Our atmosphere and climate 2020

New Zealand's Environmental Reporting Series

Ministry for the Environment
Manatū Mō Te Taiao

Stats NZ
Tatauranga Aotearoa

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Cover: Surf at Allans Beach, Dunedin.
Photo: Clare Toia-Bailey, **www.image-central.co.nz**

Contents

Message to readers

COVID-19 has dominated our lives in 2020, causing widespread and significant changes to our economy, our businesses, and the way we live our lives. The experiences we are living through may offer some insights for how to approach the challenges that climate change is fast bringing our way.

COVID-19 reminded us that large-scale disruption to our lives can be abrupt, unwanted, and unforeseen, and that some people, places, and sectors are likely to be disproportionately affected. For many people, the disruption caused the loss of jobs, businesses, and financial stability. Forced isolation was tough and served to highlight the things we value most in life, like connections with others and access to nature.

However, our responses to eliminating the virus were an example to the world. As a nation we demonstrated resilience, kindness, and the capacity to act as a team. Science, data, and modelling informed daily decision-making and guided us through the alert levels. We also rapidly adopted new technology and different ways of working, learning, and keeping in touch. These are the attitudes we can draw on to respond to climate change.

Significant changes to Aotearoa New Zealand's climate are documented in this report, and they mirror the changes being observed around the world. The impacts are widespread and threaten our environment, our way of life, and the ways we make a living. Our emissions are affecting the climate and changes in the climate are affecting us. Details of the effects on our wellbeing are included here, and while the voices of te ao Māori are stronger, future reports should go further.

Climate change is here to stay, but the opportunity to create the best possible future for our young people and mokopuna is short-lived. The responsibility on our shoulders today is to act wisely and rapidly to gift them security, health, and access to the beauty and benefits of New Zealand that we have enjoyed.

In our hands are many tools to transform our way of life and create a low-emissions future. Clean energy, protecting native forest and planting trees, re-thinking transport away from petrol and diesel, and new technologies can enhance nature, create healthier cities, and ensure people are better off.

There is an opportunity to listen and learn from each other and past experiences. When Māori journeyed to this land from Hawaiki, they were forced to discover different food and use new and unfamiliar materials to survive. Sir Paul Reeves rightly said of Māori, "We are geared toward innovative and revolutionary thinking, and practical and sustainable solutions." These ways of thinking are needed to take us forward together.

We invite you to use this report to see for yourself how much has already changed and reflect on the serious and immediate challenges we face. Then share what you discover. Use the findings with whānau, schools, businesses, government, and communities to inform choices and decisions that will shape the legacy we leave for future generations.

Vicky Robertson
Secretary for the Environment

Mark Sowden
Government Statistician

Structure and content of this report

Our atmosphere and climate 2020 is the latest in a series of environmental reports produced by the Ministry for the Environment and Stats NZ. It updates *Our atmosphere and climate 2017* and theme 5 'Our changing climate' from *Environment Aotearoa 2019*, which was the most recent report on the state of the environment as a whole.

Our changing climate is explored in five chapters that aim to show how, why, and what is happening to our climate, and how the changing climate is beginning to affect many of the things we care about. For the first time in the Environmental Reporting series, information about drivers of environmental change and future outlooks are included.

After an introduction, *Our activities are driving emissions* (chapter 2) explores the make-up of Aotearoa New Zealand's greenhouse gas emissions and the high-level forces that are driving them. Two different methods (production and consumption) of accounting for emissions are presented to provide a more complete picture of their sources.

Changes in our climate and environment are being observed (chapter 3) documents the many changes in temperature and rainfall that are already being observed here, as well as how they are affecting our environment. Data from 30 sites across New Zealand is used for the first time to explore how temperatures are changing nationwide. Changes in heatwaves, dates of the first and last frosts, drought, and fire danger are also discussed.

Chapter 4: *Climate change and our wellbeing* presents the diverse ways climate change is starting to affect the wellbeing of New Zealanders. This chapter has a particular emphasis on how Māori identity is threatened by environmental changes, including a reduced ability to manaaki or care for visitors.

In chapter 5: *Looking ahead: future emissions and climate*, projections are used to help us understand the implications for climate and wellbeing if the current emissions and warming trends continue.

The report finishes with a look at the importance of data and an understanding of uncertainty for good decision-making. See *Towards a better understanding of our climate*.

This report includes new or updated data from the following measures and indicators:

- Atmospheric ozone
- Drought
- El Niño Southern Oscillation
- Extreme rainfall
- Extreme wind
- Frost and warm days
- Greenhouse gas concentrations
- Growing degree days
- New Zealand's greenhouse gas emissions
- Rainfall
- Temperature
- Wildfire risk.

CHAPTER 1

Our climate, our future

Electric motorbike being used in a Te Puke kiwifruit orchard.

Photo: UBCO

Patterns of temperature, rain, wind, and sunshine make up the climate of Aotearoa New Zealand. Climate sculpts river valleys and mountains, influences which plants grow where, and defines our landscapes, making them instantly recognisable as New Zealand.

These patterns shape many ordinary facets of our lives too – the food on our plates, the sports we play, the crops we grow, and where we spend our leisure time and holidays. We know that warmer weather will bring fresh strawberries back to our plates. In some places we know to take an umbrella or a jacket when we go out – just in case.

Rain and sun also shape the climate of resourcefulness and ingenuity that defines the psyche of our nation. We are forced to be resilient, and take four seasons in one day in our stride. When extreme weather hits, it can build a feeling of community as people band together to clean up after nature has done her worst to our farms, roads, and houses.

Over time, we have learned to live and thrive with the climate of New Zealand. We tend to take our climate for granted because we generally know what to expect – even the unexpected.

Māori beginnings, the environment, and our climate

In the beginning there was darkness. This time, te kore, was full of potential, and from it grew consciousness, an energy that grew and led into te pō, the time of the long night. As te pō went on, life began as the creation of two supreme atua (deities) – Ranginui the sky father and Papatūānuku the Earth mother.

Ranginui and Papatūānuku were bound together by their great love for each other. Many children were born and raised in the darkness between them. The children wanted to live and grow in daylight, so they debated whether to separate their parents. The separation took place and brought the children into the world of light, te ao mārama. The children of Ranginui and Papatūānuku are atua of the natural world.

One son, Tāwhirimātea, did not agree with the plan to separate his parents, but was unable to stop it. Tāwhirimātea is the atua of winds and weather and in his sadness and anger over his parents' separation, he frequently attacks his siblings in the form of storms, cyclones, droughts, and extreme weather. Tāwhirimātea is the parent of kōhauhau (atmosphere) and āhuarangi (climate).

Another son, Tānemāhuta, is atua of forests, birds, and insects. It was Tāne who gathered the sacred red clay of Kurawaka to form the first human, and breathed life into her. She is known as Hineahuone. Tāne mated with Hineahuone and from her womb came the first human, Hinetītama (the dawn maiden), from whom all humans are descended.

This is one version of the Māori creation story that helps us understand our connection to the natural world, including the world's climate and atmosphere. 'Ko ahau te taiao ko te taiao ko ahau: I am the environment and the environment is me' is a whakataukī (proverb) that articulates the Māori worldview that all the values and traditions that make us who we are, are gifts from Papatūānuku passed down through our ancestors. In turn, we must pass them on to those who come after us.

For Māori, the gifts are described as our taonga tuku iho (treasured gifts passed down through generations). They include mātauranga (knowledge), te reo Māori (the Māori language), manaakitanga (generosity), mahinga kai (food gathering), whanaungatanga (socialising), and kaitiakitanga (guardianship). They shape who we are as people and are deeply linked to our wellbeing and sense of identity.

Gathering harakeke for weaving with whānau (extended family), diving for pāua and kina with mates in the summer, and dropping off a sack of fresh kaimoana (seafood) to our kaumātua (elders) – these are the moments we live for. These practices also make us tangata whenua (people of the land). Our identity and sense of belonging depends totally on being able to have a balanced and reciprocal relationship with the environment.

But the things that matter most – our unique way of life, identity, and the values and traditions that make us who we are – are at risk of being altered or lost forever. The impacts of climate change are already being felt by vulnerable whānau throughout Aotearoa, and are causing pain and mamae (hurt).

