss of trust, litigation and unrest. This section also identifies risks to emergency management response capability due to an increasing frequency and scale of extreme weather events overwhelming response systems. Māori have demonstrated the capacity to be first responders, including in the recent Kaikōura earthquake response; however, the geographic isolation of some Māori communities increases the risk of delayed emergency management for these communities. Gaps in the sharing and availability of mātauranga Māori to inform adaptation in conjunction with western knowledge pose a risk to informed decision-making.

7.2 Snapshot of issues and themes

Any meaningful response to climate change will involve the coordinated efforts of national, regional and local governments, non-government organisations, citizens and businesses. How these groups and institutions work together will have a significant effect on the degree to which New Zealand can reduce climate change risks and realise any opportunities arising from climate change.

As the urgency for a climate response builds, appropriate governance and decision-making are critical at a number of scales, including central and local governments, community groups, Māori organisations and iwi/hapū. Governance arrangements have been relatively effective in the past at designing policy on the basis of certainty. However, the use of static frameworks and responding to 'events', rather than using more proactive approaches, will not be sufficient in a rapidly warming and changing world. Climate change is already highlighting inadequacies in these institutional responses and the arrangements on which they are based. These range from how different levels of government understand and coordinate their roles and responsibilities in relation to climate change risk, to shortfalls in funding for addressing knowledge gaps and for building adaptive capacity. Inadequacies manifest, for example, in conflicting legislation and policy, short-term decision-making, and the application of processes and tools based on a static understanding of risk and historical parameters. Insufficient engagement with communities, stakeholders and partners exacerbates these inadequacies.

7.3 Summary of climate change risks

Table 65: Summary of climate change risks in the governance domain

Governance		
	Ratings	
Most significant risks	**Urgency**	**Consequence**
G1 Risk of maladaptation across all domains due to the application of practices, processes and tools that do not account for uncertainty and change over long timeframes.	83*	Extreme **
G2 Risk that climate change impacts across all domains will be exacerbated because current institutional arrangements are not fit for climate change adaptation. Institutional arrangements include legislative and decision-making frameworks, coordination within and across levels of government and funding mechanisms.	80	Extreme
Other priority risks examined in stage 2		
G3 Risks to governments and businesses from climate change-related litigation, due to inadequate or mistimed climate change adaptation.	78	Extreme
G4 Risk of a breach of Treaty obligations from a failure to engage adequately with and protect current and future generations of Māori from the impacts of climate change.	75	Major
G5 Risk of delayed adaptation and maladaptation due to knowledge gaps resulting from under-investment in climate change adaptation research and capacity building.	75	Major
G6 Risks to the ability of the emergency management system to respond to an increasing frequency and scale of compounding and cascading climate change impacts in New Zealand and the Pacific region.	70	Major
G7 Risk that effective climate change adaptation policy will not be implemented and sustained due to a failure to secure sufficient parliamentary agreement.	68	Extreme
G8 Risk to the ability of democratic institutions to follow due democratic decision-making processes under pressure from an increasing frequency and scale of compounding and cascading climate change impacts.	53	Major

* Urgency rating refers to the total adaptation and decision urgency rating (between 1 and 100).

** Consequence rating refers to the highest consequence rating assigned to this risk out of all three time periods (now, 2050, 2100). Section 7.4 provides the consequence rating for each time period for all the risks.

7.4 Climate change risks

7.4.1 G1 Risk of maladaptation across all domains due to the application of practices, processes and tools that do not account for uncertainty and change over long timeframes

Risk summary

Climate change adds to the uncertainties already faced by decision-makers (Beck, 2009; Scoones, 2019; Weitzman, 2011). Where decision-makers rely on practices that embed processes and tools that do not account for uncertainty and change over long timeframes, the likelihood of maladaptation across all domains will increase.

Risk description

The future contains inherent uncertainty. Uncertainty, or a state of incomplete knowledge, arises from many sources, such as data imprecision, methodological inexactness and conceptual ambiguity. In the context of climate change, uncertainties stem from unknowable socio-demographic, technological and economic trends that will influence future greenhouse gas concentrations and the sensitivity of climatic systems to these concentrations. These uncertainties affect the rate and magnitude of the impacts of climate change that are knowable. Generally, the further we project into the future, the greater that level of uncertainty will be.

Failure to account for uncertainty in decision-making processes increases the likelihood that an action will be maladaptive. That is, the action is more likely to have a high opportunity cost, reduce incentives to adapt, disproportionality burden the most vulnerable, close off other adaptation options for the future, or increase greenhouse gas emissions (Barnett and O'Neill, 2010).

Decision-makers need to act, even when there is significant uncertainty. For example, today's researchers are confident that the frequency and intensity of heavy rainfall events will increase, but do not know how frequent or how intense those events will be or exactly when these conditions will occur. Researchers are also confident of the rate and magnitude of sea-level rise out to 2050, but beyond that the certainty range is wider (see section 2). Planners and engineers are making decisions about the location and design of infrastructure and housing that will be in place for more than 100 years, within which timeframe climate change impacts will worsen (Lawrence, 2016). If decision-makers do not provide for uncertainties when locating and designing developments, these structures will be increasingly exposed to flood risk and incur high damage costs. On the other hand, if they plan and design for the most extreme events, they may incur the opportunity cost of not being able to use the land, or over-design infrastructure that is costly and becomes redundant. Either way, there can be maladaptation. This suggests that tools and processes are needed that can inform flexible planning and design of infrastructure that can be changed and shifted before damage occurs (Mastrandrea and Luers, 2012).

Government decision-making frameworks and well-established practices in disciplines including law, economics, engineering and planning continue to use practices, processes and tools that rely on static assumptions of risk, and historical parameters of climatic conditions (Lawrence and Manning, 2012; Lawrence et al, 2019a; Manning et al, 2015; Weitzman, 2011). For example, the use of single flood standards (such as a 1-in-100-year event) to plan land use and design infrastructure results in path-dependent decisions that are inflexible to changing flood risk (Lawrence et al, 2013). These measures can also create a false sense of security for those just outside the zones (Lawrence et al, 2013). Other static measures that are used routinely in planning, such as minimum flood levels, also create a false sense of security in the face of ongoing sea-level rise, increasing heavy rainfall and coastal storms. White (2019) argues that dominant institutional practices, and cultures that overwhelmingly focus on data, modelling and certainty, discourage adopting new or alternative approaches to urban planning that may better support liveability or sustainability.

It is widely recognised that decision-makers must move beyond such approaches, particularly for flood risk, drought and coastal management strategies (Climate Change Adaptation Technical Working Group, 2017, 2018; Gersonius et al, 2012; Kundzewicz et al, 2008; Lawrence and Haasnoot, 2017; Lawrence et al, 2019a). Zeitoun et al (2016) also state that prevailing approaches to water security do not consider uncertainty, diversity and politics in society, limiting policy-makers to rigid and inflexible interventions that may reproduce inequalities. In New Zealand, the use of cost–benefit analysis disproportionately burdens more vulnerable residents. The reliance on cost–benefit analysis to prioritise flood protection has led to faster implementation in higher socio-economic areas, as higher land and asset values generate higher benefit-to-cost ratios (Manning et al, 2015).

arious processes and tools available for adaptation decision-making under conditions of uncertainty. Examples include robust decision-making (Dittrich et al, 2016), real options analysis (Buurman and Babovic, 2016), and dynamic adaptive pathways planning (Haasnoot et al, 2013; Lawrence and Haasnoot, 2017; Lawrence et al, 2019). Such processes and tools are being applied in a growing number of locations in New Zealand, including the Hutt River (Greater Wellington Regional Council, 2015), Hawke’s Bay (Bendall, 2018), and Petone (Kool, 2020) but wider uptake has generally been slow (Lawrence and Manning, 2012; Lawrence et al, 2019b). This is due to factors such as resourcing for capacity building, and the necessary engagement processes and caution about using new and unfamiliar processes in settings that ‘demand’ certainty (Lawrence and Haasnoot, 2017; White, 2019).

The national *Coastal Hazards and Climate Change Guidance* (Ministry for the Environment, 2017b) sets out how to use some of these processes and tools, including the use of the dynamic adaptive pathways planning approach. Case studies such as Corbett and Bendall (2019) demonstrate practical application in New Zealand. A critique by Lawrence et al (2019b) and a practice brief (Lawrence et al, 2019a) also share lessons learned for mainstreaming these processes and tools. Further guidance is needed, however, to address the constraints of planning processes and improve understanding of the dynamic nature of climate change impacts (Lawrence, 2018).

Consequence

Applying processes and tools that characterise risks as static and rely on historical parameters that do not account for uncertainty and changing risk profiles increases the risk of maladaptation. Maladaptation may limit the choices available to future generations, increase the vulnerability of other systems, sectors or groups to climate change impacts, and increase the costs of climate change. Maladaptive actions may also disproportionately burden New Zealand’s most vulnerable people and communities, and entrench socio-economic inequity. The consequences of maladaptation are most likely to be borne by future generations.

Confidence: High agreement, robust evidence

There is a high degree of agreement and robust evidence that proactive, adaptation-oriented decision-making tools and processes that better account for uncertainty need to be mainstreamed, because of the ongoing changing risks related to climate change.

Adaptation

Work is being carried out at the local government level with support from the Ministry for the Environment. This work includes National Science Challenges (Resilience to Nature's Challenges and the Deep South National Science Challenges). Methods being deployed include:

- dynamic adaptive pathways planning
- coastal adaptation and associated vulnerability, and economic assessment methodologies and engagement practices
- local government pilot projects under the Government's Community Resilience Group.

The planned national adaptation plan (NAP) will take a cross-government approach to address climate change risk in a more comprehensive manner.

Table 66: G1 Risk of maladaptation across all domains: Urgency profile

<table>
<tr><th colspan="7">G1 Risk of maladaptation across all domains: Urgency profile</th></tr>
<tr><th>Urgency category</th><th colspan="2">Proportion of urgency</th><th colspan="4">Description of actions</th></tr>
<tr><td>More action needed</td><td colspan="2">60</td><td colspan="4">Urgent action needed to enable the uptake of proactive adaptation tools and processes to address changing climate risks across all domains.</td></tr>
<tr><td>Research priority</td><td colspan="2">20</td><td colspan="4">Understanding how tools are used (and misused) and the barriers to uptake, to catalyse adaptation action.</td></tr>
<tr><td>Sustain current action</td><td colspan="2">10</td><td colspan="4">Appropriate tools exist and are starting to be used. This needs to be sustained to build critical mass across agencies adapting to the impacts of climate change.</td></tr>
<tr><td>Watching brief</td><td colspan="2">10</td><td colspan="4">Barriers to uptake should be monitored by responsible agencies using nationally consistent criteria and principles.</td></tr>
<tr><td>Adaptation urgency</td><td colspan="2">83</td><td>Confidence</td><td colspan="3">High agreement, robust evidence</td></tr>
<tr><td>Consequence</td><td>Now</td><td>Major</td><td>2050</td><td>Extreme</td><td>2100</td><td>Extreme</td></tr>
</table>

7.4.2 G2 Risk that climate change impacts across all domains will be exacerbated because current institutional arrangements are not fit for climate change adaptation. Institutional arrangements include legislative and decision-making frameworks, coordination within and across levels of government and funding mechanisms

Risk summary

Adapting to the diverse impacts of climate change at a variety of scales requires statutory and policy alignment, coordination across levels of government and with different sectors, and significant ongoing funding (Climate Change Adaptation Technical Working Group, 2018). These enablers for anticipatory adaptation have been repeatedly identified as barriers to effective adaptation to climate change (Boston and Lawrence, 2018; Hanna et al, 2018;

Lawrence et al, 2013). If national and regional governments fail to plan and invest in anticipatory risk reduction measures and effective adaptation initiatives, the economic, social and cultural costs of climate change will be higher (Boston and Lawrence, 2018). Adaptive capacity across all domains is likely to be challenged unless there is strong alignment of relevant statutes, and coordination of actors and funding mechanisms to support adaptation.

Risk description

The Climate Change Adaptation Technical Working Group (2018) recommended several governance-related actions to the Government. These include:

- establishing governance arrangements that support long-term adaptation action (Action 5)
- reviewing existing legislation and policy to integrate and align climate change adaptation considerations (Action 7)
- defining funding arrangements for climate change adaptation (Action 16).

While Action 5 has been partially implemented through this National Climate Change Risk Assessment for Aotearoa New Zealand, local government mandates linked to the national governance arrangements and the other critical supporting recommendations have yet to be actioned. In a review of the current governance arrangements relating to climate change adaptation in New Zealand, Boston and Lawrence (2018) conclude that existing institutional and funding arrangements are not fit for purpose and lack the capacity to ensure sound anticipatory governance and the ability to deliver equitable outcomes. The authors note that:

> "without appropriate reforms, existing policy frameworks are destined to increase rather than reduce risk exposure, exacerbate future adaptation costs, and contribute to multiple inequities. In the interests of sound anticipatory governance, a better framework is required." (Boston and Lawrence, 2018, p 44)

Statutory and policy alignment

New Zealand's numerous laws and policies have inconsistencies and competing objectives related to climate change adaptation (Blackett and Hume, 2011; Lawrence et al, 2019a). For example, the Housing Accords and Special Housing Areas Act 2013 puts housing supply ahead of natural hazards provisions, increasing the risk that new housing is in unsuitable areas. Lawrence and Manning (2012) also note that misalignment between various Acts can result in short-term decisions that exacerbate risk. For example, the Soil Conservation and Rivers Control Act 1941 has a focus on protection works that give rise to static responses; the Resource Management Act 1991 has a precautionary focus; and the Building Act 2004 is the Act to default to in the absence of regional or district rules.

At the national level, many sectors operate within regulatory frameworks and policies that are not well aligned with climate change adaptation (Climate Change Adaptation Technical Working Group, 2018). Local council functions relating to climate change impacts are spread across a number of statutes. These functions include flood management, water and stormwater management, land-use controls, emergency management and the management of assets including infrastructure (Manning et al, 2015).

Coordination

To be effective, climate change adaptation practices must be coordinated across different levels of government, geographical regions, technical and disciplinary areas, and administrative boundaries, as well as between government and non-governmental institutions (Lawrence et al, 2018).

New Zealand's national institutional framework, centred on the Resource Management Act 1991 (RMA), influences adaptation practice and, along with the Local Government Act 2002*,* determines the relationships between national, regional and district scales of government. However, these two statutes do not clearly mandate climate change risk management or adaptation, nor the coordination of related roles, responsibilities and actions across these levels of government. The framework empowers local government to make decisions on land-use activities, natural hazard management, infrastructure and urban development (Lawrence et al, 2013) and allows for central government to provide consistent overarching directions and guidance through national policy statements and national environmental standards (Lawrence et al, 2012). This coordination architecture is currently under-used due to lack of a clear mandate (Climate Change Adaptation Technical Working Group, 2018; Lawrence et al, 2012), leaving local councils to individually design their responses. This fragmented effort increases the exposure of decisions to challenge in the courts, which may delay action (G3) (Lawrence et al, 2013). It also leads to resource inefficiencies and a poor understanding of climate change risks among decision-makers and community members (Lawrence et al, 2013).

Funding

Currently no dedicated funds are available for adaptation to reduce exposure to climate change-related risks. However, funding is available for recovery from hazard events, including the Natural Disaster Fund and Adverse Events Fund for the primary production sector (Boston and Lawrence, 2018). Reallocating funding towards risk reduction measures would be more cost-efficient (Deloitte Access Economics, 2013).

Significant and ongoing funding is needed to implement adaptation actions in response to climate change. Some of the most pressing adaptation needs in New Zealand relate to the impacts of ongoing sea-level rise, which include rising groundwater and salinisation, erosion and more damaging storm surges (B2). One metre of sea-level rise from the present day, which may be experienced by 2100 under representative concentration pathway (RCP) 8.5 H^+ (see table 19), will expose more than 49,000 buildings to a 100-year extreme sea-level flood event. These buildings have a replacement value of about $12.4 billion (Paulik et al, 2019b). In cases where managed retreat is the only option, significant investment will be needed to support these communities.

The following are other areas where adaptation funding arrangements are either highly limited or absent.

- *Compensation:* Governments are likely to face litigation (G3) seeking compensation for loss or damage due to climate change, or conversely due to the loss of existing use rights due to adaptation measures (Grace et al, 2019; Winkelmann et al, unpublished).
- *Research:* There is a critical under-investment in research to support climate change adaptation (G5) relating to biophysical and ecological changes, biosecurity, changes in the hydrological cycle influencing fluvial and pluvial flooding, and the implications of climate change for human systems such as the economy, health and health services (Climate Change Adaptation Technical Working Group, 2018).

- *Developing new and future-proofing existing infrastructure:* Investment will be required to redesign, reposition and future-proof public infrastructure (B2), especially transport networks (B6) and three waters services (B1, B4) (Boston and Lawrence, 2018).
- *Capacity building:* Adopting new tools and processes (G1) for decision-making in the context of uncertainty requires organisational change and capacity building at all levels of government.
- *Participation and engagement:* Extended engagement processes are needed to establish a shared understanding of climate change risks, and to avoid a breach of Treaty of Waitangi obligations (G4). Engagement processes are currently constrained by lack of resourcing (Stephenson et al, 2020).
- *Mātauranga Māori:* Indigenous knowledge is critical in developing culturally appropriate adaptation responses. Funding is required to make effective use of mātauranga Māori in adaptation.
- *Protecting taonga and the natural environment:* New Zealand's unique ecosystems and biodiversity are poorly understood (IPCC, 2014a) and are under stress from changing and intensive land uses, localised pollution, and pressures associated with tourism.

The ability to fund climate change adaptation will depend in part on bipartisan political agreement on climate change adaptation (G7), which will drive the fiscal capacity and economic position (E1) of New Zealand as a nation.

Consequence

The impacts of climate change will be greater if policy and legislation remain unaligned, actors uncoordinated, and funding for adaptation limited. Failure to plan and invest in anticipatory risk reduction measures and effective adaptation initiatives will increase the risk of maladaptation, expose governments to litigation risk, decrease trust in government and increase the likelihood of inequitable distribution of harm.

Confidence: High agreement, robust evidence

There is a high degree of agreement and robust evidence that New Zealand's current institutional framework hinders effective adaptation efforts.

Adaptation

Coordination within and across levels of government, alignment of statutes, and adaptation finance are being partly addressed through the Climate Change Response (Zero Carbon) Amendment Act 2019, the review of the RMA that is under way and the Government's Community Resilience Group work programme. Some local councils are developing adaptation plans and working together at a regional level to coordinate adaptation efforts. The planned NAP will take a cross-government approach to address climate risk in a comprehensive manner.

Table 67: G2 Risk that climate change impacts across all domains will be exacerbated: Urgency profile

<table>
<tr><th colspan="7">G2 Risk that climate change impacts across all domains will be exacerbated: Urgency profile</th></tr>
<tr><th>Urgency category</th><th colspan="2">Proportion of urgency</th><th colspan="4">Description of actions</th></tr>
<tr><td>More action needed</td><td colspan="2">60</td><td colspan="4">Lack of coordination across levels of government raises the risk of maladaptation and inaction. Relevant statutes and funding arrangements need to be aligned to reduce risk and provide the mechanisms for all levels of government to adapt to climate change impacts.</td></tr>
<tr><td>Research priority</td><td colspan="2">10</td><td colspan="4">Focused research is needed to inform adaptation action, including research into staged retreat, developing locally relevant decision triggers, and legal issues around compensation and existing use rights.</td></tr>
<tr><td>Sustain current action</td><td colspan="2">20</td><td colspan="4">Current and planned measures detailed above to continue and accelerate.</td></tr>
<tr><td>Watching brief</td><td colspan="2">10</td><td colspan="4">Ongoing monitoring and evaluation of all levels of government to determine if institutional arrangements for climate change adaptation are improving.</td></tr>
<tr><td>Adaptation urgency</td><td colspan="2">80</td><td>Confidence</td><td colspan="3">High agreement, robust evidence</td></tr>
<tr><td>Consequence</td><td>Now</td><td>Major</td><td>2050</td><td>Extreme</td><td>2100</td><td>Extreme</td></tr>
</table>

7.4.3 G3 Risks to governments and businesses from climate change-related litigation, due to inadequate or mistimed climate change adaptation

Risk summary

Governments and businesses face potential legal liability due to climate change. Plaintiffs may turn to the courts to seek compensation for loss suffered due to inadequate climate change action. Governments could be liable for a range of matters, including failing to adapt public infrastructure, planning decisions that increase exposure to coastal hazards, and failing to reduce greenhouse gas emissions (Iorns, 2019; Iorns et al, 2017). The private sector may face litigation for failing to adapt to climate change, and for damages caused by historical greenhouse gas emissions. The threat of litigation against governments who are taking action to adapt to climate change is also, perversely, delaying adaptation (Lawrence et al, 2013; Manning et al, 2015). If litigation results in delays to adaptation, it is likely to increase the costs of climate change, thereby exposing the Government and businesses to further liability.

Risk description

Over the past decade, litigation related to greenhouse gas emissions has increased markedly (Setzer and Byrnes, 2019). Seeking damages due to a failure to adapt to climate change, or a failure to prepare for foreseeable events such as floods, is an emerging area of litigation but is likely to become increasingly significant (Marjanac et al, 2017). Setzer and Byrnes (2019) emphasise that both cases relating to enforcement of existing mitigation goals and those concerning adaptation obligations are expected to increase.

Claims may be brought against governments for failing to adapt to climate change. Governments plan for, own and manage a wide range of public infrastructure and assets, many of which will now need to be adapted to climate change. In the United States, lawsuits have already been filed against federal and municipal defendants by members of the public seeking damages for failures to adapt to climate change (Marjanac et al, 2017). Insurers have also brought claims highlighting government failure to adequately prepare for foreseeable flood events (Marjanac et al, 2017).

Local governments have a range of options available under the RMA to prevent and control developments in hazard-prone areas, including areas affected by climate change (Hodder, unpublished). The New Zealand Coastal Policy Statement, which must be given effect to by local government, foreshadows managed retreat (Ministry for the Environment, 2017b). However, some land-use provisions in the RMA are a barrier to implementing managed retreat. Existing land-use provisions can only be removed by regional government, which is reluctant to do so.[16] The devolution of climate change adaptation responsibility to the local level, together with the lack of guidance for responding to flooding and other climate change hazards, is leading councils to address climate change separately and differently from each other. Under this arrangement, councils are exposed to legal liability for both adaptation action and inaction (Lawrence et al, 2013; Manning et al, 2015).

Businesses are also likely to become subject to more climate change-related litigation. For instance, private professionals and companies that design, construct, manage or maintain public assets are likely to become liable for responding to the risks posed to these assets by climate change. Cases in this area are limited, however Marjanac et al (2017) suggest that liability may arise from the application of codes and standards that have not been updated based on the best available climate science.

Recently, many public nuisance suits against major fossil fuel emitters have been lodged seeking emissions reductions and damages potentially amounting to billions of dollars to cover the cost of adaptation (Setzer and Byrnes, 2019). While these cases have been largely unsuccessful to date, developments in climate change attribution science are likely to provide better evidence of the link between emissions from private sector actors and their consequences (Marjanac et al, 2017; Winkelmann et al, unpublished).[17] It is anticipated that this area of litigation will increase in the future (Winkelmann et al, unpublished).

Plaintiffs are also making cases that governments are breaching duties and obligations to citizens by inaction on emissions reductions. The Waitangi Tribunal has already heard claimants asserting that insufficient action by the Crown on climate change mitigation is in breach of Treaty obligations (see G4). The case, *Thomson v Minister for Climate Change Issues 2017*, which challenged the New Zealand Government's responses to climate change, was unsuccessful, but demonstrates the willingness of the High Court to adjudicate on climate change issues (Winkelmann et al, unpublished).

Although much climate change-related litigation in the past has been unsuccessful, Douglas Kysar of Yale Law School argues that tort law principles must adapt to deal with the complexities of climate change litigation or become irrelevant, and that judges in tort cases might soon choose adaptation over irrelevance (Kysar, 2011). Winkelmann et al (unpublished) also anticipate that parties will increasingly resort to public law remedies, holding governments and local authorities to commitments in domestic legislation interpreted in light of international treaties and agreements. The processes set out in the Climate Change Response (Zero Carbon) Amendment Act 2019 also create an accountability mechanism through Parliament for adaptation plans.

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[16] A case is currently in progress to extinguish land titles on land rendered unusable by a large debris flow (Hanna and White, 2020).

[17] Attribution science attempts to attribute specific climate change- related events to particular emitters of greenhouse gases.

Consequence

The consequences of climate change litigation will be significant. Local councils are particularly exposed; if the Government fails to provide national direction to local councils, it is likely that individuals and communities will bring private claims to address inaction, with local councils being a key defendant (Hodder, unpublished).

There is a risk that decision-makers will fail to act pre-emptively because of the fear of litigation, particularly around land-use planning and funding of adaptation. This could increase the likelihood of decisions that lock in exposure to future risks, such as granting planning consents in floodplains and areas exposed to ongoing sea-level rise and coastal erosion, exacerbating risks such as B1, B2 and E7. Delays to decision-making will contribute to higher adjustment and adaptation costs (Boston and Lawrence, 2018). This will require additional adaptation funding (G1) and could impact on the Government's fiscal position (E1).

Confidence: High agreement, robust evidence

There is a high level of agreement and robust evidence that this risk will increase over time.

Adaptation

Limited adaptation action is under way or planned in relation to this risk. However, stakeholders note that other processes could address aspects of this risk, including the review of the RMA, efforts being undertaken by the Community Resilience Group and the establishment of the Climate Change Commission. A growing body of researchers and legal scholars is investigating this risk, including adjudication by Supreme Court judges that may lead to new jurisprudence.

Table 68: G3 Risks to governments and businesses from climate change-related litigation: Urgency profile

<table>
<tr><th colspan="7">G3 Risks to governments and businesses from climate change-related litigation: Urgency profile</th></tr>
<tr><th>Urgency category</th><th colspan="2">Proportion of urgency</th><th colspan="4">Description of actions</th></tr>
<tr><td>More action needed</td><td colspan="2">50</td><td colspan="4">Alignment of statutes to provide clarity about roles and responsibilities for climate change adaptation.
Support uptake of practices, tools and processes that support climate change adaptation.
Provision of adequate funding to enable timely climate change adaptation.
Effective engagement with the public on mitigation and adaptation options to build trust.</td></tr>
<tr><td>Research priority</td><td colspan="2">20</td><td colspan="4">Analysis of implications of international cases for New Zealand.</td></tr>
<tr><td>Sustain current action</td><td colspan="2">20</td><td colspan="4">Legal cases lodged may provide some resolution to issues of responsibility and accountability.</td></tr>
<tr><td>Watching brief</td><td colspan="2">10</td><td colspan="4">Monitor outcomes of cases.</td></tr>
<tr><td>Adaptation urgency</td><td colspan="2">78</td><td>Confidence</td><td colspan="3">High agreement, robust evidence</td></tr>
<tr><td>Consequence</td><td>Now</td><td>Moderate</td><td>2050</td><td>Major</td><td>2100</td><td>Major</td></tr>
</table>

7.4.4 G4 Risk of a breach of Treaty obligations from a failure to engage adequately with and protect current and future generations of Māori from the impacts of climate change

Risk summary

The principles associated with the Treaty of Waitangi, namely partnership, participation and protection, could be breached due to failure to protect current and future generations of Māori from climate change impacts. Claims relating to climate change already sit with the Waitangi Tribunal, which has determined that climate change is a Treaty issue because of the need to act to prevent harm to Māori coastal property around New Zealand (Iorns, 2019). Treaty obligations may also be breached if specific consideration is not given to the protection of Māori assets, meaningful engagement and involvement of Māori, and use of mātauranga Māori in climate change adaptation (Iorns, 2019).

Risk description

The most salient Treaty principles, derived from both the English and Māori language versions of the Treaty, were outlined in *New Zealand Māori Council v Attorney-General* [1987]. They have been summarised as partnership, participation and protection (Durie, 1994). Box 10 provides a more detailed explanation of the principles.

Box 10: Principles of the Treaty of Waitangi, as outlined in *New Zealand Māori Council v Attorney-General* [1987]

- **Partnership:** There is a partnership between the races, and each partner has to act towards the other “with the utmost good faith which is the characteristic obligation of partnership” (*New Zealand Māori Council v Attorney-General* [1987], at 662).
- **Right to govern:** The Crown has the right to govern and not be hampered by “unreasonable restrictions” (*New Zealand Māori Council v Attorney-General* [1987]). Māori retain the rights to their territories and resources and, where decisions made by the Crown affect such Māori rights, there is a duty to act in the interests of Māori.
- **Development:** The Treaty must be regarded as a living instrument, capable of adapting to changing circumstances, including the ability to develop and modify traditional practices.
- **Redress:** When the Crown has breached the principles of the Treaty, it has a duty to set matters right and restore the integrity and mana of the status of Māori.
- **Reciprocity:** The benefit of governing the territory does not exist without the permission of Māori, therefore the Crown should respect the interests that Māori have in that territory. Acknowledging such interests could require widespread and genuine consultation with Māori.
- **Active protection:** The Crown is obliged to take positive steps to protect Māori interests such as Māori lands, estates, forests, fisheries and other taonga.
- **Good faith:** Parties are expected to act in good faith at all stages of the Treaty process. A key sign of good faith as well as partnership is meaningful consultation: The Crown should not make decisions without the input of tangata whenua.

Principles established by the Treaty have given rise to varying levels of expectation and debate about the implications of the Treaty in contemporary society (Durie, 1994). These expectations include that the Crown will mitigate greenhouse gas emissions and reduce harm through adaptation, as well as consult with Māori on climate risk and action.

It has been recognised that the principle of active protection under the Treaty obliges the Government to participate fully in the international effort to combat climate change (Packman et al, 2001). Claims with the Waitangi Tribunal, summarised in box 11, show how the principle of active protection is being used to pressure the Government to increase efforts to reduce greenhouse gas emissions.

Box 11: Claims with the Waitangi Tribunal (Iorns, 2019)

Wai 898

In 2012 the Te Roopu Huringa Aahurarangi heard that the Crown must reduce greenhouse gas emissions to reduce the threat of climate change to Māori. The case, focused on 2030 emissions reduction targets, relates to taking all reasonable steps to reduce the threat. It invokes Māori children and youth today, and the immediate next generations who will be most adversely impacted by inaction in the present.

Wai 2607

The Mataatua District Māori Council lodged a claim in 2017 aiming to compel the Government to create more ambitious climate change policies. The claimants argued that the Crown was breaching its obligations to Māori by failing to implement adequate policies to address future threats associated with climate change. This claim was settled.

Both of these claims were considered to deal with nationally significant issues affecting Māori as a whole and, for this reason, would be better addressed in a kaupapa claim, which will be heard in the future.

Taking mitigation or adaptation action without meaningful consultation could also give rise to a breach of Treaty obligations. For example, many Māori noted the insufficient consideration of tangata whenua issues when the Government of New Zealand ratified the Kyoto protocol (Ministry for the Environment, 2007). Some Māori also express concern about the many years of delay following ratification of the protocol in 1997 before the Crown informed and engaged with Māori (Hodgson, nd).

To date, no Treaty claims have related to climate change adaptation. Based on previous determinations of Treaty principle requirements, Iorns (2019) suggests that a range of measures is likely to be required, including:

- engaging and consulting about adaptation measures as part of the decision-making process
- directing central government funding to enable maintenance of Māori relationships with the coast
- using, rather than only considering, mātauranga Māori to assist climate change adaptation.

Climate change adaptation is likely to be undertaken at the local government level through application of the RMA. However, some of the procedures and standards in the RMA have already been held to be in breach of the Treaty. Under current law, even if actions of local government breach the Treaty guarantees, claims will be made against the Crown and so will be defended by central government (Iorns, 2019).

The Treaty can only be enforced through law when a statute explicitly refers to the Treaty (Office of Treaty Settlements, 2018). The Treaty can also be enforced through the courts through Treaty principles, as for *New Zealand Māori Council v Attorney General* [1987] (Ruru, 2008).Another way of exploring Treaty breaches is through the Waitangi Tribunal. The

Tribunal is a commission of inquiry, created by the Treaty of Waitangi Act 1975 (Office of Treaty Settlements, 2018). Its role is to investigate breaches of the Treaty that relate directly to legislative breaches, as well as Crown policies and Crown acts or omissions. However, in contrast to judicial decisions, the Tribunal's recommendations are not binding and are merely recommendations.

Consequence

Breaches of the Treaty of Waitangi may have adverse impacts on Māori economic and spiritual wellbeing, resulting from failure to adequately protect Māori assets and sites of cultural significance. Breach of Treaty obligations is likely to hamper efforts to adapt to loss of land (H5), species and ecosystems (H6), and cultural heritage (H8), and will increase the risks of litigation (G3).

Confidence: High agreement, medium evidence

There is a high level of agreement that climate change and the response to climate change may result in breaches of Treaty of Waitangi obligations.

Adaptation

Efforts to minimise the risk of potential breaches of Treaty obligations are under way. Government departments are launching new consultative processes and strengthening those already in place. The newly established Climate Change Commission is required to engage with Māori/iwi under the Climate Change Response Act 2002.

Table 69: G4 Risk of a breach of Treaty obligations from a failure to engage adequately with and protect current and future generations of Māori from the impacts of climate change: Urgency profile

<table>
<tr><th colspan="7">G4 Risk of a breach of Treaty obligations from a failure to engage adequately with and protect current and future generations of Māori from the impacts of climate change: Urgency profile</th></tr>
<tr><th>Urgency category</th><th colspan="2">Proportion of urgency</th><th colspan="4">Description of actions</th></tr>
<tr><td>More action needed</td><td colspan="2">40</td><td colspan="4">Engagement between Government and Māori/iwi as partners in deciding mitigation options and planning adaptation policy.</td></tr>
<tr><td>Research priority</td><td colspan="2">30</td><td colspan="4">Research on identifying key risks for Māori, tools and new adaptation options to be developed.</td></tr>
<tr><td>Sustain current action</td><td colspan="2">20</td><td colspan="4">Legal cases in process will continue to clarify responsibility and accountability.</td></tr>
<tr><td>Watching brief</td><td colspan="2">10</td><td colspan="4">Monitor outcomes of cases.</td></tr>
<tr><td>Adaptation urgency</td><td colspan="2">75</td><td>Confidence</td><td colspan="3">High agreement, medium evidence</td></tr>
<tr><td>Consequence</td><td>Now</td><td>Moderate</td><td>2050</td><td>Major</td><td>2100</td><td>Major</td></tr>
</table>

7.4.5 G5 Risk of delayed adaptation and maladaptation due to knowledge gaps resulting from under-investment in climate change adaptation research and capacity building

Risk summary

Under-investment in research and capacity building to inform understanding of climate change risks and impacts is undermining New Zealand's ability to develop evidence-based adaptation policy. Critical research gaps relate to:

- atmospheric processes
- hydrological cycle impacts
- ecosystem responses
- biodiversity and biosecurity
- New Zealand's rural and urban communities
- the economic costs of climate change
- impacts on the primary sector
- impacts on heritage
- effects on health and health services
- use of mātauranga Māori to inform adaptation
- cascading impacts
- how to govern climate change adaptation at a number of scales.