Our responsibility as kaitiaki (guardians) of Aotearoa, is to protect and care for what we have been given, for future generations. Ours is only one moment in time. We can draw strength from carrying our ancestors with us in this challenge, 'Kia whakatōmuri te haere whakamua: we walk backwards into the future with our eyes fixed on our past'. By working together, acknowledging the past and incorporating innovative and revolutionary ways of thinking, we can walk into the future with a greater understanding of how to accept the wero (challenge) that is climate change.

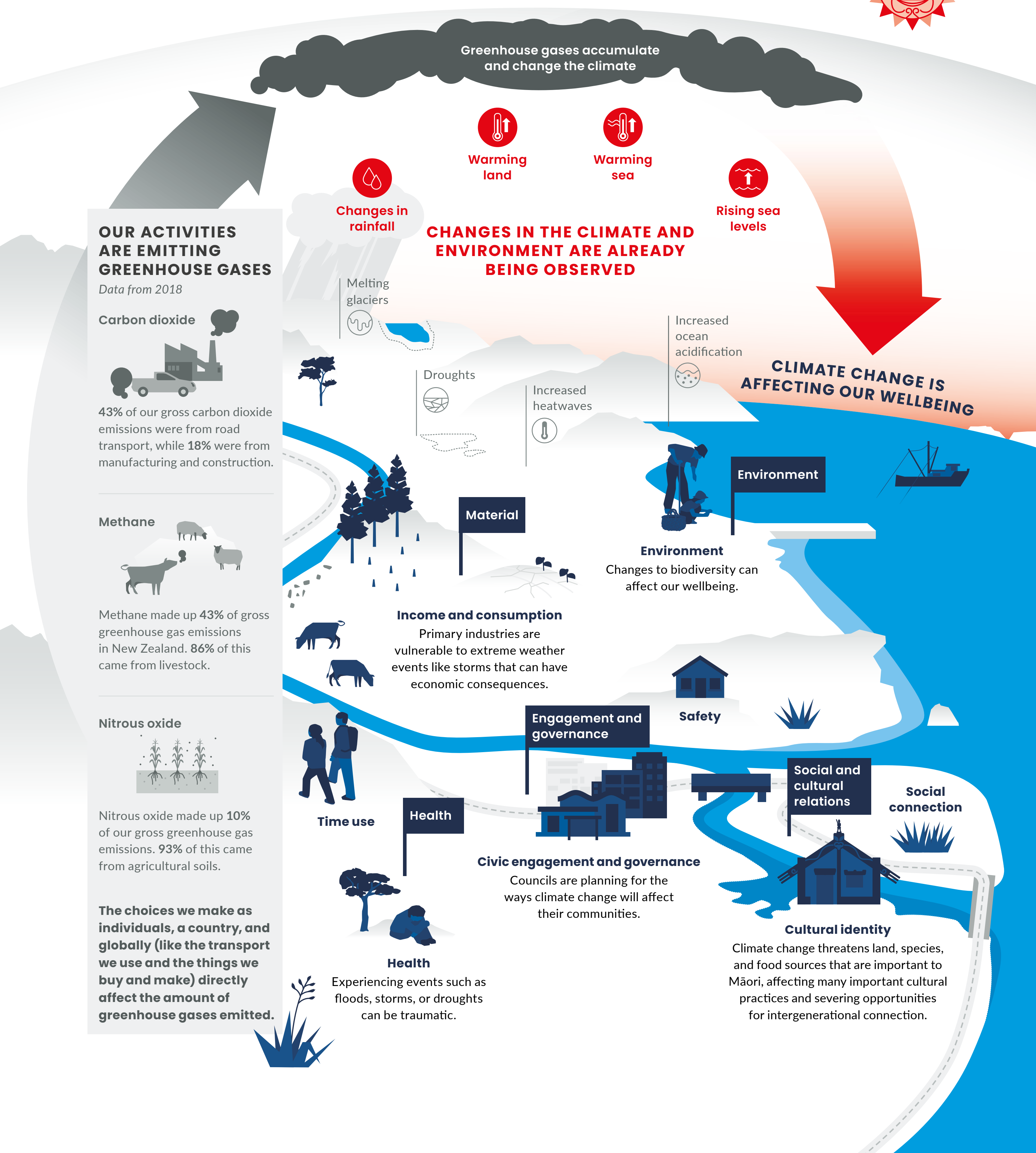
Greenhouse gas emissions are changing the climate

Greenhouse gases are accumulating in the atmosphere and changing the climate. These gases have mostly come from burning fossil fuels around the world for the past 200 years. Our daily activities – the transport we use and the products we make and buy – continue to be sources of emissions. Contributions to the build-up of greenhouse gases come from choices we make as individuals and as a nation, and from other countries.

As greenhouse gases accumulate in the atmosphere, they are altering climates around the world and in our own country. New Zealand's average annual temperature has risen by 1.13 (± 0.27) degrees Celsius from 1909 to 2019. Sea levels are rising, and changes to drought and extreme rainfall are beginning to emerge.

Our changing climate

The greenhouse gases we emit are changing the climate and our environment. These changes can affect our wellbeing.



The changing climate is affecting us

Emissions are changing the climate, and the changing climate is affecting us and our wellbeing. The native biodiversity of New Zealand and the places where we live, enjoy recreation, and make a living are also being affected. Some of the things we care about most – our ability to direct our own future, a secure life for our grandchildren, and our deep connections to the natural beauty of these islands – are all threatened by climate change.

Think about getting a coffee at your favourite café or shelling mussels at the marae with whānau (family). As changes in the climate build, coffee crops and other imports could be affected by disease, and the activities that bind generations together may have to change if kai can no longer be gathered in the same places.

When the climate we have built our lives and economy on begins to shift beyond natural variability, it creates unease and uncertainty. This can affect us as individuals, whānau, and communities, and our wellbeing suffers. The effects of a drought for example, can ripple through a region and affect the environment, the economy, and the mental health of the people who live and work there.

Global and local choices to avoid the worst impacts

As a small, trade-reliant nation, New Zealand is highly dependent on connections with the rest of the world, and therefore on climate and behaviour elsewhere. Reducing greenhouse gas emissions globally would reduce the future impacts of climate change on us and the planet.

A small window of time remains to make these reductions to avoid the severe impacts of a world that is two degrees Celsius or more warmer. As a signatory of the 2015 Paris Agreement and the United Nations Framework Convention on Climate Change, New Zealand has committed to work with the rest of the world to limit future warming.

The global community has acted together before. When damage to the ozone layer in the stratosphere was discovered over Antarctica in the 1980s it was cause for global concern. This layer of ozone stops ultraviolet (UV) radiation reaching Earth's surface, where too much can cause sunburn, skin damage, cataracts, and skin cancer. The Montreal Protocol was signed in 1987, and has resulted in the use of human-made chemicals that can destroy ozone being almost completely phased out.

The ozone hole has started to shrink. Current projections are that the Antarctic hole will gradually close and that ozone concentrations will return to mid-1980s levels in the 2060s (WMO, 2019). Without the protocol and the later amendments that further tightened actions on emissions, UV index values in New Zealand would now be 20 percent higher than those recorded in the early 1990s (McKenzie et al., 2019). (The UV index is a measure of the strength of UV radiation from the sun.)

Securing a stable climate

There is growing public desire for New Zealand to do its part to secure a stable climate. Tens of thousands of New Zealanders marched and took part in climate strikes in 2019. They joined millions worldwide to show the high value of a stable climate for personal wellbeing and safety, the environment, and for future generations.

Throughout the country, regional councils and city councils have declared climate emergencies. Whānau, hapū, and iwi have been involved in discussions about how climate change is affecting their communities, and more companies than ever have committed to quantifying and understanding their emissions. In 2019, New Zealand passed the Zero Carbon Act to put emission reduction targets into law and start the transition to a low-carbon economy.

Burning coal, oil, and gas across the globe has fuelled the breakthroughs that have led to our modern life. New Zealand is fortunate to be rich in the clean resources – wind, geothermal, hydro-power, and solar – that will fuel our future. We have begun to embrace these sources of energy and in 2018, 84 percent of our electricity was generated from renewable sources (MBIE, 2019b).

In other parts of our lives we still depend heavily on activities that emit greenhouse gases. We love our cars, and in 2018 owned 0.8 cars and passenger vehicles per person – this was the highest rate in the OECD in 2017 (OECD, 2017). All those vehicles made up 27 percent of our gross carbon dioxide emissions in 2018 (only 10 in 1,000 light vehicles were hybrids and 2 in 1,000 were fully electric) (MoT, 2019). Greenhouse gas emissions from agriculture made up close to half of our gross emissions in 2018. However, exports from natural resources or activity in primary industries (including agriculture) make up a large part of our export income (Stats NZ, 2019).

Our future is interconnected with the climate because climate shapes our social, cultural, and economic lives. But it is a two-way street – our actions and activities are also affecting the climate. This presents a responsibility and an opportunity for today. We have a responsibility to protect the people and places that will be most affected by climate change. This comes with an opportunity to play an active role in shaping our future so we are secure and resilient.

Weather, greenhouse gases, and climate change

Climate is what you expect and weather is what you get

Climate describes the expected temperature, rain, or snowfall at a certain place on a particular day – like the average high temperature for August 15th at your local rugby field. An especially freezing afternoon or a heavy downpour during a game is the weather. These weather conditions are variations from the long-term average climate.

Climate variations

Our climate varies in response to human activities (like adding greenhouse gases to the atmosphere) and to natural influences (like climate oscillations). Natural influences can cause the climate to fluctuate above and below a baseline, but by increasing the amount of greenhouse gases in the atmosphere, humans are changing the actual baseline.

How greenhouse gases affect our climate

Greenhouse gases (like carbon dioxide, methane, and nitrous oxide) in the atmosphere act like a blanket by retaining energy from the sun. They are vital for keeping the temperature on Earth in a range where life can flourish. For the past 3,000 years the average temperature in New Zealand has been relatively steady, rising and falling by less than a degree over this time (MfE, 1997).

Burning fossil fuels (like coal, oil, and gas), deforestation, and agriculture have increased the amounts of greenhouse gases in the atmosphere and caused more energy to be trapped by Earth's blanket. Most of the extra energy retained (more than 90 percent) has been absorbed by the oceans and raised sea temperatures and sea levels. Some energy is held in the atmosphere and makes our air and climate warmer (IPCC, 2014a).

Not all greenhouse gases have the same effect. Some, like carbon dioxide, are long-lived and can stay in the atmosphere for thousands of years. Long-lived gases build up when they are added to the atmosphere faster than they are taken out, effectively making the blanket thicker and thicker. Other gases, including methane, can be gone in years or decades but do a better job of holding heat in, and act more like a duvet than a blanket. These short-lived gases can have a significant warming effect if their levels are kept topped up by continued emissions.

CHAPTER 2

Our activities are driving emissions

Morning traffic on the Wellington motorway.

Photo: Sarah Wilcox, Descipher

The products we buy, the food we eat, the way we travel, and the goods and services we produce can all cause emissions of greenhouse gases.

Many of the things we do every day produce greenhouse gases. Those emissions can be caused directly, by travel or a production process for example, or indirectly because of the energy required to fuel those processes.

There are many different greenhouse gases, but the most important ones for climate change are carbon dioxide, methane, and nitrous oxide. Globally, continued emissions of greenhouse gases is causing them to accumulate in the atmosphere and warm the climate. The contribution that smaller countries like New Zealand make to global emissions also adds up.

Carbon dioxide has the biggest effect on future warming globally because it is emitted in large quantities by many different processes. Also, part of every emission stays in the atmosphere for hundreds to thousands of years. Methane is important because it has a more intense but shorter-term warming effect. Other human activities like removing trees and releasing soot contribute to the build-up of greenhouse gases and warming.

Increased economic activity (measured as gross domestic product, GDP) and population growth are the most significant high-level forces (or drivers) that shape the amount and type of emissions produced. These drivers have caused most of the growth in greenhouse gas emissions in New Zealand and globally, but improvements in energy efficiency and a greener energy supply have offset some of the increase.

Global emissions

GLOBAL CARBON DIOXIDE EMISSIONS ARE GREATER THAN EVER BEFORE

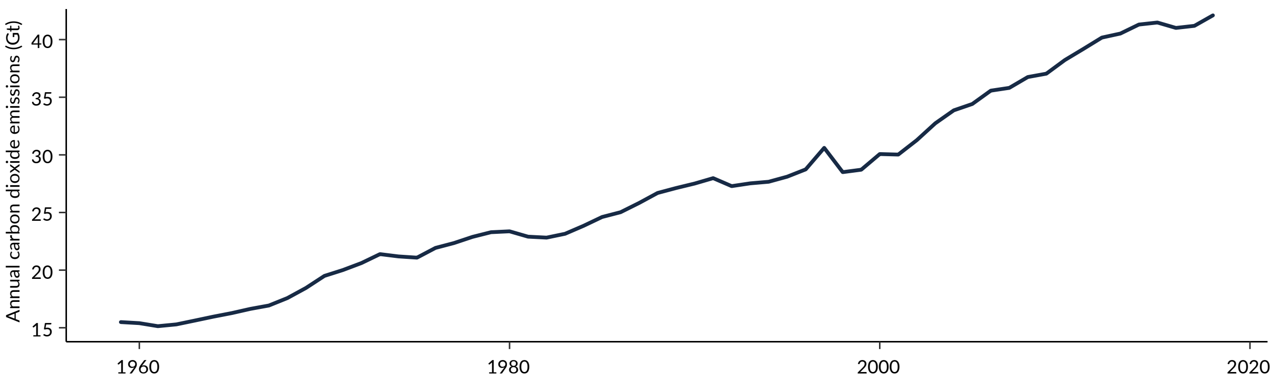
Most of the world's energy needs are met by burning fossil fuels, which releases carbon dioxide. The rise in global emissions has been dramatic: half of all human-generated carbon dioxide emissions since 1750 have occurred since 1970 (IPCC, 2014a). Humans added about 42 gigatonnes of carbon dioxide to the atmosphere in 2018, more than 190 times the weight of every person in the world combined (Bar-On, Phillips, & Milo, 2018; Friedlingstein et al., 2019).

Global carbon dioxide emissions from fossil fuels in 2018 were about 2.1 percent more than 2017, and higher than the 1.3 percent average increase per year for the previous decade (2009–18) (see figure 1). Most of the emissions were from burning coal (40 percent), oil (34 percent), and natural gas (20 percent) (Friedlingstein et al., 2019).

This rate of increase is dramatic. It is causing changes to the climate that challenge the ability of our social, economic, and environmental systems to adapt. Although Earth's climate has varied naturally in the past, even 'abrupt' natural changes at the global scale have typically taken many hundreds to thousands of years. But now is different. Current carbon dioxide levels in the atmosphere have increased about 100 times faster than the fastest rise at the end of the last ice age (Gaffney & Steffen, 2017).

In the previous 7,000 years, the climate was cooling slightly at a rate of -0.01 degrees Celsius per century. But this has changed, mainly because of human activities that increase greenhouse gas concentrations in the atmosphere (IPCC, 2014a). In the past 45 years the global average temperature has increased about 170 times faster than the rate of change before humans began emitting greenhouse gases in large amounts (Gaffney & Steffen, 2017).

Figure 1: Global carbon dioxide emissions from fossil fuels, industry, and land-use change, 1959–2018



Data source: Friedlingstein et al., 2019

- Global carbon dioxide emissions have doubled since about 1970.

LARGE EMITTERS OF CARBON DIOXIDE

Three countries and the European Union emitted 59 percent of all carbon dioxide in 2018 – China 28 percent, the USA 15 percent, the European Union 9 percent, and India 7 percent. These areas include many of our trading partners that produce goods and services we import and use every day (see New Zealand's consumption-based carbon dioxide emissions). The rest of the world emitted the remaining 41 percent (Friedlingstein et al., 2019).

Some countries have decreased their carbon dioxide emissions in the last decade (2009–18). This includes the European Union (by 1.4 percent per year) and the USA (by 0.5 percent per year). Nineteen countries (mainly in the European Union) decreased their emissions while their economies grew, but some of the decrease may be due in part to moving the production of goods to other countries (Friedlingstein et al., 2019; IPCC, 2014b).