These research gaps are a critical barrier to informed decision-making. While these gaps remain, maladaptive actions are a key risk.

Risk description

Managing climate change risks requires knowledge-intensive adaptation action and policy-making. Table 70**Error! Reference source not found.** provides an overview of key knowledge gaps identified by this risk assessment.

Table 70: Key knowledge gaps identified in this risk assessment

Area of knowledge	Research gaps
Mātauranga Māori	Ways for mātauranga Māori to inform climate change science, policy-making and management.
Climate change science	• The impact of additional greenhouse gas emissions on atmospheric processes. • The implications of long-term global climate change on patterns of natural climate variability such as the El Niño–Southern Oscillation (IPCC, 2014a). • The impact of changing atmospheric processes on the frequency and intensity of pluvial and fluvial flooding (Climate Change Adaptation Technical Working Group, 2018). • The impacts of sea-level rise on groundwater levels and estuarine and river systems (Climate Change Adaptation Technical Working Group, 2018).
Ecosystems and biodiversity	• Ecological and physiological thresholds in terrestrial and aquatic species and ecosystems (IPCC, 2014a) and how they will respond to extreme events (Climate Change Adaptation Technical Working Group, 2018). • The impact of climate change on biosecurity and biodiversity.

Area of knowledge	Research gaps
	• Species traits that determine tolerance to various environmental conditions.
Economy	• The economic cost of inaction on climate change at different scales and across sectors (Climate Change Adaptation Technical Working Group, 2018). • How climate change impacts may flow into and through New Zealand's financial system (A Wreford, Lincoln University, pers. comm., 28 March 2020). • How climate change will impact on the banking and insurance sectors.
People and culture	• How to identify, assess and track the structural causes and expressions of social vulnerability in New Zealand, and how these may change in the future (P Blackett, NIWA, pers. comm., 23 March 2020). • The interactions between cultural values, biophysical sciences and adaptive capacity (IPCC, 2014a). • The impacts of climate change on human health and demand for health services (Climate Change Adaptation Technical Working Group, 2018), particularly in relation to potential diseases.
Built environment	• How built environment assets, particularly landfills, cultural sites and indigenous built structures, are exposed and vulnerable to climate change. • How exposure to natural hazards, such as flooding from rivers and surface waters, differs across New Zealand. • How impacts on built environment assets will flow through to other domains.
Cascading risks	• How risks cascade and feed back over time (Lawrence et al, 2018, 2020) and between different geographies (IPCC, 2014a). • How uses of land and water may be impacted by the compounding effects of climate change (Climate Change Adaptation Technical Working Group, 2018). • The implications of cascading consequences for the governance of social and ecological systems (Lawrence et al, 2018, 2020).
Governance	• The socio-cultural, technological and disciplinary barriers to adaptation actions at multiple scales (IPCC, 2014a). • How adaptation planning can better engage communities. • How central and local government coordination can be empowered to undertake adaptation action through changes to laws. • Developing locally relevant decision triggers and planning approaches for managed retreat. • Legal issues that may arise from compensation for harm to, or loss or extinguishing of, existing use rights. • The implications of international and national climate change-related court cases for New Zealand. • How parliamentary mechanisms can be deployed to support funding and implementation of climate change adaptation. • Understanding how adaptation tools are used and misused, and the barriers to uptake. • How past events can inform climate change risk management, such as the Canterbury and Kaikōura earthquakes, pandemics and biosecurity incursions.

Ideally these knowledge gaps should be addressed through coordinated and multidisciplinary processes. The co-production of knowledge and information by many stakeholders using different disciplines (science, policy and social science) enhances the usability of knowledge (Lemos and Morehouse, 2005). It also better enables communication and transparency, and builds trust among decision-makers (Cradock-Henry et al, 2020; Howarth and Monasterolo, 2017; Stephenson et al, 2020). However, resourcing knowledge co-production has proved challenging to date (Lemos and Morehouse, 2005).

Targeted and timely funding (G2) will be critical to addressing knowledge gaps to support decision-making processes. Understanding the barriers to uptake of best-practice decision-support tools, practices and processes (G1) will reduce the risk of maladaptation. Mātauranga Māori encompasses a wealth of unique knowledge that can inform climate change science, policy -making and management; however, this knowledge can only be accessed with trust and good relations between Treaty partners (G4).

Consequence

Ongoing research is critical for informing adequate climate change risk assessment and adaptation action. Based on the current level of knowledge, particularly for compounding and cascading events, there is a risk of significantly underestimating climate change risks, intervening at the wrong points in the system and taking maladaptive actions. Lack of knowledge may be used to justify inaction (Hulme, 2009). For example, in the natural environment domain, a lack of consistent data is hindering conservation efforts even before climate change is considered.

Confidence: High agreement, robust evidence

There is a high level of agreement and a robust body of evidence to demonstrate under-investment in relevant and targeted research to inform climate change adaptation in New Zealand.

Adaptation

Some research is under way that supports understanding of climate change impacts and adaptation. Efforts to date include research funded through:

- Deep South National Science Challenge
- Resilience to Nature's Challenges National Science Challenge
- Sustainable Land Management and Climate Change Fund
- Climate Change Adaptation Technical Working Group.

Table 71: G5 Risk of delayed adaptation and maladaptation due to knowledge gaps resulting from under-investment in climate change adaptation research and capacity building: Urgency profile

G5 Risk of delayed adaptation and maladaptation due to knowledge gaps resulting from under-investment in climate change adaptation research and capacity building: Urgency profile		
Urgency category	**Proportion of urgency**	**Description of actions**
More action needed	50	Research and capacity building are needed to enable best-practice adaptation decision-making and action.
Research priority	20	See table 70 for a list of key gaps. A coordinated and comprehensive research platform to inform effective adaptation is also missing.
Sustain current action	10	Current research that supports understanding of climate change impacts and adaptation options should continue.
Watching brief	20	Current research plans are not adequate.

Adaptation urgency	75		**Confidence**	High agreement, robust evidence		
Consequence	Now	Moderate	2050	Moderate	2100	Major

7.4.6 G6 Risks to the ability of the emergency management system to respond to an increasing frequency and scale of compounding and cascading climate change impacts in New Zealand and the Pacific region

Risk summary

Climate change will increase the frequency, severity and spatial extent of natural hazard events, and create new hazards that need emergency management responses. This increased demand for emergency management services may be compounded by damaged infrastructure critical to delivery of those services. Infrastructure can be affected by extreme events such as floods, fires or landslides, as well as by gradual, ongoing impacts such as sea-level rise and coastal inundation that degrade critical infrastructure. The cascading effects of these increasing natural hazards across systems could also lead to coordination challenges, including lack of clarity about responsibility for risk management.

Risk description

New Zealand faces significant natural hazard risks, many of which could be exacerbated by climate change due to increased frequency, severity and complexity of extreme weather, combined with ongoing hazards such as sea-level rise (IPCC, 2012). This will lead to a range of challenges for the emergency management sector (Ministry of Civil Defence and Emergency Management, 2019). These challenges include:

- the intersection of these impacts with other stressors, such as health and safety risks, that require joint agency planning and interoperability
- supply chain vulnerabilities (New Zealand Lifelines Council, 2017)
- the need to revise building codes (New Zealand Lifelines Council, 2017)
- the need to adapt land-use planning to changing circumstances (Saunders et al, 2013).

As events become increasingly complex, a multi-hazards approach to organising the emergency management sector is likely to be needed (Lawrence and Saunders, 2017).

If extreme events increase, so will the demands on full-time and volunteer emergency service personnel and non-government organisations. Meeting this demands would require increased resourcing, including volunteer support, and partnership between the public and private sectors to meet critical infrastructure needs (Handmer et al, 2012; Mitchell et al, 2010; Ozanne and Ozanne, 2013). These additional responses required by the emergency management system may affect the health, safety and emotional wellbeing of emergency management workers.

Cascading and concurrent events are likely to increase with climate change, stretching the capacity of the sector to respond (Australasian Fire and Emergency Service Authorities Council, 2018). New Zealand has already experienced concurrent and cascading severe and extreme events. For example, in 2017 a series of ex-tropical cyclones and storm events caused significant damage across parts of New Zealand. In March 2017, the ‘Tasman Tempest’ caused heavy rainfall and flooding in the upper North Island, floods and landslides in southeast

Auckland and Coromandel, and restricted water supply in Auckland due to siltation of reservoirs in the Hunua Ranges. In April 2017, ex-Tropical Cyclone Debbie brought significant rainfall to the upper North Island, particularly the Bay of Plenty, where failure of a stopbank on the Rangitāiki River flooded Edgecumbe (Coomer et al, 2018). Shortly after this, ex-Tropical Cyclone Cook brought extensive rain and high winds to the upper and eastern North Island. In July 2017, heavy rain and high tides led to hundreds of homes being evacuated and a state of emergency in Waitaki, Dunedin, Christchurch, Selwyn, Timaru and eventually the entire Otago region, as floodwaters inundated parts of the eastern coast of the South Island (Coomer et al, 2018).

The effective response and significant community support facilitated by Māori in the aftermath of the Canterbury and Kaikōura earthquakes and the floods in Edgecumbe, as well as in other emergencies, have demonstrated and generated interest in Māori disaster resilience (Ministry of Civil Defence and Emergency Management, 2019; Saunders, 2017, 2018). Māori community values and practices promote a collaborative approach to disaster response and recovery, commitment to environmental restoration, and extension of hospitality to others experiencing adversity. Māori also have assets and places that are often mobilised to secure community wellbeing in the aftermath of disasters (Ministry of Civil Defence and Emergency Management, 2019). However, as described in the human domain (see section 4), many of these assets and places may be affected by climate change.

In addition to concurrent domestic events, extra demand is likely to be placed on New Zealand's capacity to provide emergency response services to its regional neighbours, and vice versa. New Zealand provides humanitarian aid, including disaster assistance, to the broader Asia-Pacific region. New Zealand shares close cultural political, and social links with the Pacific region and is considered a trusted partner that can respond quickly to support Pacific governments when a disaster occurs. The expected increase in concurrent and coincident events may also limit New Zealand's ability to draw support from other states in the region during a crisis. For instance, equipment and personnel sharing arrangements with Australia and the United States may be jeopardised by the increasing overlap of fire seasons (Australasian Fire and Emergency Service Authorities Council, 2018).

Consequence

Climate change affects the emergency management sector's capacity to support preparedness, response and recovery efforts. This is likely to increase the consequences of climate hazards for communities. In particular, rural populations, which include a high representation of Māori communities, are usually dispersed across less accessible landscapes, which can leave them more exposed to the impacts of hazards.

Confidence: Medium agreement, limited evidence

There is agreement that increasingly frequent and severe extreme events will place strain on emergency management capability. However, only a limited number of studies have directly explored the various impacts of coincident, cascading and compound hazard events on the integrity of emergency management systems.

Adaptation

Adaptation efforts relating to climate change and emergency management in New Zealand are at an early stage. The Hazard Risk Board, composed of chief executives of Government departments and ministries, is responsible for the cross-government strategic governance of natural hazard events. The National Emergency Management Agency and the National Disaster

Resilience Strategy are taking steps to ensure the continuity of emergency management services in a changing climatic future.

Table 72: G6 Risks to the ability of the emergency management system to respond to an increasing frequency and scale of compounding and cascading climate change impacts in New Zealand and the Pacific region: Urgency profile

<table>
<tr><th colspan="7">G6 Risks to the ability of the emergency management system to respond to an increasing frequency and scale of compounding and cascading climate change impacts in New Zealand and the Pacific region: Urgency profile</th></tr>
<tr><th>Urgency category</th><th colspan="2">Proportion of urgency</th><th colspan="4">Description of actions</th></tr>
<tr><td>More action needed</td><td colspan="2">40</td><td colspan="4">Build capacity to anticipate and prepare for multiple, concurrent climate-related events in New Zealand and regionally.</td></tr>
<tr><td>Research priority</td><td colspan="2">10</td><td colspan="4">Research is needed into the likely integrity of New Zealand's emergency management system in response to coincident, cascading and compound hazard events.</td></tr>
<tr><td>Sustain current action</td><td colspan="2">40</td><td colspan="4">Current efforts to reduce risks to the built environment domain (lifeline infrastructure) and all other domains will support emergency management capability.</td></tr>
<tr><td>Watching brief</td><td colspan="2">10</td><td colspan="4">Continue monitoring risk as the residual risk increases over time.</td></tr>
<tr><td>Adaptation urgency</td><td colspan="2">70</td><td></td><td colspan="3">Medium agreement, limited evidence</td></tr>
<tr><td>Consequence</td><td>Now</td><td>Major</td><td>2050</td><td>Major</td><td>2100</td><td>Major</td></tr>
</table>

7.4.7 G7 Risk that effective climate change adaptation policy will not be implemented and sustained due to a failure to secure sufficient parliamentary agreement

Risk summary

To minimise future damages from climate change, pre-emptive and sustained action by the Government is needed. It is necessary for successive governments to have a strong political mandate for and commitment to climate change adaptation. The structure of New Zealand's political system, together with an economy characterised by dominant sectors that have politicised climate change, has hindered meaningful action on both emissions reduction and climate change adaptation. The recent passing of the Climate Change Response (Zero Carbon) Amendment Act 2019 with bipartisan support is a positive development. An ongoing spirit of bipartisanship will be critical to enabling necessary climate action.

Risk description

Climate change has been described as a 'super wicked problem' (Lazarus, 2009; Levin et al, 2012) that requires successive governments to commit to policy reform, confronting vested and special interests, and to take actions now to avoid future harm (Boston, 2016).

Bipartisan alignment on issues and solutions is generally recognised as contributing to better policy development (Harbridge, 2015). Bipartisanship supports long-term policy development, which is necessary for large-scale coordinated climate change mitigation and adaptation efforts. It allows for consistent government guidance and ongoing funding commitments to reduce climate change risk. It also provides the certainty that institutions, planners and industries need to effectively respond to climate change.

The challenge faced by elected representatives to address the trade-off between the cost of responding to climate risks and the benefits to future generations is compounded by New Zealand's short electoral cycle (Jacobs, 2011). The triennial electoral cycle concentrates decision-making on the short term and often leads to the postponement of policies that may be effective but politically unpopular (Palmer, 2015). The cost of adaptation to safeguard future wellbeing sits in dramatic contrast to its uncertain and indirect future benefits, which makes it difficult for governments to justify this cost to the public (Boston and Lawrence, 2018). To take preventative steps requires the government to make 'hard calls' that are potentially politically unpopular, and governments are unable to bind their successor to such a policy, who may just as easily reverse it. The history of market-based greenhouse gas mitigation policies in New Zealand illustrates this challenge: governments delayed enacting policies to reduce emissions and, when policies were implemented, they were either overturned or significantly diluted by new governments (Chapman, 2015).

Lobbying is an important element of political participation. It involves efforts by individuals or collectives to directly influence decisions of legislators and public officials (Chapple and Anderson, 2018). New Zealand has a long history of lobby groups exerting influence on public policy. Much of this has been for the benefit of the public. For example, the Māori activist group Ngā Tamatoa successfully lobbied Parliament for Māori language teaching in schools in the 1970s, and from 1975–2004 the Women's Electoral Lobby encouraged women's participation in public life (Miller, 2012). However, lobbying can also represent the narrow interests of specific groups; for example, property developers who lobby local authorities to approve subdivisions and other developments in areas likely to be vulnerable to ongoing sea-level rise (Boston and Lawrence, 2018). As another example, Barnett (2017) describes lobbying by landowners, particularly in major coastal cities, to fortify coastlines with sea walls that are often maladaptive.

Lobbying is unregulated in New Zealand. Further, despite investigation by Chapple and Anderson (2018, p 16), "it is still unclear who lobbyists work for and how they act, with little hard evidence available to illuminate the true nature of the industry". This lack of clarity about the degree to which unregulated lobbying is influencing the policy-making and decision-making necessary for climate change adaptation is concerning (Boston, 2016).

Consequence

Because central government actions are needed for large-scale and coordinated adaptation responses, a failure to sustain bipartisan agreement on climate change would pose a barrier to adaptation efforts. For instance, local governments, to which much adaptation responsibility is devolved, would not be adequately funded (G5), and action would be less coordinated between and across levels of government (G1), which would increase litigation-related risks (G3). Without consistent bipartisan alignment, actions across all domains are less likely to be taken in a timely and cost-effective manner, and the actions that are taken have a higher chance of being maladaptive.

Confidence: Moderate agreement, medium evidence

There is a high degree of consensus and robust evidence about the need for central government action and the consequences of inaction. There is less evidence, and more divided opinion, about the causes of inadequate central government action.

Adaptation

The recent establishment of the independent Climate Change Commission, along with cross-party working groups on climate change, has created mechanisms that encourage long-term bipartisan decision-making.

Table 73: G7 Risk that effective climate change adaptation policy will not be implemented and sustained due to a failure to secure sufficient parliamentary agreement: Urgency profile

<table>
<tr><th colspan="7">G7 Risk that effective climate change adaptation policy will not be implemented and sustained due to a failure to secure sufficient parliamentary agreement: Urgency profile</th></tr>
<tr><th>Urgency category</th><th colspan="2">Proportion of urgency</th><th colspan="4">Description of actions</th></tr>
<tr><td>More action needed</td><td colspan="2">40</td><td colspan="4">Increased transparency and more mechanisms to build support for cross-parliamentary agreement.</td></tr>
<tr><td>Research priority</td><td colspan="2">10</td><td colspan="4">Exploration of potential effectiveness of parliamentary mechanisms such as cross-party working groups and independent commissions.</td></tr>
<tr><td>Sustain current action</td><td colspan="2">30</td><td colspan="4">Sustain current bipartisan mechanisms.</td></tr>
<tr><td>Watching brief</td><td colspan="2">20</td><td colspan="4">Monitor outcomes.</td></tr>
<tr><td>Adaptation urgency</td><td colspan="2">68</td><td>Confidence</td><td colspan="3">Moderate agreement, medium evidence</td></tr>
<tr><td>Consequence</td><td>Now</td><td>Major</td><td>2050</td><td>Extreme</td><td>2100</td><td>Extreme</td></tr>
</table>

7.4.8 G8 Risk to the ability of democratic institutions to follow due democratic decision-making processes under pressure from an increasing frequency and scale of compounding and cascading climate change impacts

Risk summary

Much of the discourse about climate change has focused on the potential impacts on natural systems, physical infrastructure, human wellbeing, and economies. However, climate change may also pose a risk to democratic decision-making processes, particularly in the aftermath of an intense, unanticipated extreme event. The risks to due process resulting from urgent responses to extreme events are likely to increase as hazards increase in frequency, intensity and spatial scale.

Risk description

Democracies depend on an informed and engaged citizenry that can hold elected officials accountable for effective policy-, law- and decision-making to ensure, among other things, equity and justice (Morlino, 2004). To enable citizens to play this role, governments need to engage, share information and be transparent.

While research into how climate change might affect democratic functioning is scarce, the 10 principles of law-making, outlined by Geiringer et al (2011), provide guidance for evaluating the quality of governance in a changed climate future (box 12). More severe and frequent extreme events, and ongoing changes in climate change impacts like sea-level rise, have implications for the ability of governments to consistently meet some of these principles. It is foreseeable that frequent, cascading and compound hazards, such as coastal and riverine flooding, could create situations that bypass standard consultative processes and curtail public involvement, potentially violating principles 1, 2 3, 4 and 6 outlined in box 12.

Box 12: The 10 principles of good law-making

1. Legislatures should allow time and opportunity for informed and open policy deliberation.
2. The legislative process should allow sufficient time and opportunity for the adequate scrutiny of bills.
3. Citizens should be able to participate in the legislative process.
4. Parliaments should operate in a transparent manner.
5. The House should strive to produce high-quality legislation.
6. Legislation should not jeopardise fundamental constitutional rights and principles.
7. Parliaments should follow stable procedural rules.
8. Parliament should foster, not erode, respect for itself as an institution.
9. The Government has a right to govern, so long as it commands a majority in the House.
10. Parliament should be able to enact legislation quickly in (actual) emergencies.

For example, in response to the first earthquake in the Canterbury sequence, Parliament passed the Canterbury Earthquake Response and Recovery Act 2010 in a single day of sitting, despite serious constitutional concerns expressed in the House (Hansard Parliamentary Debates, 2010). According to constitutional scholar Dean Knight (2010), this Act, hurried through Parliament to enable recovery processes, gave "ministers vast and untrammelled power to change laws in the name of earthquake recovery – without adequate checks and balances" and, in doing so, the legislation "violat[ed] basic principles within our constitution and upset our democratic infrastructure" (para 2).

Knight was not alone in his concern; the Law Society's Rule of Law committee expressed concerns about the structure of the legislation, specifically its "potential interference with existing court proceedings and removal of the right of access to the courts, along with reliance on restraint from government and public officials in the exercise of very broad powers of law" (New Zealand Law Society, 2010, para 8).

This criticism was recognised: the Act was repealed six months after it was passed, and replaced by the Canterbury Earthquake Recovery Act 2011.

Inclusive, accountable and transparent decision-making and engagement processes build capacity among the public, Māori and iwi and other stakeholders to understand and adapt to climate change. For example, the process of managed retreat from exposure to ongoing sea-level rise will have profound consequences for community cohesion and wellbeing if processes are not transparent, fair and equitable (Hanna and White, 2020). To reduce the trauma associated with managed retreat, there must be a strong element of trust supported by democratic accountability (Warren, 2018).

Decision-makers in New Zealand are faced with the challenge of anticipating the consequences of a rapidly changing set of risk profiles and how best to respond (Boston, 2016). The Christchurch earthquakes demonstrated that extreme, unexpected and ongoing impacts have the potential to disrupt even a robust and well-functioning democracy like New Zealand's (Hayward, 2013). The rushed legislative response and its broad powers revealed how unexpectedness and urgency can compromise established processes and principles. Existing legislation was unable to accommodate the disruption caused by the earthquakes, in part because legislators had been unable to foresee and prepare for a crisis of such magnitude.

It will be incumbent on governments to provide nuanced and democratically consistent responses that respond to immediate needs and respect constitutional norms. The Canterbury Earthquake Recovery Act 2011 demonstrates how a truncated parliamentary process can be rectified in a later amendment (Gobbi et al, 2011). Responding to the needs of New Zealanders need not compromise due process (Knight, 2010). The capacity to sustain trust and accountability in government and other institutions as climate change impacts worsen will also depend on collaboration between levels of government and with communities, the judiciary, the civil sector and the media.

Trust in government (G3) is an essential prerequisite for democratic decision-making processes and can be enhanced by these same processes. Avoiding breaches of Treaty of Waitangi obligations (G4) will also be necessary to ensure that Māori are willing and able to engage in policy- and decision-making.

Consequence

The consequences of breaches in due democratic process are major and equally significant across all timeframes. Democratic institutions and processes are critical for building adaptive capacity to climate change across all domains.

Confidence: Medium agreement, limited evidence

Evidence of risks to democratic processes in the context of climate change is an emerging field of research. There is a medium level of agreement, but no primary evidence to suggest that the New Zealand Government will respond to climate hazards in an undemocratic manner. However historical events such as the Canterbury earthquakes provide a valuable case study to infer potential responses under a changed climate future.

Adaptation

Limited adaptation action is under way or planned. However stakeholders note that such action is implicit in other processes such as the review of the RMA, and in the remit of the independent Climate Change Commission.

Table 74: G8 Risk to the ability of democratic institutions to follow due democratic decision-making processes under pressure from an increasing frequency and scale of compounding and cascading climate change impacts: Urgency profile

G8 Risk to the ability of democratic institutions to follow due democratic decision-making processes under pressure from an increasing frequency and scale of compounding and cascading climate change impacts: Urgency profile		
Urgency category	**Proportion of urgency**	**Description of actions**
More action needed	10	This should include transparent debriefs after climate change-related and other 'events' to build learning in relation to anticipating and addressing widespread and complex climate change impacts.
Research priority	30	Explore new ways of reducing this risk. For example, through case studies of other major or widespread events like the Canterbury and Kaikōura earthquakes, pandemics and biosecurity incursions.
Sustain current action	40	Some lessons learned from Canterbury and Kaikōura earthquakes. Robust scrutiny by the national media. Strong and independent judiciary.

G8 Risk to the ability of democratic institutions to follow due democratic decision-making processes under pressure from an increasing frequency and scale of compounding and cascading climate change impacts: Urgency profile

Urgency category	Proportion of urgency		Description of actions			
Watching brief	30		Watch and monitor processes.			
Adaptation urgency	53		**Confidence**	Medium agreement, limited evidence		
Consequence	Now	Moderate	2050	Major	2100	Major

7.5 Gaps in knowledge

There is a high degree of consensus on and robust evidence for the need for central government action, and the consequences of inaction, related to climate change adaptation. There is less evidence, and more divided opinion, as to the causes of inadequate central government action.

As detailed in G5, significant knowledge gaps remain in the governance domain. These gaps primarily relate to understanding the cascading and compounding impacts of climate changes across different scales of government, geographic regions and timeframes. Other gaps include the legal implications of climate change action and inaction for different levels of government, and how institutional arrangements can best enable timely and effective adaptation in New Zealand.

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Appendix A: Glossary

Key term	Definition
Adaptation	The process of adjustment to actual or expected climate and its effects. In human systems, adaptation seeks to moderate or avoid harm or exploit beneficial opportunities. In some natural systems, human intervention may facilitate adjustment to expected climate and its effects (IPCC, 2014c).
Adaptive capacity	The ability of systems, institutions, humans and other organisms to adjust to potential damage, to take advantage of opportunities or to respond to consequences (IPCC, 2014c).
Assets	"Things of value", which may be exposed or vulnerable to a hazard or risk. Physical, environmental, cultural or financial/economic element that has tangible, intrinsic or spiritual value (see Taonga) (Ministry for the Environment, 2019a).
Baseline (or reference)	Any datum against which change is measured.
Biodiversity	The variability among living organisms from terrestrial, marine and other ecosystems. Biodiversity includes variability at the genetic, species and ecosystem levels (IPCC, 2014c).
Cascading effects (of climate change)	The effects that flow on from a primary hazard to compound and affect many systems in a dynamic sequence.
Climate	In the usual narrow sense, the average weather. More rigorously, the statistical description of the mean and variability of relevant quantities over a period of time ranging from months to thousands or millions of years. The classical period for averaging these variables is 30 years, as defined by the World Meteorological Organization. The relevant quantities are most often surface variables such as temperature, precipitation and wind. Climate in a wider sense is the state, including a statistical description, of the climate system (IPCC, 2014c).
Climate change	A change in the state of the climate that can be identified (for example, by using statistical tests) by changes or trends in the mean and/or the variability of its properties, and that persists for an extended period, typically decades to centuries. Climate change includes natural internal climate processes or external climate forcings such as variations in solar cycles, volcanic eruptions and persistent changes due to human activity in the composition of the atmosphere or in land use (IPCC, 2014c).
Climate projection	The simulated response of the climate system to a scenario of future emission or concentration of greenhouse gases and aerosols, generally derived using climate models. Climate projections are distinguished from climate predictions in that they depend on the emission, concentration or radiative forcing scenario used, which is in turn based on assumptions about, for example, future socio-economic and technological developments that may or may not be realised (IPCC, 2014c).
Co-benefits (or ancillary benefits)	The positive effects that a policy or measure aimed at one objective might have on other objectives, irrespective of the net effect on overall social welfare. Co-benefits are often subject to uncertainty and depend on local circumstances and implementation practices, among other factors. Co-benefits are also referred to as ancillary benefits (Ministry for the Environment, 2019a).

Key term	Definition
Community	May be a geographic location (community of place), a community of similar interest (community of practice) or a community of affiliation or identity (such as industry) (Ministry for the Environment, 2019a).
Compound hazards and stressors	Combined occurrences of multiple hazards and stressors (that is, cumulative hazards) that will become more significant in the future as adaptation thresholds are reached. For example, in a low-lying coastal area, a persistent wet season (high groundwater, reduced field capacity) could be followed by a coastal storm in the context of sea-level rise, coinciding with intense rainfall, leading to compound flooding impacts (Ministry for the Environment, 2019a).
Confidence	A qualitative measure of the validity of a finding, based on the type, amount, quality and consistency of evidence (for example, data, mechanistic understanding, theory, models and expert judgement) and the degree of agreement (Ministry for the Environment, 2019a).
Consequence	The outcome of an event that may result from a hazard. It can be expressed quantitatively (for example, units of damage or loss, disruption period, monetary value of impacts or environmental effect), semi-quantitatively by category (for example, high, medium or low level of impact) or qualitatively (a description of the impacts) (adapted from Ministry of Civil Defence and Emergency Management, 2019). It is also defined as the outcome of an event affecting objectives (ISO/IEC 27000:2014 and ISO 31000: 2009) (Ministry for the Environment, 2019a).
Disaster	Severe alterations in the normal functioning of a community or a society due to hazardous physical events interacting with vulnerable social conditions, leading to widespread adverse human, material, economic or environmental effects that require immediate emergency response to satisfy critical human needs and that may require external support for recovery (IPCC, 2014c).
Driver	An aspect that changes a given system. Drivers can be short term but are mainly long term in their effects. Changes in both the climate system and socio-economic processes, including adaptation and mitigation, are drivers of hazards, exposure and vulnerability, so drivers can be climatic or non-climatic (Ministry for the Environment, 2019a).
Emissions	The production and discharge of substances that are potentially radiatively active (that is, absorb and emit radiant energy) in the atmosphere (for example, greenhouse gases, aerosols) (Ministry for the Environment, 2019a).
Exposure	The presence of people, livelihoods, species or ecosystems, environmental functions, services, resources, infrastructure, or economic, social or cultural assets in places and settings that could be adversely affected by a change in the external stresses a system is exposed to. In the context of climate change, these are normally specific climate and other biophysical variables (IPCC, 2007). The number, density or value of people, property, services or other things we value (taonga) that are present in an area subject to one or more hazards (that is, within a hazard zone), and that may experience potential loss or harm (Ministry of Civil Defence and Emergency Management, 2019).

Key term	Definition
Extreme weather event	An event that is rare at a particular place and time of year. Definitions of 'rare' vary, but an extreme weather event would normally be as rare as or rarer than the 10th or 90th percentile of a probability density function estimated from observations. By definition, the characteristics of what is called extreme weather may vary from place to place in an absolute sense. When a pattern of extreme weather persists for some time, such as a season, it may be classed as an extreme climate event, especially if it yields an average or total that is itself extreme (for example, drought or heavy rainfall over a season) (IPCC, 2014c).
Financial risk	Risks that involve financial loss to firms. Financial risks in general relate to markets, credit, liquidity and operations.
Frequency	The number or rate of occurrences of hazards, usually over a particular period of time (Ministry for the Environment, 2019a).
Greenhouse gas	The gaseous constituents of the atmosphere, both natural and anthropogenic, that absorb and emit radiation at specific wavelengths within the spectrum of thermal infrared radiation emitted by Earth's surface, the atmosphere itself and clouds. This property causes the greenhouse effect. Water vapour (H_2O), carbon dioxide (CO_2), nitrous oxide (N_2O), methane (CH_4) and ozone (O_3) are the primary greenhouse gases in Earth's atmosphere.
Hazard	The potential occurrence of a natural or human-induced physical event, trend or physical impact that may cause loss of life, injury or other health impacts, as well as damage and loss to property, infrastructure, livelihoods, service provision, ecosystems and environmental resources (IPCC, 2014c). In this report, the term 'hazard' usually refers broadly not only to climate-related physical hazard events (such as floods or heatwaves) but also to evolving trends or their gradual onset physical impacts (IPCC, 2014c).
Heatwave	A period of abnormally and uncomfortably hot weather (IPCC, 2014c).
Impacts (or consequences or outcomes)	The effects on natural and human systems of extreme weather and climate events and of climate change. Impacts generally refer to effects on lives, livelihoods, health, ecosystems, economies, societies, cultures, services and infrastructure due to the interaction of climate changes or hazardous climate events occurring within a specific time period, and the vulnerability of an exposed society or system. Impacts are also referred to as consequences and outcomes (IPCC, 2014c).
Intergovernmental Panel on Climate Change (IPCC)	A scientific and intergovernmental body that works under the authority of the United Nations.
Kaupapa Māori	Literally translates to 'a Māori way'. Smith (2005) describes kaupapa Māori as related to "being Māori, connected to Māori philosophy and principles, taking for granted the validity and legitimacy of Māori, taking for granted the importance of Māori language and culture, and is concerned with the 'struggle for Māori autonomy over Māori cultural well-being'" (Cram, 2017). As an analytical approach, kaupapa Māori is about thinking critically, including developing a critique of non-Māori constructions and definitions of Māori and affirming the importance of Māori self-definitions and self-valuations.