GLOBAL GREENHOUSE GAS CONCENTRATIONS ARE AT A RECORD HIGH

The result of all of these emissions is that greenhouse gases are building up in the atmosphere faster than they are removed, and their concentrations are increasing. This accumulation of carbon dioxide in the atmosphere is the most important factor governing the amount of global warming we will experience this century and beyond (IPCC, 2014a).

In May 2020, carbon dioxide concentrations reached a seasonal peak of 417 parts per million at the Mauna Loa Observatory in Hawaii. This observatory has the world's longest unbroken record of carbon dioxide measurements directly from the air, and this is the highest monthly reading ever recorded (NOAA, 2020). Global levels of carbon dioxide in the atmosphere are now at their highest level for the past 3 million years at least (Willeit, Ganopolski, Calov, & Brovkin, 2019).

Measurements in New Zealand are consistent with the global concentrations, but are slightly lower in the Southern hemisphere. The concentration of carbon dioxide in the atmosphere measured at Baring Head near Wellington reached 409 parts per million in September 2019. (See indicator: Greenhouse gas concentrations.) This is about 46 percent higher than the pre-industrial level of 280 ppm (IPCC, 2014a).

Methane concentrations at Baring Head have increased by 4 percent in the last decade (2010–19) and reached 1,838 parts per billion in September 2019. This is more than 160 percent higher than pre-industrial levels. Nitrous oxide levels were 23 percent higher than pre-industrial levels and increased by 3 percent in the last decade.

New Zealand's greenhouse gas emissions

COUNTING UP OUR EMISSIONS

Greenhouse gas emissions can be estimated using different approaches (see Approaches to measuring New Zealand's greenhouse gas emissions on the Stats NZ website). A production-based approach counts all emissions that are created within our border by the production of all goods and services, whether they are exported or used in New Zealand. A consumption-based approach counts emissions that are created from producing the goods and services we consume here, whether they are imported or produced locally. Both are shown to give a fuller understanding of the sources of our emissions. Note: consumption-based emissions estimates were only available for carbon dioxide when this report was prepared.

The New Zealand greenhouse gas inventory publishes estimates of greenhouse gas emissions each year as part of our international reporting obligations. This reporting only counts emissions that are produced in New Zealand. Information on the production of emissions from an industry and household, and regional basis is available from Stats NZ. Information from Stats NZ on consumption-based emissions at a national level was not available when this report was prepared.

Emissions can be analysed by considering gross emissions (total emissions) and net emissions (total emissions plus carbon dioxide added or removed by land use, land-use change, and forestry). Net emissions are more variable than gross emissions because of the influence of forest planting and harvesting cycles.

For information on how New Zealand's emissions may change in the future, and how we are tracking towards emission reduction targets see chapter 5: Looking ahead: future emissions and climate.

Estimating our emissions

In 2015, New Zealand imported more CO_2 emissions than we exported.

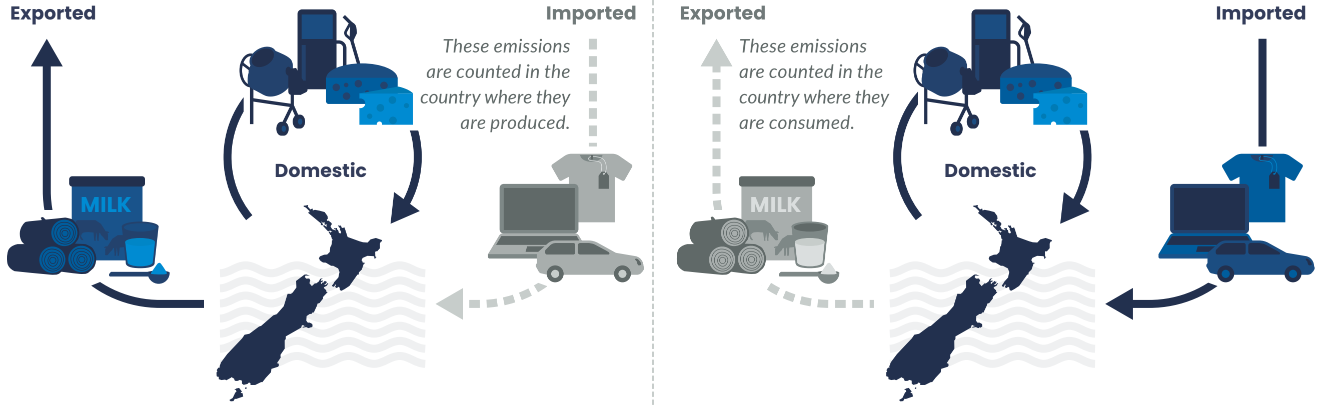
New Zealand's emissions can be estimated in different ways.

PRODUCTION-BASED APPROACH

Emissions produced here are counted

CONSUMPTION-BASED APPROACH

Emissions consumed by New Zealanders are counted



Production-based approach:

Counted
emissions from goods and services produced in New Zealand and exported to another country, like milk powder and logs

Counted
emissions from goods and services produced and consumed in New Zealand like cheese, petrol, and cement

Not counted
emissions from goods and services produced elsewhere and consumed in New Zealand like cars, clothing, and technology

This approach is used to calculate emissions in the New Zealand Greenhouse Gas Inventory.

35,839 kilotonnes
New Zealand's gross carbon dioxide emissions in 2015 using a production-based approach.

Consumption-based approach:

Not counted
emissions from final goods and services produced in New Zealand and exported to another country, like milk powder and logs

Counted
emissions from final goods and services produced and consumed in New Zealand like cheese, petrol, and cement

Counted
emissions from final goods and services produced elsewhere and consumed in New Zealand like cars, clothing, and technology

This approach is useful for calculating a country's carbon footprint.

42,800 kilotonnes
New Zealand's gross carbon dioxide emissions in 2015 using a consumption-based approach.

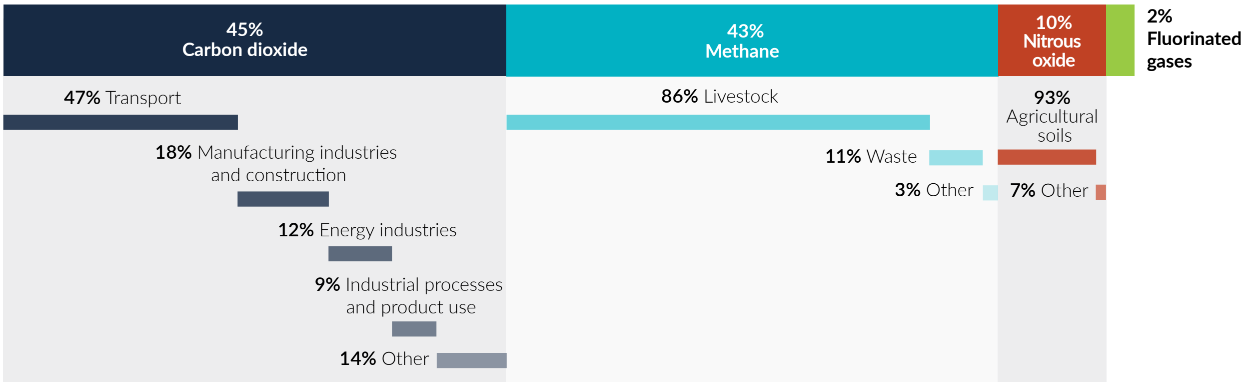
PRODUCTION-BASED EMISSIONS HAVE INCREASED

New Zealand's net emissions have increased by 57 percent from 1990 to 2018. (See indicator: New Zealand's greenhouse gas emissions.) Our gross greenhouse gas emissions in 2018 were 24 percent higher than in 1990 but have changed little in the last decade despite increases in economic activity and population. However, as long as our net emissions of long-lived greenhouse gases (mainly carbon dioxide and nitrous oxide) are greater than zero, we are contributing to further climate change.

The profile (or mix) of greenhouse gases we produce is unusual (see figure 2). In most developed countries, carbon dioxide produced by burning fossil fuels dominates emissions, especially burning coal and gas for electricity, and burning diesel and petrol for transport. A large proportion (84 percent in 2018) of New Zealand's electricity has renewable sources so electricity generation does not make up a large part of our emissions (MBIE, 2019b).

Nearly half (48 percent) of New Zealand's gross emissions in 2018 came from agriculture. These emissions, almost all methane and nitrous oxide, increased 5 percent from 2009 to 2018. In a typical developed country, only about 12 percent of total gross emissions come from agriculture (MfE, 2020c). Road transport also makes a large contribution to our gross emissions (19 percent).

Figure 2: New Zealand's gross greenhouse gas emissions, 2018



Data source: Ministry for the Environment

- The livestock and road transport sectors combined contributed well over half (57 percent) of New Zealand's gross greenhouse gas emissions in 2018.

Greenhouse gases are not all equal

Different greenhouse gases last for different amounts of time in the atmosphere before being removed by natural processes. Long-lived gases can stay in the atmosphere for centuries or even millennia, which allows them to build up. (Nitrous oxide has an average lifetime of 121 years, while carbon dioxide can remain in the atmosphere for thousands of years). Emissions of long-lived gases have to be reduced to zero to stabilise the climate at any temperature.

Short-lived gases typically remain in the atmosphere for years to decades – methane stays in the atmosphere for about 12 years on average. Emissions of short-lived greenhouse gases do not accumulate over centuries and do not have to be reduced to zero to stabilise the climate. However, these gases generally have a powerful warming effect and make the climate warmer than it would be from emissions of carbon dioxide alone. The less we emit, the lower their ongoing contribution to climate change will be.

Different gases also have different abilities to absorb energy or retain heat. The global warming potential (GWP) relates different gases to the average warming produced by carbon dioxide over a given time period, usually 100 years. For example, methane has a GWP of 25 (under current reporting conventions), so in the 100 years following their emission, 1 kilogramme of methane will cause 25 times the average warming as 1 kilogramme of carbon dioxide.

Other greenhouse gases (like hydrofluorocarbons) have very high GWPs – sometimes thousands of times higher than carbon dioxide. These gases are generally short-lived (about 15 years on average) and are emitted in much smaller quantities than carbon dioxide, methane, and nitrous oxide.

GWP is used for reporting under the Paris Agreement and by New Zealand to set and account for its 2030 emissions target under the agreement. GWPs from the Intergovernmental Panel on Climate Change Fourth Assessment Report are used in this report but updated GWPs are available from other sources and will be used in future reporting periods. Other metrics give short-lived gases a greater or lesser weighting compared to carbon dioxide because they focus on effects of the gas on different aspects of climate change.

Gas	Carbon dioxide	Methane	Nitrous oxide	Hydrofluorocarbons
Global warming potential (IPCC, 2007)	1	25	298	Up to 14,800
Lifetime in the atmosphere (IPCC, 2014a)	Up to thousands of years	12 years	121 years	15 years (weighted by usage of different gases)

CARBON DIOXIDE EMISSIONS HAVE INCREASED

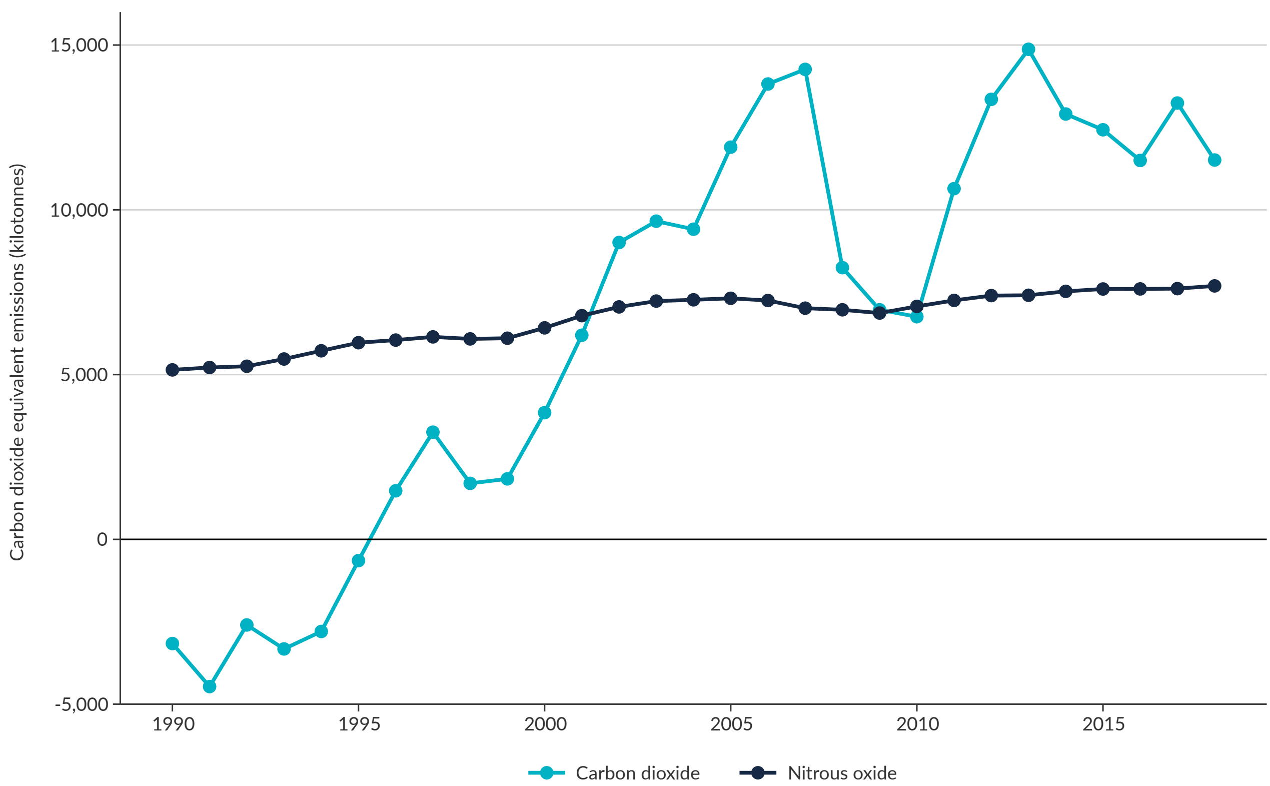
Carbon dioxide is the most important long-lived greenhouse gas for climate change, followed by nitrous oxide. Because long-lived gases build up in the atmosphere, every additional emission of these gases will affect the climate for hundreds to thousands of years into the future. The net emissions of all long-lived gases have to be brought to zero globally for Earth's warming climate to stabilise

Other long-lived gases play a similar role but are emitted in much lower quantities. How quickly New Zealand reaches net-zero emissions of these gases will determine how much more our emissions contribute to long-term warming of the climate.

Net carbon dioxide emissions have increased by about 14,700 kilotonnes from 1990 to 2018 (see figure 3).

New Zealand's gross carbon dioxide emissions were 7.7 tonnes per person in 2017, which is 17th out of 32 OECD countries (with available data) (OECD, 2020; UNPD, 2020). This is despite the high percentage of renewable electricity generated here, and shows the large emissions of carbon dioxide that continue to be produced by sectors such as transport, manufacturing, and construction.

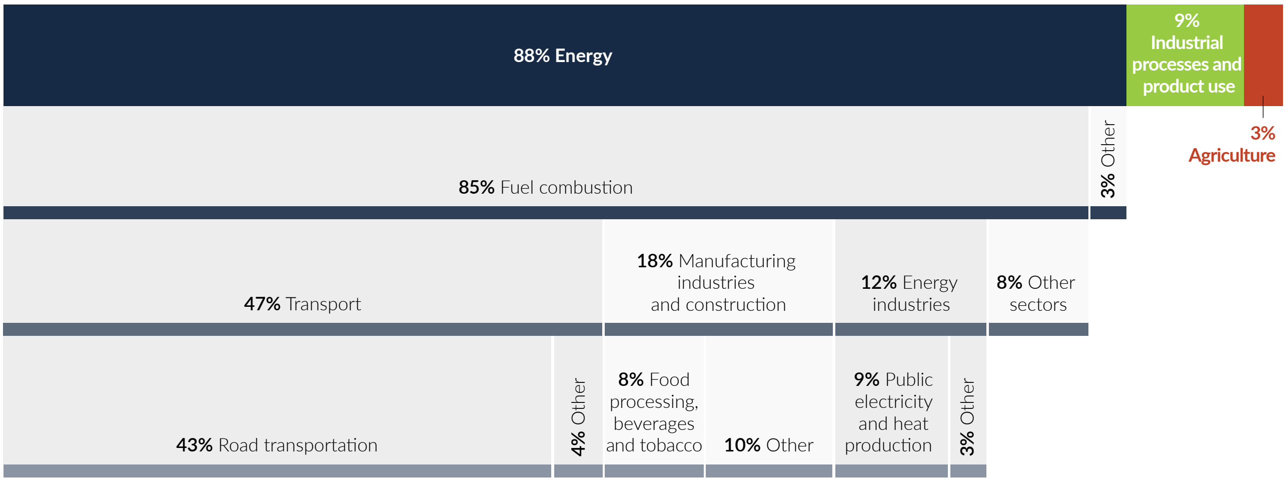
Figure 3: Net carbon dioxide and nitrous oxide emissions, 1990–2018



Data source: Ministry for the Environment

- Before 1996, land use, land-use change, and forestry removed and stored more carbon dioxide than was emitted.