Key term	Definition
Land use	The total of arrangements, activities and inputs undertaken in a certain land cover type (a set of human actions). Also means the social and economic purposes for which land is managed (for example, grazing, timber extraction and conservation). In urban settlements, it is related to land uses within cities and their hinterlands. Urban land use has implications for city management, structure and form and so for energy demand, greenhouse gas emissions and mobility, among other aspects (IPCC, 2014c).
Land-use change	A change in the use or management of land by humans, which may lead to a change in land cover. Land cover and land-use change may impact on the surface albedo, evapotranspiration, sources and sinks of greenhouse gases, or other properties of the climate system and in this way may lead to radiative forcing or other impacts on climate, locally or globally (IPCC, 2014c).
Likelihood	The chance of a specific outcome occurring, where this might be estimated probabilistically (IPCC, 2014c).
Lock in	The generic situation where decisions, events or outcomes at one point in time constrain adaptation, mitigation or other actions or options at a later point in time (IPCC, 2014c).
Māori values and principles	Values and principles deriving from Māori views of the world. They are instruments through which Māori make sense of, experience and interpret the world. They form the basis for Māori ethics and principles (Ministry for the Environment, 2019a).
Mātauranga Māori (or Māori knowledge)	This has many definitions that cover belief systems, epistemologies, values and knowledge, both in a traditional and contemporary sense. Mātauranga Māori incorporates knowledge, comprehension and understanding of everything visible and invisible in the universe (Ministry for the Environment, 2019a).
Mitigation	A human intervention to reduce the sources or enhance the sinks of greenhouse gases (IPCC, 2014c).
Percentile	A value on a scale of 100 that indicates the percentage of the data set values that is equal to or below it. The percentile is often used to estimate the extremes of a distribution. For example, the 90th (or 10th) percentile may be used to refer to the threshold for the upper (or lower) extremes.
Representative concentration pathway (RCP)	A suite of representative future scenarios of additional radiative heat forcing at Earth's surface by 2100 (in Watts per square metre), which is the net change in the balance between incoming solar radiation and outgoing energy radiated back up in the atmosphere. Each RCP can be expressed as a greenhouse gas concentration (not emissions) trajectory adopted by the IPCC for its Fifth Assessment Report (AR5) in 2014 (IPCC, 2014c).
Residual risk	The risk that remains (and may continue to rise) in unmanaged form, after risk management measures and adaptation policies have been implemented to adapt to climate change and more frequent hazards, and for which emergency response and additional adaptive capacities must be maintained or limits to adaptation addressed. Policy interventions and adaptation plans will need to reconcile changing residual risks with changing (evolving) societal perceptions of tolerable risk.

Key term	Definition
Resilience	The capacity of social, economic and environmental systems to cope with a hazardous event, trend or disturbance by responding or reorganising in ways that maintain their essential function, identity and structure, while also maintaining the capacity for adaptation, learning and transformation (IPCC, 2014c).
Risk	The potential for consequences where something of value is at stake and where the outcome is uncertain, recognising the diversity of values. Risk is often represented as probability or likelihood of occurrence of hazardous events or trends, multiplied by the impacts if these events or trends occur. The term 'risk' is used to refer to the potential, when the outcome is uncertain, for adverse consequences on lives, livelihoods, health, ecosystems and species, economic, social and cultural assets, services (including environmental services) and infrastructure. Risk results from the interaction of vulnerability, exposure and hazard. To address the evolving impacts of climate change, risk can also be defined as the interplay between hazards, exposure and vulnerability (IPCC, 2014c).
Risk assessment	The overall qualitative and/or quantitative process of risk identification, risk analysis and risk evaluation, with multiple entry points for communication and engagement and monitoring and reviews (AS/NZS ISO 31000:2009, Risk Management Standard).
Shock	A sudden, disruptive event with an important and often negative impact.
Stress	A long-term, chronic issue with an important and often negative impact.
Stressor (climate)	Persistent climatic occurrence (for example, change in pattern of seasonal rainfall) or rate of change or trend in climate variables, such as the mean, extremes or the range (for example, ongoing rise in mean ocean temperature or acidification), which occurs over a period of time (for example, years, decades or centuries), with important effects on the system exposed, increasing vulnerability to climate change (Ministry for the Environment, 2019a).
System	A set of things working together as parts of an interconnected network and/or a complex whole .
Taonga Māori	Tangible and intangible items that are highly valued in Māori culture. Taonga Māori include: • natural environment (whenua/land, ngahere/forests, awa/rivers, maunga/mountains and moana/ocean) • human and non-human capital (whānau/families, hapū/sub-tribes, iwi/tribes) and spiritual (mauri/the intrinsic life force within living entities) • social capital (mātauranga Māori/Māori knowledge, intergenerational transfer of knowledge) • economic capital (financial value of assets including land holdings) • material capital (buildings including marae, commercial investments and private homes) (Ministry for the Environment, 2019).
Three waters	Drinking water, wastewater and stormwater.

Key term	Definition
Uncertainty	A state of incomplete knowledge that can result from a lack of information or from disagreement about what is known or even knowable. It may have many types of sources, from imprecision in the data to ambiguously defined concepts or terminology, or uncertain projections of human behaviour (IPCC, 2014c).
Value domain	The NCCRA framework outlines five 'value domains' for assessing risks and opportunities. These value domains represent groups of values, assets and systems that may be at risk from exposure to climate change-related hazards or could benefit from them (opportunities). These value domains are a hybrid of New Zealand Treasury's Living Standards Framework and those used in the National Disaster Resilience Strategy (Ministry of Civil Defence and Emergency Management, 2019; New Zealand Treasury, 2018). The value domains are interconnected and apply at individual, community and national levels. They include tangible and intangible values.
Vulnerability	The propensity or predisposition to be adversely affected. Vulnerability encompasses a variety of concepts and elements, including sensitivity or susceptibility to harm and lack of capacity to cope and adapt (IPCC, 2014c). Assessing vulnerability is broader than conventional risk assessments, because it includes indirect and intangible consequences on the four wellbeings and considers adaptiveness and adaptive capacity (for example, communities, whānau, hapū and iwi may be resourceful and adaptive but may lack the resources, insurance access and mandate or capacity to adapt) (Ministry for the Environment, 2019a).
Wellbeing	Wellbeing is achieved when people are able to lead fulfilling lives with purpose, balance and meaning to them (Te Puni Kōkiri and New Zealand Treasury, 2019). In New Zealand, the Treasury's Living Standards Framework notes that intergenerational wellbeing relies on growth, distribution and sustainability of four capitals: natural capital, social capital, human capital and financial/physical capital. The capitals are interdependent and work together to support wellbeing. The Crown–Māori relationship is integral to all four capitals (New Zealand Treasury, 2018). Within te ao Māori – the Māori world – wellbeing is not simply driven by stocks of capitals identified in the Living Standards Framework. Instead, the drivers of wellbeing are considered against the values that imbue te ao Māori with a holistic perspective. These values are interconnected and span many aspects of wellbeing. Wellbeing results from applying these values through knowledge, beliefs and practices (Te Puni Kōkiri and New Zealand Treasury, 2019).

Appendix B: Direction of change for climate hazards

RCP = representative concentration pathway

Table 75: Higher mean temperatures: air and water

Higher mean temperatures: air and water			
Recent and past effects or changes		**Climate sub-national zones affected**	
• Mean air temperature in New Zealand has increased 0.9°C since 1909 (IPCC, 2014a). • The five warmest years since 1909 are: 2016, 2018, 1998, 1999 and 2013 (0.84–0.72°C above 1981–2010 average) (Ministry for the Environment (2018), Stats NZ and NIWA seven-station series). • Sea surface temperatures have risen by 0.71°C over 1909–2009 (Climate Change Adaptation Technical Working Group, 2017), or by about 0.07°C per decade over 1909–2009 (IPCC, 2014a).		• All (highest air-temperature increases in northeast and slightly smaller increase in south). • Warming greatest at higher elevations (Climate Change Adaptation Technical Working Group, 2017).	
Projected changes by ~2050 (30 years) RCP 4.5	**Projected changes by ~2100 (60–80 years) RCP 4.5**	**Projected changes by ~2050 (30 years) RCP8.5**	**Projected changes by ~2100 (60–80 years) RPC 8.5**
Air			
• Ensemble average increase for period 2031–50, eg, annual average air-temperature increases for all zones +0.7 to +0.9°C (Ministry for the Environment, 2018). Generally, summer warms the most, spring warms the least. • The daily maximum temperature is expected to increase faster than the overnight daily minimum temperature (Ministry for the Environment, 2018); ie, the diurnal temperature range is projected to increase.	• Ensemble average increase for period 2081–2100, eg, air-temperature increases for all zones +1.3 to +1.4°C (Ministry for the Environment, 2018). Summer warms the most for zones 1–3, winter warms the most for zones 4–7. Spring warms the least. • The daily maximum temperature is expected to increase faster than the overnight daily minimum temperature (Ministry for the Environment, 2018); ie, the diurnal temperature range is projected to increase.	• Ensemble average increase for period 2031–50, eg, all zones mean annual temperature increase +0.8 to +1.1°C (Ministry for the Environment, 2018). • By 2040, northern North Island (Northland to Taranaki) temperature increase of 1.1°C, and Southland temperature increase of 0.9°C (Ministry for the Environment, 2018). • The daily maximum temperature is expected to increase faster than the overnight daily minimum temperature (Ministry for the Environment, 2018); ie, the diurnal temperature range is projected to increase.	• Ensemble average increase for period 2081–2100, eg, all zones mean annual temperature increase +2.8 to +3.1°C (Ministry for the Environment 2018, Pearce et al, 2018). Lowest warming in Otago/Southland. • The daily maximum temperature is expected to increase faster than the overnight daily minimum temperature (Ministry for the Environment, 2018); ie, the diurnal temperature range is projected to increase.
Water			
• Coastal sea-surface temperatures are projected to have similar changes as mean air temperatures for New Zealand (IPCC, 2014a). • The north Tasman Sea is expected to experience greater warming than the rest of New Zealand's surrounding ocean (Climate Change Adaptation Technical Working Group, 2017). • All zones: +0.8°C increase in sea temperature by 2040. Tasman Sea (zones 2–3) shows the largest absolute temperature change. Zone change in sea surface temperature (SST) (°C), by 2040: zone 1, ~0.8°C; zone 2, ~1.1°C; zone 3, ~1.1°C; zone 4, 1°C; zone 5, ~0.8°C; zone 6, ~0.8°C; zone 7, ~0.3°C (Law et al, 2017b). • Regional Zone change in SST (%), by 2040: zone 1, 4%; zone 2, 6%; zone 3, ~6%; zone 4, 7%; zone 5, 5.5%; zone 6, 7%; zone 7, 5.2% (Law et al, 2017b).	• The north Tasman Sea is expected to experience greater warming than the rest of New Zealand's surrounding ocean (Climate Change Adaptation Technical Working Group, 2017). • Sea-surface temperature projections for coastal waters are similar to mean air temperature increase (Rouse et al, 2017; IPCC, 2014a). • All zones: +1.1°C increase in sea temperature by 2090. Tasman Sea (Zones 2–3) show the largest absolute temperature change. Zone change in SST (°C), by 2090: zone 1, ~1.25°C; zone 2, ~1.3°C; zone 3, ~1.3°C; zone 4, ~1.1°C; zone 5, ~1.2°C; zone 6, ~1.1°C; zone 7, ~0.6°C. • Regional Zone change in SST (per cent), by 2090: zone 1, 5.5%; zone 2, 8%; zone 3, 7.5%; zone 4, ~8%; zone 5, ~6.5%; zone 6, 8%; zone 7, 8% (Law et al, 2018).	• The north Tasman Sea is expected to experience greater warming than the rest of New Zealand's surrounding ocean (Climate Change Adaptation Technical Working Group, 2017). • All zones: ~1°C increase in sea temperature by 2040. Tasman Sea (zones 2–3) shows the largest absolute temperature change. Regional Zone change in SST (°C), by 2040: zone 1, ~1.25°C; zone 2, 1.5°C; zone 3, 1.5°C; zone 4, 1.3°C; zone 5, 1.3°C; zone 6, 1.3°C; zone 7, ~0.65°C. • Regional Zone change in SST (%), by 2040: zone 1, 6%; zone 2, 9%; zone 3, ~8.5%; zone 4, 9%; zone 5, 8%; zone 6, ~9.8%; zone 7, ~9.1%. (Law et al, 2017b).	• Mean sea-surface temperature expected to increase by 2.5°C by 2090 (Climate Change Adaptation Technical Working Group, 2017). • All zones: +2.5°C increase in sea temperature by 2100. Tasman Sea (zones 2–3) shows the largest absolute temperature change, warming to exceed 3.1°C. Zone change in SST (°C), by 2090: zone 1, ~2.85°C; zone 2, ~3.3°C; zone 3, ~3.3°C; zone 4, ~2.8°C; zone 5, ~2.65°C; zone 6, ~2.55°C; zone 7, 1.5°C. • Regional Zone change in SST (%), by 2090: zone 1, 13%; zone 2, 20.5%; zone 3, 19%; zone 4, 20%; zone 5, 16%; zone 6, 19.5%; zone 7, 20% (Law et al, 2017b).

Table 76: **Changes in climate seasonality with longer summers and shorter winters**

Changes in climate seasonality with longer summers and shorter winters			
Recent and past effects or changes		**Climate sub-national zones affected**	
Significant trend since 1950: Cool extremes have become rarer and hot extremes more frequent and intense (IPCC, 2014a).		• All zones (South Island more than North Island). • 2050: All zones. • 2100: All zones.	
Projected changes by ~2050 (30 years) RCP 4.5	**Projected changes by ~2100 (60–80 years) RCP 4.5**	**Projected changes by ~2050 (30 years) RCP8.5**	**Projected changes by ~2100 (60–80 years) RPC 8.5**
Warming greatest summer–autumn and least winter–spring (Climate Change Adaptation Technical Working Group, 2017; Ministry for the Environment, 2018; Pearce et al, 2018).	Warming greatest summer–autumn and least winter–spring (Climate Change Adaptation Technical Working Group, 2017; Ministry for the Environment, 2018; Pearce et al, 2018).	Warming greatest summer–autumn and least winter–spring (Ministry for the Environment, 2018; Pearce et al, 2018)	Warming greatest summer–autumn and least winter–spring (Ministry for the Environment, 2018; Pearce et al, 2018). Spring and autumn frost-free land to at least triple by 2080; up to 60 more hot days (>25°C max) for northern areas by 2090 (IPCC, 2014a).

Table 77: **Heatwaves: increasing persistence, frequency and magnitude**

Heatwaves: increasing persistence, frequency and magnitude			
Recent and past effects or changes		**Climate sub-national zones affected**	
• No significant changes in heatwaves observed yet (Climate Change Adaptation Technical Working Group, 2017). • Increased numbers of high-temperature records observed in recent years, fewer low-temperature records observed (NIWA climate summaries).		• 2050: All zones following temperature changes. Largest increase in northern North Island and interior South Island. • 2100: All zones following temperature changes. Largest increase in northern North Island in 2100.	
Projected changes by ~2050 (30 years) RCP 4.5	**Projected changes by ~2100 (60–80 years) RCP 4.5**	**Projected changes by ~2050 (30 years) RCP8.5**	**Projected changes by ~2100 (60–80 years) RPC 8.5**
• 40% to 100% increase in hot days across New Zealand (maximum temperature of 25°C or higher) (Climate Change Adaptation Technical Working Group, 2017). • Zone 1: Increase 10–20 more hot days/year (>25°C) (Pearce et al, 2018) • Zones 2–3: Increase 5–15 more hot days/year (Ministry for the Environment, 2018). Most in Wairarapa, least at high elevations. Six-day increase of hot days (>25°C) for Wellington (12/year) and 19-day increase for Masterton (50/year) by 2040. Heatwaves three consecutive days >25°C, two-day increase for Wellington (3 /year) and 16 day increase for Masterton (32/year) by 2040 (Joynt and Golubiewski, 2019; Pearce et al, 2019). • Zone 4: Increase 0–15 more hot days/year (Ministry for the Environment, 2018). • Zone 5: Increase 5–15 more hot days/year (Ministry for the Environment, 2018). • Zone 6: Increase 0–20 more hot days/year (Ministry for the Environment, 2018) – highest in central Otago.	• 40% to 300% increase in hot days across New Zealand (maximum temperature of 25°C or higher) (Climate Change Adaptation Technical Working Group, 2017). • Zone 1: Increase 25–30 more hot days/year (>25°C) (Joynt and Golubiewski, 2019; Pearce et al 2018). • Zones 2–3: Increase 5–25 hot days/year (Ministry for the Environment, 2018). Most in Wairarapa and Hawke's Bay. 10-day increase of hot days (>25°C) for Wellington (16/year) and 30-day increase for Masterton (61/year) by 2090. Heatwaves three consecutive days >25°C, four-day increase for Wellington (5/year) and 26-day increase for Masterton (42/year) by 2090. Masterton to change from no extreme consecutive heatwave days >30°C to 2/year by 2090 (Joynt and Golubiewski, 2019; Pearce et al, 2019). • Zone 4: Increase 5–20 more hot days/year (Ministry for the Environment, 2018) – most in Marlborough valleys. • Zone 5: Increase 10–25 hot days/year (Ministry for the Environment, 2018). Most in Canterbury Plains. • Zone 6: Increase 0–28 hot days/year (Ministry for the Environment, 2018). Most in central Otago.	• Zone 1: Increase 15–20 more hot days/year (>25°C) (Pearce et al, 2018). • Zone 2: Increase 0–10 more hot days/year (Ministry for the Environment, 2018). • Zone 3: Increase 5–25 more hot days/year (Ministry for the Environment, 2018). Most in Wairarapa. Heatwaves three consecutive days >25°C, two-day increase for Wellington (3/year) and 17-day increase for Masterton (33/year) by 2040; Masterton to change from no extreme consecutive heatwave days >30°C to 1day/year by 2040 (Joynt and Golubiewski, 2019; Pearce et al, 2019). • Zone 4: Increase 0–10 hot days/year. Most in Marlborough valleys (Ministry for the Environment, 2018). • Zone 5: Increase 5–25 hot days/year. Most in Canterbury Plains (Ministry for the Environment, 2018). • Zone 6: Increase 0–25 hot days/year. Most in central Otago (Ministry for the Environment, 2018).	• Zones 2–3: Increase 30–40 hot days/year for most areas, fewer for high elevations (<20), more for Wairarapa (>60). Extreme hot days (>30°C): a 20-day increase for Masterton (21.5/year), a three-day increase for Wellington (3/year, currently has no extreme hot days) by 2090. Heatwaves three consecutive days >25°C, 15-day increase for Wellington and 67-day increase for Masterton by 2090; Masterton to change from no extreme consecutive heatwave days >30°C to 11 days/year by 2090 (Joynt and Golubiewski, 2019; Pearce et al, 2019). • Zone 4: Increase 5–35 hot days/year. Most in Marlborough and Tasman valleys, least at high elevations (Ministry for the Environment, 2018). • Zone 5: Increase 25–40 hot days/year (Ministry for the Environment, 2018). • Zone 6: Increase 0–50 days/year (most in Mackenzie, least in Fiordland) (Ministry for the Environment, 2018).