Figure 4: New Zealand's gross carbon dioxide emissions by sector, 2018



Data source: Ministry for the Environment

- Road transportation (cars, light duty trucks, heavy duty trucks and buses, and motorcycles) emitted 43 percent of New Zealand's gross carbon dioxide emissions in 2018.

TRANSPORT IS THE LARGEST SOURCE OF CARBON DIOXIDE EMISSIONS

Road transport made up 43 percent of New Zealand's gross carbon dioxide emissions in 2018 (see figure 4). For 2009–18, emissions from this source increased by 22 percent, about 2,700 kilotonnes. Emissions from light duty trucks had the greatest increase (78 percent, almost 1,700 kilotonnes) during these 10 years.

Cars and other passenger vehicles were responsible for 27 percent of New Zealand's gross carbon dioxide emissions in 2018. These vehicles emitted 7 percent more carbon dioxide than 10 years previously. Petrol-electric hybrids made up 1 in every 100 light vehicles. Fully electric-powered vehicles made up a tiny but growing portion of New Zealand's fleet in 2018 at about 2 in every 1,000 light vehicles (MoT, 2019).

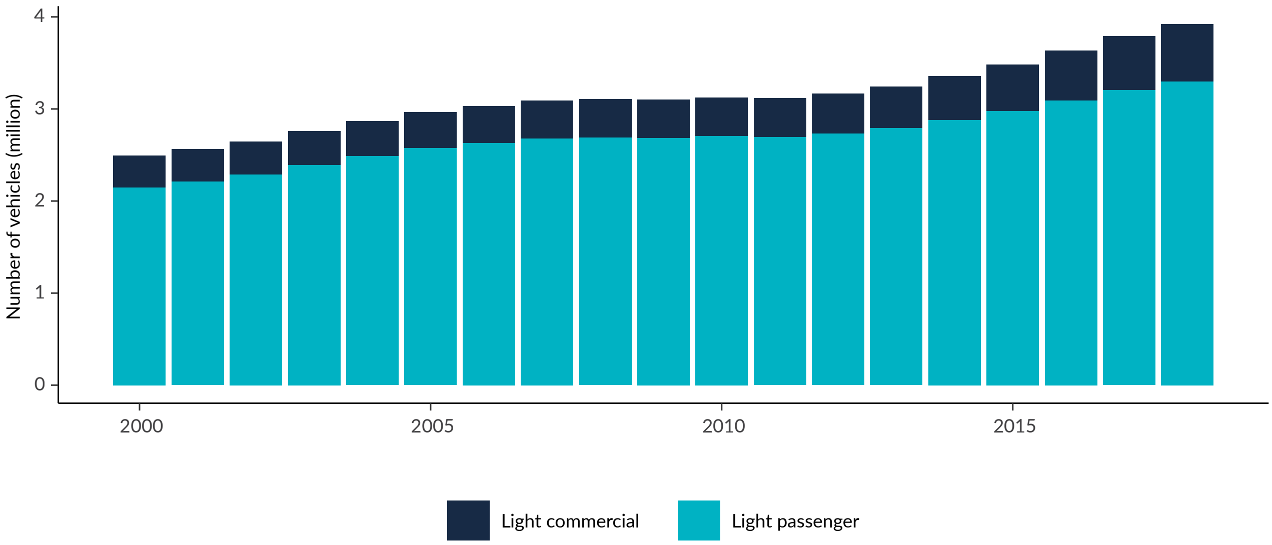
New Zealanders' vehicle preferences are affecting greenhouse gas emissions. Light commercial vehicles such as utes, SUVs, and vans, made up 16 percent of the light vehicle fleet in 2018, 75 percent of which run on diesel (see figure 5). These larger, heavier vehicles are increasingly popular, while sales of smaller petrol-engined vehicles show a corresponding decline.

This means that transport emissions are not reducing despite improvements in engine technology. Also, commercial vehicles, especially those that run on diesel, generally travel much further than their petrol equivalents (particularly in the first 10 years when an average diesel vehicle travels 30 percent further) (MoT, 2019).

The number of heavy trucks and buses, and the distance they travelled has increased every year since 2013. Heavy vehicles are expected to continue to make the largest contribution to carbon dioxide emissions on a per vehicle basis (MoT, 2019).

New Zealand has one of the highest per capita rates of carbon dioxide emissions from road transport in the 43 OECD countries with data for road transport emissions. This was 5th highest in 2018, coming behind Luxembourg, USA, Canada, and Australia. Our rate of 3.2 tonnes of carbon dioxide emitted per person per year from road transport was higher than Iceland (2.9 tonnes), Ireland (2.4 tonnes), Germany (1.9 tonnes), and the UK (1.7 tonnes), and was similar to Australia (3.4 tonnes) and Canada (4.1 tonnes) (UNFCCC, 2020; UNPD, 2020).

Figure 5: New Zealand's light vehicle fleet composition, 2000–18



Data source: Ministry of Transport, 2019

- New Zealand's light vehicle fleet in 2018 was the largest to date.

MANUFACTURING PRODUCES CARBON DIOXIDE

The manufacturing industries and construction sector was New Zealand's next biggest source of gross carbon dioxide emissions after transport, at 18 percent of our total in 2018. The emissions were mainly from using fossil fuels to produce heat and energy. These emissions increased by 21 percent (about 1,100 kilotonnes) from 2009–18.

The food processing, beverage, and tobacco product subsector made up the largest portion of manufacturing emissions, mainly because fossil fuels are still used in many industrial boilers. In 2018, the subsector produced 8 percent of New Zealand's total gross carbon dioxide emissions.

CARBON DIOXIDE REMOVAL BY FORESTS IS VARIABLE

Carbon dioxide can be removed from the atmosphere when plants grow and store carbon. In New Zealand, land use, land-use change, and forestry removed about 23,400 kilotonnes of greenhouse gases in 2018. This was 15 percent less than was removed in 2009, mainly because more plantation forests were harvested during this time. Note: the carbon dioxide removed and stored by plantation forests as they grow, or when new forests are planted on grassland, is included in this figure. Emissions produced during harvesting and planting are also included.

New Zealand's consumption-based carbon dioxide emissions

Consumption-based emissions are like a greenhouse gas footprint, and reflect the goods and services a country uses, as well as its lifestyle choices. Counting all the emissions along the way to the final use of a good or service, helps us understand the emissions that are embodied in our activities. For example, if a product is produced overseas and used in New Zealand, the greenhouse gases released during its production count as New Zealand's emissions. Similarly, emissions from products produced here but exported count against another country's greenhouse gas emissions and not ours. Looking at emissions this way helps show how trade between countries with different carbon intensities (the amount of carbon released to produce a unit of energy) can affect emissions.

In an example for consumption-based carbon dioxide emissions, an estimated 42,800 kilotonnes was emitted from goods and services consumed in New Zealand in 2015. Because New Zealand has a relatively small manufacturing sector and is reliant on imports for many products, this figure is almost 20 percent higher than the estimated 35,839 kilotonnes of production-based carbon dioxide emissions in 2015. Forty-four percent of the carbon dioxide emissions created by the goods and services we use happens overseas, making us a net importer of carbon dioxide (OECD, 2019).

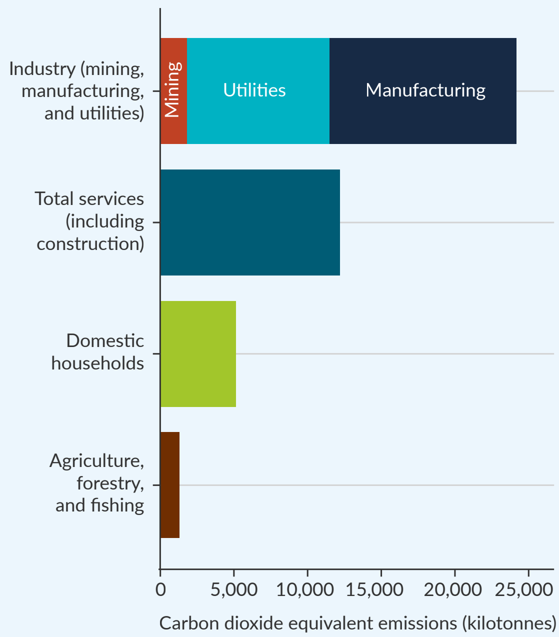
Carbon dioxide emitted when goods were manufactured made up a large proportion of our consumption-based emissions – 30 percent in 2015. Emissions from services, including construction, created 29 percent of emissions. Carbon dioxide emissions from utilities made up 23 percent in 2015, but decreased by 30 percent from 2005 to 2015 (OECD, 2019) (see figure 6).

New Zealand's 42,800 kilotonnes of consumption-based carbon dioxide emissions in 2015 equates to 9.3 tonnes of carbon dioxide per person, which is mid-range (18 out of 37) for OECD countries (OECD, 2020a, UNPD, 2020). The highest emitters were the USA and Australia with 18.1 tonnes and 17.9 tonnes per person, respectively. (For comparison, our per person estimates for production-based emissions were 7.8 tonnes of carbon dioxide in 2015 (UNPD, 2020)).

Estimating consumption-based emissions is challenging because it depends on the emissions intensity (the amount of energy required to produce a unit of gross domestic product, GDP) of overseas activities, and also on the methodology used – for example, how far back in the supply chain are indirect emissions included? Some data is also lacking, which prevents us seeing a full picture.

Consumption-based emissions were not available for methane, nitrous oxide, or other greenhouse gases when this report was prepared, although further analysis is underway. Together these gases made up more than half of the total production-based greenhouse gas emissions in New Zealand in 2018. Most of the emissions of these gases are from producing agricultural products, which make up a large proportion of our export value. Because of this, it is likely that New Zealand would be a net exporter of greenhouse gas emissions in a consumption-based approach that includes all greenhouse gases.

Figure 6: Carbon dioxide emissions embodied in domestic final demand in 2015



Data source: Organisation for Economic Co-operation and Development

- Carbon dioxide emissions embodied in the use of manufactured goods, and from services were the largest sources of New Zealand's consumption-based emissions in 2015.

MOST OF OUR METHANE EMISSIONS COME FROM LIVESTOCK

Methane is a short-lived gas – it remains in the atmosphere for about 12 years, and with a global warming potential of 25, has a much greater warming effect than carbon dioxide (see Greenhouse gases are not all equal). Continued methane emissions top up the concentrations in the atmosphere, and make the climate warmer than it would be from carbon dioxide emissions alone. If methane emissions were reduced rapidly, the warming caused by past emissions (and their contribution to climate change) would decrease naturally within a few decades.

Methane emissions were at the same level in 2018 as they were 10 years prior in 2009 (see figure 7).

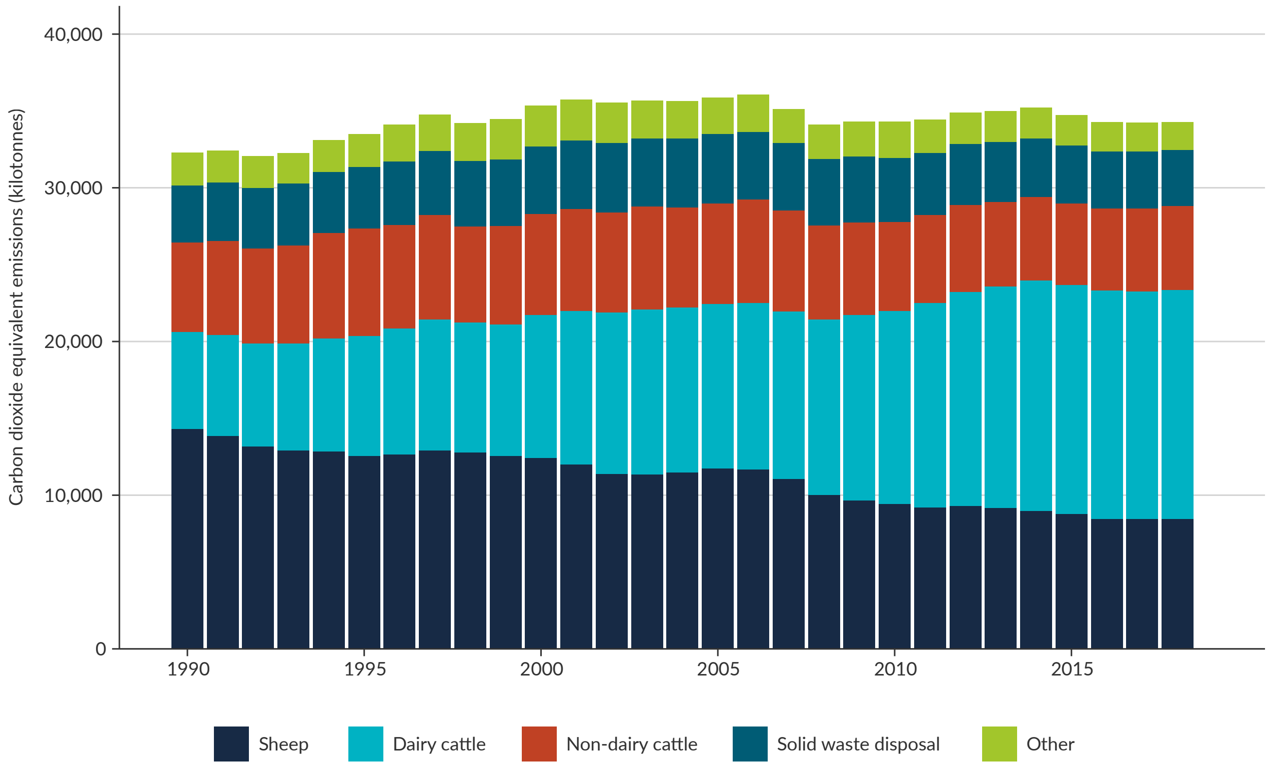
Agriculture is a major part of the New Zealand economy, and methane emissions from livestock make up a large proportion of our emissions profile. Methane made up 43 percent of our gross greenhouse emissions in 2018, with 86 percent from livestock. Methane from dairy cattle increased by 21 percent in the 10 years from 2009 to 2018, whereas emissions from sheep and beef cattle decreased by 11 percent (see figure 6). This reflects a shift from sheep and beef farming to dairy farming with higher stocking rates (see *Our land 2018*).

Waste contributed 11 percent to methane emissions in 2018 but decreased by 13 percent from 2009–18. This is mainly from solid waste disposal in landfills and wastewater treatment. Methane is also emitted as part of fossil fuel extraction and use. While these emissions are significant globally, they make up 2 percent of total methane emissions in New Zealand.

NITROUS OXIDE IS MAINLY EMITTED BY AGRICULTURAL SOILS

Like carbon dioxide, nitrous oxide is a long-lived gas, with a lifetime in the atmosphere of about 120 years. Nitrous oxide made up 10 percent of New Zealand's emissions in 2018, having increased by 14 percent in the 10 years from 2009 to 2018. Ninety-three percent of all nitrous oxide emissions were from agricultural soils. These emissions mainly come from the urine and dung of grazing animals and synthetic nitrogen fertiliser, which is converted to nitrous oxide by soil microbes.

Figure 7: New Zealand's gross methane emissions, 1990–2018



Data source: Ministry for the Environment

▸ Methane emissions have been about the same level over the past 10 years but this masks shifts in emissions from livestock.