Table 78: **Increasing hail severity or frequency**

Increasing hail severity or frequency			
Recent and past effects or changes		**Climate sub-national zones affected**	
No information available.		No information available.	
Projected changes by ~2050 (30 years) RCP 4.5	**Projected changes by ~2100 (60–80 years) RCP 4.5**	**Projected changes by ~2050 (30 years) RCP8.5**	**Projected changes by ~2100 (60–80 years) RPC 8.5**
No information available on hail, although the Ministry for the Environment (2018) states that there may be some increase in storm intensity, local wind extremes and thunderstorms. See also limited information on projections of changes to convective storms (based on Mullan et al, 2011).			

Table 79: **Increasing fire-weather conditions: harsher, prolonged season**

Increasing fire-weather conditions: harsher, prolonged season			
Recent and past effects or changes		**Climate sub-national zones affected**	
No information available.		• 2050: All zones. • 2100: All zones – fire season length to increase with climate change, through fire seasons starting earlier or finishing later (Pearce et al, 2012). Fire climate severity is likely to rise significantly with climate change in many parts of the country as a result of increases in temperature or wind speed, and lower rainfall or humidity (Pearce et al, 2012). The areas most likely to increase from current levels are the east and south of the South Island, especially coastal Otago and Marlborough, and southeastern Southland, and the west of the North Island (particularly around Whanganui). Fire danger in other areas may remain **unchanged, or in fact decrease by the 2080s**, due mainly to increased rainfall. These areas include the West Coast of the South Island and western areas of the North Island such as Taranaki where fire dangers are already low, and East Cape and the Coromandel. Potential also exists for decreased fire danger in Northland, Southland and parts of Canterbury under some models (Pearce et al, 2012).	
Projected changes by ~2050 (30 years) RCP 4.5	**Projected changes by ~2100 (60–80 years) RCP 4.5**	**Projected changes by ~2050 (30 years) RCP8.5**	**Projected changes by ~2100 (60–80 years) RPC 8.5**
All zones: ncreased fire risk, especially zones 1, 3, 4, 5 (Watt et al, 2019). Increase in days with very high and extreme fire danger index from around 0% to 400% by 2040 (IPCC, 2014a). **Seasonal severity rating**: • **50–100%** increase from coastal Otago into Southland (zone 5 southern) • **30–50%** increase in the rest of the lower South Island (with the exception of the Queenstown) and to the areas immediately around New Plymouth and Taupō (zones 5–6, 2) • **20–30%** increase in upper South Island and lower North Island, except Nelson (zones 2–3, 4) • **<20%** Wellington and East Cape (excluding Gisborne), Auckland and Northland (zones 2, 3, 1) (Pearce et al, 2012). **Very high + extreme fire danger:** • **>150%** Southland region • **30–40%** Marlborough region (Pearce et al, 2012).	All zones: Increased fire risk, especially zones 1, 3, 4, 5 (Watt et al, 2019). Increase in days with very high and extreme fire danger index from around 0% to 700% by 2090 (IPCC, 2014a). **Seasonal severity rating** : • **40–100%** increase across the south of the South Island (zone 6) • **30–40%** increase for central North Island area (zones 1, 2, 3) • **<20%** central New Zealand (zone 4) • **no change** for Wellington (zone 3) • **13% reduction** for Kaikōura (zone 4) • **up to 20%** reduction for Northland (zone 1) (Pearce et al, 2012). **Very high + extreme fire danger:** • **>150%** over the entire lower South Island • increases **> 50%** for the central and eastern North Island Coromandel • **up to –20%** for Northland and Kaikōura • **up to –10%** for the West Coast (Pearce et al, 2012).	All zones: Increased fire risk, especially zones 1, 3, 4, 5 (Watt et al, 2019). Significantly higher **seasonal severity rating** values across much of the country: • **>150%** around coastal Otago and Marlborough • **100–150%** increases in the lower North Island • **30–50%** increases in most of the remainder of the North Island • **<30%** in Gisborne, the eastern Bay of Plenty (Rotorua) and the Coromandel. In the South Island, the central Canterbury and West Coast regions are expected to show **little or no change** (Pearce et al, 2012). **Very high + extreme fire danger:** The potential for significantly more days right across the country for the 2050s. In the South Island, only inland Canterbury and the West Coast regions are projected to show **little or no increase** (Pearce et al, 2012).	All zones: Increased fire risk, especially zones 1, 3, 4, 5 (Watt et al, 2019). Zones 3 and 5: 44–48 more fire days. Highest increases in Wellington (zone 2) at 89% and Dunedin (zone 5) at 207% (Watt et al, 2019). **Seasonal severity rating:** • **>100%** around Dunedin and Kaikōura • **>50%** in the central North Island and through western parts of Auckland and Northland, extending to the lower North Island • **>30%** for Canterbury and the West Coast (Pearce et al, 2012). **Very high + extreme fire danger:** • **>150%** in the frequency of severe fire danger days across much of the country • **<50%** for the West Coast and inland Canterbury in the South Island, and East Cape in the North Island (Pearce et al, 2012).

Table 80: More and longer dry spells and drought

More and longer dry spells and drought	
Recent and past effects or changes	**Climate sub-national zones affected**
• Rainfall deficit is a common feature of New Zealand's climatic environment; it is not uncommon to experience short-duration dry spells (Watt et al, 2012). • Most parts of New Zealand (except the Southern Alps and Fiordland) have historically spent, or currently spend, between 5% and 10% of the year in drought conditions, on average (Clark et al, 2011).	• 2050: Zones 1, 2, 3 – The frequency of dry days (<1 mm precipitation) increases with time and RCP for much of the North Island, and for high-altitude inland regions in the South Island (Ministry for the Environment, 2018). Climate drought severity is projected to increase in most areas of the country, except for Taranaki-Manawatu, West Coast and Southland (Collins and Zammit, 2016). • 2100: Zones 1, 2, 3 – The frequency of dry days (<1 mm precipitation) increases with time and RCP for much of the North Island, and for high-altitude inland regions in the South Island (Ministry for the Environment, 2018). Climate drought severity is projected to increase in most areas of the country, except for Taranaki-Manawatu, West Coast and Southland (Collins and Zammit, 2016).

Projected changes by ~2050 (30 years) RCP 4.5	Projected changes by ~2100 (60–80 years) RCP 4.5	Projected changes by ~2050 (30 years) RCP8.5	Projected changes by ~2100 (60–80 years) RPC 8.5
• Time spent in drought in eastern and northern New Zealand is projected to double or triple by 2040 (IPCC, 2014a). • Zones 1, 3, 5: 5–10% additional time in drought (Clark et al, 2011) • Zone 1: 0–8 more dry days per year (Ministry for the Environment, 2018). Increase of 3–9 dry days/year for Auckland. Increased potential evapotranspiration deficit (PED) of 60–100 mm. Low flow thresholds to be reached earlier in year (Pearce et al, 2018). • Zone 2: 0–5 more dry days per year, increased PED of 0–50 mm for most areas in west, 50–100 mm in Manawatu (Ministry for the Environment, 2018). • Zone 3: 5–8 more dry days per year (Ministry for the Environment, 2018). Greater Wellington territory: 3-day dry spells, Wellington +4 (185 days/year), Masterton +7 (177 days/year) by 2040; 5-day dry spells, Wellington +6 (125 days/year), Masterton +7 (121 days/year) by 2040; 10-day dry spells, Wellington +6 (33 days/year), Masterton +9 (37 days/year) by 2040. Increase of 50–100 mm PED for most areas. The annual probability of PED exceeding 300 mm (indicating very dry conditions) increases throughout the region, except for highest Tararua Range altitudes (Pearce et al, 2019). • Zone 4. Change in dry days of -5 to +5 per year. Increase in PED of 50–100 mm for most areas, 100–150 mm inland valleys (Ministry for the Environment, 2018). • Zone 5: Reduction in dry days of 0–5 per year on plains and coast, 0–10 more dry days per year inland. Increase in PED of 50–100 mm for lowland and coast, 100–150 mm inland (Ministry for the Environment, 2018). • Zone 6: Generally, 0–10 fewer dry days per year, largest reduction on West Coast. Increase in PED 0–50 mm in most areas (Ministry for the Environment, 2018). • Zones 1–5: Low flow thresholds reached earlier in the year (>40 days earlier than present for central North Island) (Collins and Zammit, 2016). • Zone 6: Low flow thresholds reached later in the year for west and south (Collins and Zammit, 2016).	• Zones 1, 3, 5: 10% additional time in drought (Clark et al, 2011). • Zone 1: 5–10 more dry days per year (Ministry for the Environment, 2018). Increase in 6–12 dry days/year for most of Auckland. Increased PED of 60–100 mm (Pearce et al, 2018). • Zone 2: 5–10 more dry days per year. Increase in PED 25–100 mm for most areas (Ministry for the Environment, 2018). Greater Wellington territory: 3-day dry spells, Wellington +9 (190 days/year), Masterton +10 (180 days/year) by 2090; 5-day dry spells, Wellington +10 (129 days/year), Masterton +7 (121 days/year) by 2090; 10-day dry spells, Wellington +4 (31 days/year), Masterton +2 (30 days/year) by 2090. The annual probability of PED exceeding 300 mm (indicating very dry conditions) increases throughout the region, except for highest Tararua Range altitude. For the Wairarapa, future probability ranges for PED >300 mm increase from 40–60% to 60–80% by 2090. Wellington City may experience an annual probability increase of PED >300 mm from 5–10% to 20–40% by 2090 (Pearce et al, 2019). • Zone 3: 5–15 more dry days per year. Increase in PED 100–150 mm for most areas (Ministry for the Environment, 2018). • Zone 4: 0–15 more dry days per year. Increase in PED of 50–100 mm for most areas, 100–150 mm inland valleys (Ministry for the Environment, 2018). • Zone 5: 0–5 fewer dry days per year on plains and coast, 5–15 more dry days per year inland. Increase in PED of 50–100 mm for lowland and coast, 100–150 mm inland (Ministry for the Environment, 2018). • Zone 6: 0–5 fewer dry days per year in east. 5–15 fewer dry days per year in west. 0–5 more dry days per year in interior. Increase in PED 0–50 mm in most areas, 50–100 mm interior (Ministry for the Environment, 2018). • Zones 1–5: Low flow thresholds reached earlier in the year (>40 days earlier than present for central North Island) (Collins and Zammit, 2016). • Zone 6: Low flow thresholds reached later in the year for west and south (Collins and Zammit, 2016).	• Dry day and PED projections by 2040 for RCP8.5 are the same as for RCP4.5 in first column. • Zone 1: Drought conditions projected to become more frequent. Increase of 3–9 dry days/year, larger increase in dry days projected for spring (3–6 days). Increased PED of 60–100 mm. Low river flow thresholds to be reached earlier in year (Pearce et al, 2018). • Zones 2–3 (Greater Wellington territory): 3-day dry spells, Wellington +8 (189 days/year), Masterton +8 (178 days/year) by 2040; 5-day dry spells, Wellington +7 (126 days/year), Masterton +5 (119 days/year) by 2040; 10-day dry spells, Wellington +5 (32 days/year), Masterton +6 (34 days/year) by 2040. The annual probability of PED exceeding 300 mm (indicating very dry conditions) increases throughout the region, except for highest Tararua Range altitude (Pearce et al, 2019). • Zones 1–5: Low flow thresholds reached earlier in the year (>40 days earlier than present for central North Island) (Collins and Zammit, 2016). • Zone 6: Low flow threshold reached later in the year for west and south (Collins and Zammit, 2016).	• Zones 1, 3: 10–20 more dry days per year. Zone 1: 100–150 mm increase in PED. Zone 3. 150–200 mm increase in PED for most areas. Low river flow thresholds to be reached earlier in year >40 days earlier than present (Pearce et al, 2018). • Zone 2: 5–15 more dry days per year. 50–100 mm increase in PED for most areas. • Zone 4: 5–15 more dry days per year. 150–200 mm increase in PED for most areas. • Zone 5: 0–10 fewer dry days per year on coast and plains, 10–20 more dry days per year inland. 50–100 mm increase in PED on plains, 150–200 mm increase in PED at high elevations. • Zone 6: 15–20 fewer dry days per year on West Coast, 5–15 more dry days for much of Southland and Otago. 0–50 mm increase in PED for most areas, 100–150 mm increase in PED in inland Otago. • By 2090, up to 10 or more additional dry days per year (~5% increase) throughout the North Island and in inland South Island (Ministry for the Environment, 2018). • Decrease of up to 5% or more in relative humidity by 2090, especially in the South Island (Ministry for the Environment, 2018). • Zones 1, 3, 5: Drought probability up 50–70%. Time spent in drought increase 5–20% (Clark et al, 2011). • Zones 1–5: Low flow thresholds reached earlier in the year (>40 days earlier than present for central North Island) (Collins and Zammit, 2016). • Zone 6: Low flow thresholds reached later in the year for west and south (Collins and Zammit, 2016).

Table 81: Increased storminess and extreme winds/rainfall

<table>
<tr><th colspan="4">Increased storminess and extreme winds/rainfall</th></tr>
<tr><th colspan="2">Recent and past effects or changes</th><th colspan="2">Climate sub-national zones affected</th></tr>
<tr><td colspan="2">Extreme annual one-day rainfall decrease in north and east and increase in west since 1930 (IPCC, 2014a).
Mean westerly flow of wind increased during the late 20th century (1978–98) (IPCC, 2014a).
Between 1972 and 2016, trends in the frequency and magnitude of extreme wind decreased at some sites across New Zealand; however, these results should be treated with caution due to some missing records for some stations and unavailable data (Stats NZ, 2017c).</td><td colspan="2">2050: All zones – Increases in extreme wind in southern half of North Island and the South Island (Climate Change Adaptation Technical Working Group, 2017; Ministry for the Environment, 2018). Increases in rainfall intensity projected everywhere, but largest for zones 1, 3, 6 (southeast) (Carey-Smith et al, 2018).
2100: All zones – Increases in extreme wind in southern half of North Island and the South Island (Climate Change Adaptation Technical Working Group, 2017; Ministry for the Environment, 2018). Increases in rainfall intensity projected everywhere, but largest for zones 1, 3, 6 (southeast) (Carey-Smith et al, 2018).</td></tr>
<tr><th>Projected changes by ~2050 (30 years) RCP 4.5</th><th>Projected changes by ~2100 (60–80 years) RCP 4.5</th><th>Projected changes by ~2050 (30 years) RCP8.5</th><th>Projected changes by ~2100 (60–80 years) RPC 8.5</th></tr>
<tr><td>Extreme wind speeds increase up to 10% or more in parts of the country (Climate Change Adaptation Technical Working Group, 2017; Ministry for the Environment, 2018).
Zone 1: Intensity of tropical cyclones projected to increase (also applicable for zones 2, 3, 4). Increase in extreme/rare rainfall events. 0–2% decrease in extreme winds (Pearce et al, 2018).
Moderately extreme daily precipitation (99th percentile of daily rain) increases over most of the country except for parts of Northland and Hawke’s Bay. Very extreme precipitation (average recurrence interval (ARI) of two years or more) increases throughout the country (Ministry for the Environment, 2018).
Shorter-duration extreme rainfalls (eg, 1-in-100 year, 1-hour duration) increase the most (13.6%/°C increase), compared with more common longer-duration events (eg, 1-in-2 year, 120-hour duration, 4.8%/°C increase) (Carey-Smith et al, 2018).</td><td>Extreme wind speeds increase up to 10% or more in parts of the country (Climate Change Adaptation Technical Working Group, 2017; Ministry for the Environment, 2018).
Mean westerly flow of wind to increase by around 20% in spring and around 70% in winter, and to decrease by around 20% in summer and autumn by 2090 (IPCC, 2014a).
The frequency of extreme winds by 2100 is likely to increase in almost all regions of New Zealand in winter and decrease in summer especially for the Wellington region and the South Island (Mullan et al, 2011).
Zone 1: Intensity of tropical cyclones projected to increase (also applicable for zones 2, 3, 4). Increase in extreme/rare rainfall events. 1–4% decrease in extreme wind (Pearce et al, 2018).
Moderately extreme daily precipitation (99th percentile of wet days) increases over most of the country except for parts of Northland and Hawke’s Bay. Very extreme precipitation (ARI of two years or greater) increases throughout the country (Ministry for the Environment, 2018).
Shorter-duration extreme rainfalls (eg, 1-in-100 year, 1-hour duration) increase the most (13.6%/°C increase), compared with more common longer-duration events (eg, 1-in-2 year, 120-hour duration, 4.8%/°C increase) (Carey-Smith et al, 2018).</td><td>Poleward shift of mid-latitude cyclones and possible small reduction in frequency. The most severe ex-tropical cyclones are expected to be stronger. More analysis needed to quantify (Climate Change Adaptation Technical Working Group, 2017).
Zone 1. Intensity of tropical cyclones projected to increase (also applicable to zones 2, 3, 4). Increase in extreme/rare rainfall events. 0–2% decrease in extreme wind (Pearce et al, 2018).
Moderately extreme daily precipitation (99th percentile of wet days) increases over most of the country except for parts of Northland and Hawke’s Bay. Very extreme precipitation (ARI of 2 years or greater) increases throughout the country (Ministry for the Environment, 2018).
Shorter-duration extreme rainfalls (eg, 1-in-100 year, 1-hour duration) increase the most (13.6% /°C increase), compared with more common longer-duration events (eg, 1-in-2 year, 120-hour duration, 4.8%/°C increase) (Carey-Smith et al, 2018).</td><td>Poleward shift of mid-latitude cyclones and possible small reduction in frequency. The most severe ex-tropical cyclones are expected to be stronger. More analysis needed to quantify (Climate Change Adaptation Technical Working Group, 2017).
The frequency of extreme winds by 2100 is likely to increase in almost all regions of New Zealand in winter and decrease in summer especially for the Wellington region and the South Island (Mullan et al, 2011).
Zone 1: Intensity of tropical cyclones projected to increase (also applicable to zones 2, 3, 4). Increase in extreme/rare rainfall events. Increased frequency of consecutive days of heavy rainfall (>40 mm). 2–4% decrease in extreme wind (Pearce et al, 2018).
Occurrence of conditions conductive to convective storm development is projected to increase by 3–6% from 2070–2100, relative to 1970–2000, especially in the South Island (IPCC, 2014a).
Moderately extreme daily precipitation (99th percentile of wet days) increases over most of the country except for parts of Northland and Hawke’s Bay. Very extreme precipitation (ARI of two years or greater) increases throughout the country (Ministry for the Environment, 2018).
Shorter-duration extreme rainfalls (eg, 1-in-100 year, 1-hour duration) increase the most (13.6%/°C increase), compared with more common longer-duration events (eg, 1-in-2 year, 120-hour duration, 4.8%/°C increase) (Carey-Smith et al, 2018).</td></tr>
</table>

Table 82: **Change in mean annual rainfall**

<table>
<tr><th colspan="4">Change in mean annual rainfall</th></tr>
<tr><th colspan="2">Recent and past effects or changes</th><th colspan="2">Climate sub-national zones affected</th></tr>
<tr><td colspan="2">No significant trends in mean annual rainfall. Winter rainfall decreased in Whangarei, Wellington and New Plymouth and summer rainfall increased in Dunedin and Kerikeri 1960–2016 (Ministry for the Environment, 2017d).</td><td colspan="2">• 2050: Annual pattern of increases in west and south of New Zealand, and decreases in north and east (Ministry for the Environment, 2018). Projected changes in rainfall show a marked seasonality and variability across regions. It is very likely that for winter and spring rainfall will increase in the west of both the North and South Islands, with drier conditions in the east and north. This is a robust prediction both in 2040 and 2090, caused by the westerly winds over New Zealand increasing during these seasons. For summer it is likely that there will be more rainfall in the east of both islands, with less in the west and central North Island (Collins and Zammit, 2016).
• 2100: Annual pattern of increases in west and south of New Zealand, and decreases in north and east (Ministry for the Environment, 2018).</td></tr>
<tr><th>Projected changes by ~2050 (30 years) RCP 4.5</th><th>Projected changes by ~2100 (60–80 years) RCP 4.5</th><th>Projected changes by ~2050 (30 years) RCP8.5</th><th>Projected changes by ~2100 (60–80 years) RPC 8.5</th></tr>
<tr><td>• Minimal changes in annual rainfall, most change seen at seasonal scale.
• Zones 1, 2, 3: Negligible change in annual rainfall. Winter–spring reductions, small summer increases (Ministry for the Environment, 2018).
• Zones 2–3 (Greater Wellington territory): Minimal change in annual wet days and wet spells (Pearce et al, 2019).
• Zones 4, 5: Negligible change in annual rainfall. Small autumn–winter increases in Tasman and Marlborough, winter decreases in Canterbury (Ministry for the Environment, 2018).
• Zone 6: Small increase in annual rainfall. Larger winter increase (10%) in Hokitika (Ministry for the Environment, 2018).</td><td>• Minimal changes in annual rainfall, most change seen at seasonal scale.
• The largest rainfall changes by the end of the century will be for particular seasons rather than annually (Climate Change Adaptation Technical Working Group, 2017).
  – Winter decreases: Gisborne, Hawke’s Bay and Canterbury.
  – Winter increases: Nelson, West Coast, Otago and Southland.
  – Spring decreases: Auckland, Northland and Bay of Plenty (Ministry for the Environment, 2018).
• Zone 1: Minimal change in annual rainfall. Increase or decrease by <5%. Spring has largest rainfall deduction (5%) (Pearce et al, 2018).
• Zone 2: Minimal change in annual rainfall. Largest increase in winter (eg, +9% for Taumarunui, +5% New Plymouth) (Ministry for the Environment, 2018).
• Zone 3: Small decrease in annual rainfall. Largest decrease in winter and spring (eg, spring –6% Gisborne, –5% Napier) (Ministry for the Environment, 2018).
• Zones 2–3 (Greater Wellington territory): Decrease in annual number of wet day spells/year (>1 mm rain/day): 3-day wet spells, Wellington –6 (65/year), Masterton –3 (74/year) by 2090; 5-day wet spells, Wellington –3 (23/year), Masterton –1 (26/year) by 2090; 10-day wet spells, Wellington 0 (2/year), Masterton –1 (0/year) by 2090 (Pearce et al, 2019).
• Zone 4: Small increase in annual rainfall. Largest increase for winter (+7% Nelson) (Ministry for the Environment, 2018).
• Zone 5: Small increase in annual rainfall (eg, +6% Tekapo). Largest increase in winter for Tekapo (+14%), but small decreases in winter for Christchurch and Hanmer (–4%) (Ministry for the Environment, 2018).
• Zone 6: Increases in annual rainfall, largest increases in winter (+16% Hokitika, +19% Queenstown) (Ministry for the Environment, 2018).
• Zone 7: Increase in annual rainfall (+4%), largest increase in winter (+7%) (Ministry for the Environment, 2018).</td><td>• Zone 1. Increase or decrease by <5%. Spring has largest rainfall deduction, Autumn largest increase in rainfall (Pearce et al, 2018).
• Zone 2. Minimal change in annual rainfall, largest increases in winter (+5% Whanganui) (Ministry for the Environment, 2018).
• Zone 3. Small reductions in annual rainfall. Largest decreases in winter/spring (Ministry for the Environment, 2018). Zones 2–3 (Greater Wellington territory): Annual rain days >10 mm – Wellington -0.1 day (35.9/year), Masterton +0 day (20/year) by 2040; >20 mm – Wellington +0.9 (14.9/year), Masterton +0.2 (4.2/year) by 2040; >30 mm – Wellington +0.7 (7.7/year), Masterton +0.3 (1.3/year) by 2040. Annual number of wet day spells/year, >1 mm rain/day: 3-day wet spells, Wellington -6 (65/year), Masterton -3 (74/year) by 2040; 5-day wet spells, Wellington -3 (23/year), Masterton -1(26/year) by 2040; 10-day wet spells, Wellington 0 (2/year), Masterton -1(0/year) by 2040 (Pearce et al, 2019).
• Zone 4. Minimal change in annual rainfall. Increase in winter (15–20% for parts of interior) and decreases in summer (5–10%) (Ministry for the Environment, 2018).
• Zone 5. Minimal change in annual rainfall. Increases for winter (5–10% most areas) and decreases for interior in other seasons (Ministry for the Environment, 2018).
• Zone 6. Increase in annual rainfall (5–15%). Largest increase in winter (>20%) (Ministry for the Environment, 2018).</td><td>• The largest rainfall changes by the end of the century will be for particular seasons rather than annually (Climate Change Adaptation Technical Working Group, 2017).
• Zone 1: Reduction in annual rainfall, particularly in Northland (5–10%). Largest decrease in summer (15–20%). Smaller decreases for southern parts of region. Increases in autumn–winter (Ministry for the Environment, 2018).
• Zone 2: Annual rainfall increase. Small decreases during spring, summer and autumn, larger increases in winter (10–20%) (Ministry for the Environment, 2018).
• Zone 3: Annual rainfall decrease (5–15%). Reductions in all seasons, especially summer and winter (Ministry for the Environment, 2018).
• Zones 2–3 (Greater Wellington territory): Annual rain days >10 mm – Wellington +0.3 day (36.3/year), Masterton –0.8 day (19.2/year) by 2090; >20 mm – Wellington +2 (16/year), Masterton +0.2 (4.2/year) by 2090; >30 mm – Wellington +2 (9/year), Masterton +0.2 (1.2/year) by 2090. Annual number of wet day spells/year, >1 mm rain/day: 3-day wet spells, Wellington –11 (60/year), Masterton –12 (65/year) by 2090; 5-day wet spells, Wellington –6 (20/year), Masterton –8 (19/year) by 2090; 10-day wet spells, Wellington –1 (1/year), Masterton –1 (0/year) by 2090 (Pearce et al, 2019).
• Zone 4: Annual rainfall increase (5–10%). Significant increases in winter (>20%) (Ministry for the Environment, 2018).
• Zone 5: Annual rainfall increases for most areas (5–10%). Dominated by winter increases (>10%) (Ministry for the Environment, 2018).
• Zone 6: Annual rainfall increases (>20% for west coast). Increases in all seasons but significantly in winter (>40% in some areas) (Ministry for the Environment, 2018).</td></tr>
</table>

Table 83: Reducing frost, snow and ice cover

Reducing frost, snow and ice cover			
Recent and past effects or changes		**Climate sub-national zones affected**	
• Total ice volume of the Southern Alps for the small and medium glaciers has decreased by 33% from 1977–2018 (Salinger et al, 2019). • Significant reduction in frequency of cold nights in many locations (Climate Change Adaptation Technical Working Group, 2017). • Ice volume declined by 36–61% from the late 1800s to the late 1900s, with glacier volume reducing by 15% 1976–2008 (IPCC, 2014a).		• 2050: Zone 2 (Central Plateau), zone 4, zone 6. • 2100: Zone 2 (Central Plateau), zone 4, zone 6.	
Projected changes by ~2050 (30 years) RCP 4.5	**Projected changes by ~2100 (60–80 years) RCP 4.5**	**Projected changes by ~2050 (30 years) RCP8.5**	**Projected changes by ~2100 (60–80 years) RPC 8.5**
• Decrease of 10–25 frost days for central North Island and most of the South Island (inland from coast) (Ministry for the Environment, 2018). • Number of days of frost decrease most in the coldest regions (Climate Change Adaptation Technical Working Group, 2017). • Zones 4, 5 and 6 (Southern Alps): Largest change in absolute amounts is along the Main Divide of the Alps. Greatest percentage of changes is at lower altitudes/elevations. • Snowline elevation (snow duration exceeds three months) lifts from 1550 m (1990s) to 1550–1750 m by 2040. Overall decrease in snow duration for elevations below 2900 m by year 2040: at an elevation of 2000 m, the mean decrease is 6%; at 1000 m, the mean decrease is 11%; at lower elevations, the mean decrease is 45%. Average maximum snow water equivalence (SWE) substantially decreases at all elevations except above 2900 m elevation by 2040: at an elevation of 2000 m, the mean decrease is 9%; at 1000 m, the mean decrease is 28%; at lower elevations, the mean decrease is 53% (Hendrikx et al, 2012).* • Note: No information about snow water equivalent or snow amounts is available yet from IPCC AR5 downscaling for New Zealand.	• Decrease of 10–25 frost days for central North Island and most of the South Island, and 25–50 fewer frost days for high elevations in Southern Alps (Ministry for the Environment, 2018). • By 2090, peak snow accumulation is projected to decline by 32–79% at 1000 m and by 6–51% at 2000 m (IPCC, 2014a). • Zones 4, 5 and 6 (Southern Alps): Largest change in absolute amounts is along the Main Divide of the Alps. Greatest percentage of changes is at lower altitudes/elevations. • Snowline elevation (snow duration exceeds three months) lifts from 1550 m (1990s) to 1700–2000 m by 2090. Overall decrease in snow duration for elevations below 2900 m by year 2090: at an elevation of 2000 m, the mean decrease is 15%; at 1000 m, the mean decrease is 31%; at lower elevations, the mean decrease is 76%. Average maximum SWE substantially decreases at all elevations by 2090: at an elevation of 2000 m, the mean decrease is 26%; at 1000 m, the mean decrease is 57%; at lower elevations, the mean decrease is 82% (Hendrikx et al, 2012).* • Note: No information about snow water equivalent or snow amounts is available yet from IPCC AR5 downscaling for New Zealand.	• Decrease of 10–25 frost days for central North Island and most of the South Island, and 25–50 fewer frost days for high elevations in Southern Alps (Ministry for the Environment, 2018). • Note: No information about snow water equivalent or snow amounts is available yet from IPCC AR5 downscaling for New Zealand.	• Decrease of 25–50 frost days for central North Island and most of the South Island (inland from coast). 50–75 fewer frost days for Southern Alps. Much of New Zealand (outside of alpine areas) to be frost free under this scenario. • Snow days per year reduce by 30 days or more by 2090 (Ministry for the Environment, 2018). • Note: No information about snow water equivalent or snow amounts is available yet from IPCC AR5 downscaling for New Zealand. • Zones 2–3 (Tararua Ranges): The ranges will experience at least 60 fewer nights <5°C by 2090 (Pearce et al, 2019).

Note: * Authors use RCP6.0 for these estimates.

Table 84: River and flow changes in frequency and magnitude in rural and urban areas

River and flow changes in frequency and magnitude in rural and urban areas			
Recent and past effects or changes		**Climate sub-national zones affected**	
No information available.		- 2050: All zones. Different level of effects across the regions. Largest increases in mean annual flood (MAF) for Southland. - 2100: All zones. Different level of effects across the regions. Largest increases in MAF for Southland.	
Projected changes by ~2050 (30 years) RCP 4.5	**Projected changes by ~2100 (60–80 years) RCP 4.5**	**Projected changes by ~2050 (30 years) RCP8.5**	**Projected changes by ~2100 (60–80 years) RPC 8.5**
- Zone 1: Mean annual flood decreases in some areas (Collins and Zammit, 2016). - Zones 2, 3: Mean annual flood stays the same or slightly increases in some areas (Collins and Zammit, 2016). - Zone 4, 5, 6: Mean annual flood slightly increases in most areas, slightly decreases in south Canterbury plains. - Lower river flows in summer will raise water temperatures and exacerbate water quality problems, such as through increased algae growth (Climate Change Adaptation Technical Working Group, 2017). - Note: No research yet on changes to large flood flows and return periods – highly uncertain at this point.	- Zone 1: Mean annual flood decreases in most areas (Collins and Zammit, 2016). - Zone 2: Mean annual flood increases in west, decreases in central North Island. - Zone 3: Mean annual flood generally decreases. - Zones 4, 5: Mean annual flood slightly increases in most areas, slightly decreases in inland Marlborough, Canterbury Plains. - Zone 6: Mean annual flood increases, particularly for Southland. - Lower river flows in summer will raise water temperatures and exacerbate water quality problems, such as through increased algae growth (Climate Change Adaptation Technical Working Group, 2017). - Note: No research yet on changes to large flood flows and return periods – highly uncertain at this point.	- Zone 1. MAF decrease for most of the region, increase for Waikato (Collins and Zammit, 2016). - Zone 2. MAF increase. - Zone 3. MAF generally decrease. - Zone 4, 5, 6. MAF slightly increases in most areas, slightly decreases in Banks Peninsula, south Canterbury, northern Southland. - Lower river flows in summer will raise water temperatures and exacerbate water quality problems, such as through increased algae growth (Climate Change Adaptation Technical Working Group, 2017). - Note: no research yet on changes to large flood flows and return periods – highly uncertain at this point.	- Zone 1: MAF increases everywhere except Far North (decrease). - Zone 2: MAF increases. - Zone 3: MAF increases, but smaller increases than for zone 2. - Zone 4: MAF increases, particularly in northern areas. - Zone 5: MAF increases, particularly in inland and south of region. - Zone 6: MAF increases significantly, particularly in south and east of region. - Lower river flows in summer will raise water temperatures and exacerbate water quality problems, such as through increased algae growth (Climate Change Adaptation Technical Working Group, 2017). - Note: No research yet on changes to large flood flows and return periods – highly uncertain at this point. - **National:** Increases in MAF for most of the country's agricultural areas, with only slight reductions in the rest. The percentage increases tend to be greater for the more extreme RCPs and late century, with swathes of particularly large increases in several parts of the country depending on the RCP and time period: south Auckland down to west Waikato; central Manawatu–Whanganui; southern Hawke's Bay; and much of Canterbury, Otago and Southland. The substantial increases observed in Southland are the most consistent late century.

Table 85: Coastal and estuarine flooding: increasing persistence, frequency and magnitude

<table>
<tr><th colspan="4">Coastal and estuarine flooding: increasing persistence, frequency and magnitude</th></tr>
<tr><th colspan="2">Recent and past effects or changes</th><th colspan="2">Climate sub-national zones affected</th></tr>
<tr><td colspan="2">• Increased storm surge and coastal inundation. Increased coastal erosion observed around New Zealand.
• About 20 cm of sea-level rise (SLR) in New Zealand since 1900 (Ministry for the Environment, 2017b).
• Rate of SLR in New Zealand was 1.7 mm/year 1900–2008. Rate of SLR 1993–2016 was 3.4 mm/year – indicating an acceleration of SLR (Ministry for the Environment 2017b):
– Wellington: 2.23 (±0.16) mm/year 1891–1893 and 1901–2015
– Auckland: 1.60 (±0.08) mm/year 1899–2015
– Dunedin: 1.42 (±0.08) mm/year 1899–2015
– Lyttelton: 2.12 (±0.09) mm/year 1901–2015
– Moturiki (Mount Maunganui): 1.9 (±0.25) mm/year 1973–2015
– New Plymouth: 1.37 (±0.16) mm/year for 1920 and 1955–2015 (Stats NZ, 2017b).
• Zones 2–3 (Wellington Harbour): Average rate of relative SLR of 2.03±0.15 mm/year, or 0.2 m in past 100 years up to 2011. Wellington Harbour exhibits the highest relative SLR rate in New Zealand for the long term (>45 years), due to the higher subsidence present in lower New Zealand (certainly within the last few decades). Lyttelton (zone 5) has the second highest, rate of SLR of 2.19 mm/year up the end of 2017 (Bell et al, 2018).</td><td colspan="2">• 2050: All coastal areas.
• 2100: All coastal areas.</td></tr>
<tr><th>Projected changes by ~2050 (30 years) RCP 4.5</th><th>Projected changes by ~2100 (60–80 years) RCP 4.5</th><th>Projected changes by ~2050 (30 years) RCP8.5</th><th>Projected changes by ~2100 (60–80 years) RPC 8.5</th></tr>
<tr><td>• Rising sea levels are expected to cause salinisation of groundwater and coastal wetlands (Climate Change Adaptation Technical Working Group, 2017).
• All zones: Exposure to extreme storm tides will increase with further SLR (Pearce et al, 2019).
• 0.24 m SLR projected by 2050 under RCP4.5 (Ministry for the Environment, 2017b).</td><td>• Rising sea levels are expected to cause salinisation of groundwater and coastal wetlands (Climate Change Adaptation Technical Working Group, 2017).
• All zones: Exposure to extreme storm tides will increase with further SLR (Pearce et al, 2019).
• 0.55 m SLR projected by 2100 under RCP4.5 (Ministry for the Environment, 2017b).
• Extreme sea levels that are expected to be reached once every 100 years (on average) at present-day mean sea level (MSL) will occur at least once per year or more (on average) by 2050–70; earlier for areas with smaller tide ranges (Ministry for the Environment, 2017b).</td><td>• Rising sea levels are expected to cause salinisation of groundwater and coastal wetlands (Climate Change Adaptation Technical Working Group, 2017).
• All zones: Exposure to extreme storm tides will increase with further SLR (Pearce et al, 2019).
• 0.28 m SLR projected by 2050 under RCP8.5, 0.37 m under RCP8.5+ (allowing for ice sheet instabilities) (Ministry for the Environment, 2017b).</td><td>• Rising sea levels are expected to cause salinisation of groundwater and coastal wetlands (Climate Change Adaptation Technical Working Group, 2017).
• All zones: Exposure to extreme storm tides will increase with further SLR (Pearce et al, 2019).
• 0.79 m SLR projected by 2050 under RCP8.5, 1.05 m under RCP8.5+ (allowing for ice sheet instabilities) (Ministry for the Environment, 2017b).
• Extreme sea levels that are expected to be reached once every 100 years (on average) at present-day MSL will occur at least once per year or more (on average) by 2050–70; earlier for areas with smaller tide ranges (Ministry for the Environment, 2017b).</td></tr>
</table>

Table 86: Sea-level rise and salinity stresses on brackish and aquifer systems and coastal lowland rivers

<table>
<tr><th colspan="4">Sea-level rise and salinity stresses on brackish and aquifer systems and coastal lowland rivers</th></tr>
<tr><th colspan="2">Recent and past effects or changes</th><th colspan="2">Climate sub-national zones affected</th></tr>
<tr><td colspan="2">Sea-level rise (SLR) trends as above.</td><td colspan="2">• 2050: All coastal areas.
• 2100: All coastal areas.</td></tr>
<tr><th>Projected changes by ~2050 (30 years) RCP 4.5</th><th>Projected changes by ~2100 (60–80 years) RCP 4.5</th><th>Projected changes by ~2050 (30 years) RCP8.5</th><th>Projected changes by ~2100 (60–80 years) RPC 8.5</th></tr>
<tr><td>• SLR trends as above.
• No information about projections for salinisation of aquifers etc, except that this will increase under higher levels of SLR. Changes to salinity will also depend on rainfall and runoff patterns.</td><td>• SLR trends as above.
• No information about projections for salinisation of aquifers etc, except that this will increase under higher levels of SLR. Changes to salinity will also depend on rainfall and runoff patterns.</td><td>• SLR trends as above.
• No information about projections for salinisation of aquifers etc, except that this will increase under higher levels of SLR. Changes to salinity will also depend on rainfall and runoff patterns</td><td>• SLR trends as above.
• No information about projections for salinisation of aquifers etc, except that this will increase under higher levels of SLR. Changes to salinity will also depend on rainfall and runoff patterns.</td></tr>
</table>

Table 87: Increasing coastal erosion: cliffs and beaches

Increasing coastal erosion: cliffs and beaches

Recent and past effects or changes	Climate sub-national zones affected
• Present-day land subsidence rates average ~2 mm/year, with a maximum of up to ~4 mm/year along the east coast of the North Island south of Hawke's Bay, and on the south and west coasts of the North Island as far north as Bulls. This land subsidence will exacerbate the effects of sea-level rise (SLR) (Beavan and Litchfield, 2012). • SLR trends as above.	• 2050: All coastal areas. • 2100: All coastal areas.

Projected changes by ~2050 (30 years) RCP 4.5	Projected changes by ~2100 (60–80 years) RCP 4.5	Projected changes by ~2050 (30 years) RCP8.5	Projected changes by ~2100 (60–80 years) RPC 8.5
• All zones: Highly variable erosion; depends on geology, tidal range, geomorphology, exposure. • Areas with small tidal range more sensitive to erosion than large tidal range (east coast and Wellington more sensitive than west coast) (Ministry for the Environment, 2017b).	• All zones: Highly variable erosion; depends on geology, tidal range, geomorphology, exposure. • Areas with small tidal range more sensitive to erosion than large tidal range (east coast and Wellington more sensitive than west coast) (Ministry for the Environment, 2017b).	• All zones: highly variable erosion; depends on geology, tidal range, geomorphology, exposure. • Areas with small tidal range more sensitive to erosion than large tidal range (east coast and Wellington more sensitive than west coast) (Ministry for the Environment 2017b).	• All zones: Highly variable erosion; depends on geology, tidal range, geomorphology, exposure. • Areas with small tidal range more sensitive to erosion than large tidal range (east coast and Wellington more sensitive than west coast) (Ministry for the Environment 2017b).

Table 88: Increasing landslides and soil erosion

Increasing landslides and soil erosion

Recent and past effects or changes	Climate sub-national zones affected
No information available.	• 2050: All zones. • 2100: All zones.

Projected changes by ~2050 (30 years) RCP 4.5	Projected changes by ~2100 (60–80 years) RCP 4.5	Projected changes by ~2050 (30 years) RCP8.5	Projected changes by ~2100 (60–80 years) RPC 8.5
• Increase in landslides and erosion with increasing extreme rainfall intensity. Increased fire risk will exacerbate soil erosion. • Risks of earthflow erosion in zones 1, 2, 3. Increased rainfall and temperature (impacting evapotranspiration) may affect earthflow erosion. • Risks of increased gully erosion in zones 1, 2, 3. Any increases to rainfall exacerbate this. • All zones at risk of increased sheet erosion (exacerbated by increased rainfall and runoff). • Bank erosion may increase with increasing river flows (all zones, particularly south and west). • Wind erosion may increase in susceptible areas (sand dunes, volcanic plateau, eastern South Island) – particularly in areas that will become drier and windier (Basher et al, 2012).	• Increase in landslides and erosion with increasing extreme rainfall intensity. Increased fire risk will exacerbate soil erosion. • Risks of earthflow erosion in zones 1, 2, 3. Increased rainfall and temperature (impacting evapotranspiration) may affect earthflow erosion. • Risks of increased gully erosion in zones 1, 2, 3. Any increases to rainfall exacerbate this. • All zones at risk of increased sheet erosion (exacerbated by increased rainfall and runoff). • Bank erosion may increase with increasing river flows (all zones, particularly south and west. • Wind erosion may increase in susceptible areas (sand dunes, volcanic plateau, eastern South Island) – particularly in areas that will become drier and windier (Basher et al, 2012).	• Increase in landslides and erosion with increasing extreme rainfall intensity. Increased fire risk will exacerbate soil erosion. • Risks of earthflow erosion in zones 1, 2, 3. Increased rainfall and temperature (impacting evapotranspiration) may affect earthflow erosion. • Risks of increased gully erosion in zones 1, 2, 3. Any increases to rainfall exacerbate this. • All zones at risk of increased sheet erosion (exacerbated by increased rainfall and runoff). • Bank erosion may increase with increasing river flows (all zones, particularly south and west). • Wind erosion may increase in susceptible areas (sand dunes, volcanic plateau, eastern South Island) – particularly in areas that will become drier and windier (Basher et al, 2012).	• Increase in landslides and erosion with increasing extreme rainfall intensity. Increased fire risk will exacerbate soil erosion. • Risks of earthflow erosion in zones 1, 2, 3. Increased rainfall and temperature (impacting evapotranspiration) may affect earthflow erosion. • Risks of increased gully erosion in zones 1, 2, 3. Any increases to rainfall exacerbate this. • All zones at risk of increased sheet erosion (exacerbated by increased rainfall and runoff). • Bank erosion may increase with increasing river flows (all zones, particularly south and west). • Wind erosion may increase in susceptible areas (sand dunes, volcanic plateau, eastern South Island) – particularly in areas that will become drier and windier (Basher et al, 2012).

Table 89: Marine heatwaves: more persistent high summer sea temperatures

<table>
<tr><th colspan="4">Marine heatwaves: more persistent high summer sea temperatures</th></tr>
<tr><th colspan="2">Recent and past effects or changes</th><th colspan="2">Climate sub-national zones affected</th></tr>
<tr><td colspan="2">• Tasman Sea marine heatwaves in the previous two summers (Salinger et al, 2019).
• Hottest Tasman marine heatwave on record 2017/18 summer (Bureau of Meteorology and NIWA, 2018).</td><td colspan="2">• 2050: All marine areas.
• 2100: All marine areas.</td></tr>
<tr><th>Projected changes by ~2050 (30 years) RCP 4.5</th><th>Projected changes by ~2100 (60–80 years) RCP 4.5</th><th>Projected changes by ~2050 (30 years) RCP8.5</th><th>Projected changes by ~2100 (60–80 years) RPC 8.5</th></tr>
<tr><td>• Southwest Pacific sea surface temperature (SST) increases ~0.8°C by mid-century under RCP4.5 (Law et al, 2017b).
• Marine heatwaves projected to increase in frequency and intensity with ongoing atmospheric and ocean warming.</td><td>• Highest ocean temperature increases in north Tasman Sea – projected to exceed 3°C by 2100 (Climate Change Adaptation Technical Working Group, 2017).
• Southwest Pacific SST increases ~1.1°C by late century under RCP4.5 (Law et al, 2017b).
• Marine heatwaves projected to increase in frequency and intensity with ongoing atmospheric and ocean warming.</td><td>• Southwest Pacific SST increases ~1°C under RCP8.5 by mid-century (Law et al, 2017b).
• Marine heatwaves projected to increase in frequency and intensity with ongoing atmospheric and ocean warming.</td><td>• Southwest Pacific SST increases ~2.5°C under RCP8.5 by end century. For Tasman Sea, warming exceeds 3.1°C. Warming lowest in southern waters. Proportional warming of +16–20% for most marine areas around New Zealand (Law et al, 2017b).
• Marine heatwaves projected to increase in frequency and intensity with ongoing atmospheric and ocean warming.</td></tr>
</table>

Table 90: Ocean chemistry changes: nutrient cycling and pH changes

<table>
<tr><th colspan="4">Ocean chemistry changes: nutrient cycling and pH changes</th></tr>
<tr><th colspan="2">Recent and past effects or changes</th><th colspan="2">Climate sub-national zones affected</th></tr>
<tr><td colspan="2">• The trend of the pH of New Zealand's subantarctic waters was a decrease of 0.0015 units a year 1998–2016. Ocean acidification is ranked as the most serious human-based threat to New Zealand's marine habitats (Stats NZ, 2017a).
• Present-day pH 8.11 for southwest Pacific (Law et al, 2017b).</td><td colspan="2">• 2050: Subantarctic coastal zones.
• 2100: Subantarctic coastal zones.</td></tr>
<tr><th>Projected changes by ~2050 (30 years) RCP 4.5</th><th>Projected changes by ~2100 (60–80 years) RCP 4.5</th><th>Projected changes by ~2050 (30 years) RCP8.5</th><th>Projected changes by ~2100 (60–80 years) RPC 8.5</th></tr>
<tr><td>• pH: 7.98 for southwest Pacific (decrease of 0.12).
• Reduction in macronutrients, net primary production, chlorophyll-a. Reductions are larger with time and RCP (Law et al, 2017b).
• All zones: Surface macronutrient concentrations, no significant decrease by 2040. No significant change of net primary production by 2040. Zones detrital flux change (particle flux): all, –1.3%; zone 1, –3.1%; zone 2, –0.5%; zone 3, –0.9%; zone 4, –1.4%; zone 5, –2.9%; zone 6, –3.1%; zone 7, 0.5% (Law et al, 2017b).</td><td>• pH: 7.95 for southwest Pacific (decrease of 0.16).
• Reduction in macronutrients, net primary production, chlorophyll-a. Reductions are larger with time and RCP (Law et al, 2017b).
• All zones: Mixed layer depth to decrease by a mean of –6 m. Significant decrease of surface macronutrient concentrations by 2100. Net primary production to decrease 1.2 by 2100. Particle flux decrease of 4.5% by 2100. Zones 1–2 (subtropical waters): decrease of 11.1% for particle flux. Zones detrital flux change (particle flux): all, –4.5%; zone 1, 11.1%; zone 2, 0.2%; zone 3, –2.6%; zone 4, 0.6%; zone 5, –6.3%; zone 6, –7.8%; zone 7, 0.4% (Law et al, 2017b).</td><td>• pH: 7.93 for southwest Pacific (decrease of 0.18).
• Reduction in macronutrients, net primary production, chlorophyll-a. Reductions are larger with time and RCP (Law et al, 2017b).
• All zones: surface macronutrient concentrations, no significant decrease by 2040. No significant change of net primary production by 2040. Zones detrital flux change (particle flux): all, -4.4%; zone 1, -7.8%; zone 2, -3.3%; zone 3, -4.7%; zone 4, -2.3%; zone 5, –5.4%; zone 6, -6.7%; zone 7, -1%. pH decline to 7.935 by 2050 (Law et al, 2017b).</td><td>• pH: 7.77 for southwest Pacific (decrease of 0.33).
• Reduction in macronutrients, net primary production, chlorophyll-a. Reductions are larger with time and RCP (Law et al, 2017b).
• All zones: Decreases in surface mixed layer depth (15%), macronutrients (7.5–20%), net primary production (4.5%) and particle flux (12%). Zones 1–2 (subtropical waters): decrease of 23.6% for particle flux. Largest macronutrient declines in the eastern Chatham Rise and subantarctic waters; dissolved iron increases in subtropical waters. Surface pH projections indicate a 0.335 decline to ~7.77 by 2100. Zones detrital flux change (particle flux): all, –12%; zone 1, –23.6%; zone 2, –5.7%; zone 3, –8.9%; zone 4, –3.7%; zone 5, –15.2%; zone 6, –12.6%; zone 7, –4.7% (Law et al, 2017b).</td></tr>
</table>

Table 91: International influences from climate change and greenhouse gas mitigation preferences

<table>
<tr><th colspan="4">International influences from climate change and greenhouse gas mitigation preferences</th></tr>
<tr><td colspan="2">**Recent and past effects or changes**</td><td colspan="2">**Climate sub-national zones affected**</td></tr>
<tr><td colspan="2">No information available.</td><td colspan="2">• 2050: All zones.
• 2100: All zones.</td></tr>
<tr><th>Projected changes by ~2050 (30 years) RCP 4.5</th><th>Projected changes by ~2100 (60–80 years) RCP 4.5</th><th>Projected changes by ~2050 (30 years) RCP8.5</th><th>Projected changes by ~2100 (60–80 years) RPC 8.5</th></tr>
<tr><td colspan="4">• Findings from Royal Society report on *Climate Change Implications for New Zealand* (non-specific timeframes, region or RCP).
• All aspects of food security are potentially affected by climate change, including food access, use, 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 intergroup 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.
• While New Zealand agriculture could benefit from increasing global commodity prices in the long term, there are many negatives.
• We gain significant revenue from long-haul tourism, which could be reduced if the acceptability of long-haul travel, and costs of fossil fuels, are affected by climate change.</td></tr>
</table>

Note: The baseline (zero) for Ministry for the Environment (2018) and IPCC projections is the average over 1986–2005.