Other emissions also affect the climate

BLACK CARBON

Besides greenhouse gases, emissions of aerosols (fine particles in the air) play a role in heating or cooling the planet. One aerosol is black carbon or soot, which strongly absorbs sunlight because of its dark colour. Unlike carbon dioxide, black carbon only stays in the atmosphere for about a week but the changes it causes to the climate happen rapidly. Black carbon typically has local rather than global effects.

In New Zealand, most black carbon comes from vehicle exhaust (especially from diesel engines), burning wood or coal for home heating, and outdoor burning. New Zealand does not have an inventory for black carbon emissions. However, monthly black carbon concentrations decreased (at the 95 percent confidence level) at three out of four monitoring sites in Auckland between 2006 and 2016, but are high compared to the levels in cities in Europe, the United Kingdom, and the United States (see *Our air 2018*).

SULPHUR DIOXIDE

Emissions of sulphur dioxide gas cool the climate by forming particles of sulphate that scatter incoming sunlight and create clouds.

Most of the sulphate in the atmosphere is from the global burning of fossil fuels (especially coal) but large volcanic eruptions can also add significant amounts that cause cooling for months or years. Burning coal in manufacturing and construction, and public electricity generation and heat production was the main source of sulphur dioxide emissions in New Zealand in 2015. Emissions from domestic shipping were also important (see *Our air 2018*).

Ozone-depleting substances and hydrofluorocarbons

Ozone-depleting substances (ODSs) are human-made chemicals that react with ozone in the stratosphere and destroy it. A build-up of these substances in the atmosphere led to the development of lower levels of ozone over Antarctica during the spring, known as the ozone hole. Lower average levels of ozone globally and ozone holes over the northern polar region were also observed occasionally (WMO, 2019).

Global concern about the damage these chemicals were causing led to the 1987 Montreal Protocol under the Vienna Convention, which agreed on phasing out the global production of ODSs. Since then, production has decreased by 98 percent (data for 1986–2015). (See indicator: Global production of ozone-depleting substances.) Since 2012 unreported emissions from eastern Asia have partially offset this (WMO, 2019).

The ozone hole does not have a large effect on ozone concentrations over New Zealand and therefore levels of UV. (See indicators: Ozone hole and UV intensity.) However, when the hole breaks up in late spring it can send plumes of ozone-depleted air from Antarctica over the country that briefly decrease the column ozone levels by about 5 percent. This is about the same amount as daily variation but adds to it (Ajtić et al., 2004).

New Zealand has naturally higher levels of UV radiation during summer than countries in the Northern Hemisphere at similar latitudes. This is partly because of a naturally thinner ozone layer over New Zealand at this time, lower background air pollution, and because Earth is closer to the sun during the Southern Hemisphere summer than it is during the Northern Hemisphere summer.

The ozone hole has started to shrink in response to the global phasing out of ODSs (WMO, 2019). Also, in 2019, the hole was the smallest since 1982, due to abnormally high temperatures in the stratosphere over Antarctica (NOAA, 2019). Current projections are that the Antarctic hole will gradually close and springtime ozone concentrations will return to mid-1980s levels in the 2060s (WMO, 2019).

In 2018, ozone over New Zealand reached its highest annual average thickness since 1994 at 315 Dobson units (DU). (See indicator: Atmospheric ozone.) Annual average ozone column thickness in 2018 and 2019 (309 DU) was also above the long-term average of 308 DU from 1979 to 2019. Average daily ozone column thickness varied by about 100 DU throughout the year, with the highest levels occurring in spring and the lowest in autumn.

Many ODSs are also powerful greenhouse gases (see Greenhouse gases are not all equal). Projections estimate that by 2100 phasing out of their use would reduce global warming by about 0.2 to 0.4 degrees Celsius (WMO, 2019).

Hydrofluorocarbons (HFCs) can be used instead of ODSs, particularly as refrigerants, but they are also powerful greenhouse gases. Emissions of HFCs used as substitutes for ODSs increased by 86 percent for 2009–18. HFCs made up 2 percent of New Zealand's gross greenhouse gas emissions in 2018. Because they have a greenhouse warming potential of up to 14,800, these gases can contribute to climate warming during the short time (on average) they remain in the atmosphere.

High-level forces drive emissions

UNDERSTANDING EMISSIONS

High-level forces, also known as drivers, are behind the greenhouse gas emissions that are changing the climate and environment. Globally, these forces control how much and which greenhouse gases are accumulating in the atmosphere.

The forces reflect the many choices we have made and continue to make as individuals, communities, countries, and as a global population. Understanding the forces behind New Zealand's emissions shows what is shaping our contribution to global emissions. Once we appreciate what is driving our emissions, we can better understand why emissions from different sources are changing and make choices to address their causes.

Four interacting elements can be used to understand the main factors that are driving the amount of carbon dioxide that is emitted from activities using energy (for power, heat, or transport):

1. economic activity per person (GDP per capita, excluding the effects of inflation): GDP is a measure of the total economic activity occurring within a country, and GDP per capita is GDP divided by the population size
2. population size
3. energy intensity of the economy (energy intensity of GDP): the amount of energy required to produce a unit of GDP
4. carbon intensity of the energy supply: the amount of carbon dioxide emitted for each unit of energy produced.

ECONOMIC GROWTH IS DRIVING GLOBAL EMISSIONS

At a global scale, this analysis demonstrates that increasing carbon dioxide emissions are driven by economic growth as more goods and services are produced and used both per person and in total (IPCC, 2014b). This growth, and how energy intensive it is, has a big influence on emissions. The trends can go in opposite directions, so the relative rates of change are important – for example, if economic activity per person increases faster than the energy intensity decreases, overall emissions will rise.

It takes energy to produce goods and services. Because globally most of this energy still comes from burning fossil fuels, there is a strong correlation between economic activity and carbon dioxide emissions. Countries with higher incomes per person also tend to have higher energy use per person because its citizens live more energy-intensive lifestyles (IPCC, 2014b).

The source of the increased GDP also matters. Growth from advances in technology (which tend to be less energy intensive) has less of an impact on greenhouse gas emissions than growth from using more resources or expanding existing energy intensive activities (IPCC, 2014b).

Population growth adds to the growth of global emissions. Each person who is added to the world's population increases the demand for resources and energy. Where they live, however, makes a huge difference (up to 91-fold) in their typical emissions. In general the regions with the highest population growth have significantly lower emissions and lower wealth per capita than regions with low or no population growth (IPCC, 2014b).

Energy intensity has decreased globally in the past 40 years because of improvements in technology and efficiency. The change is driven by the decisions we make at an individual and economy wide level, to buy and use energy efficient products for example. The decrease, however, has not been fast enough to offset the growth in energy use from the world's increasing population and increasing energy use per person. From 1970 to 2010, total global energy use increased by 130 percent, while global population increased by 87 percent. Energy use per person also increased by 30 percent (IPCC, 2014b).

Carbon intensity of the energy supply has decreased globally due to the move from fuels with a high carbon content like coal, to lower-carbon fuels like natural gas and near-zero carbon fuels such as nuclear, wind, and solar. As with energy intensity, this reduction has not been fast enough to offset the growth in energy use (IPCC, 2014b).

Emissions of other greenhouse gases such as methane and nitrous oxide are also growing, driven by similar trends. These include the worldwide increase in living standards and increased demand for goods and services, particularly from agriculture (IPCC, 2014b).

ECONOMIC ACTIVITY IS DRIVING NEW ZEALAND'S CARBON DIOXIDE EMISSIONS

The growth of economic activity has driven New Zealand's carbon dioxide emissions. Economic activity per person rose by 31 percent between 2000–18 and by 15 percent in the last decade from 2009–18 (see figure 8) (Stats NZ, 2020c). During this time, direct carbon dioxide emissions from households increased by 16 percent and by 13 percent from manufacturing (Stats NZ, 2020b).

Between 2007 and 2018, an average of 90 percent of direct household emissions came from transport (Stats NZ, 2020b). The light vehicle fleet includes passenger vehicles (primarily cars) and light commercial vehicles (vans, utes, SUVs, and trucks). Growth in the fleet has mirrored population growth – the fleet was the largest to date in 2018 (MoT, 2019).

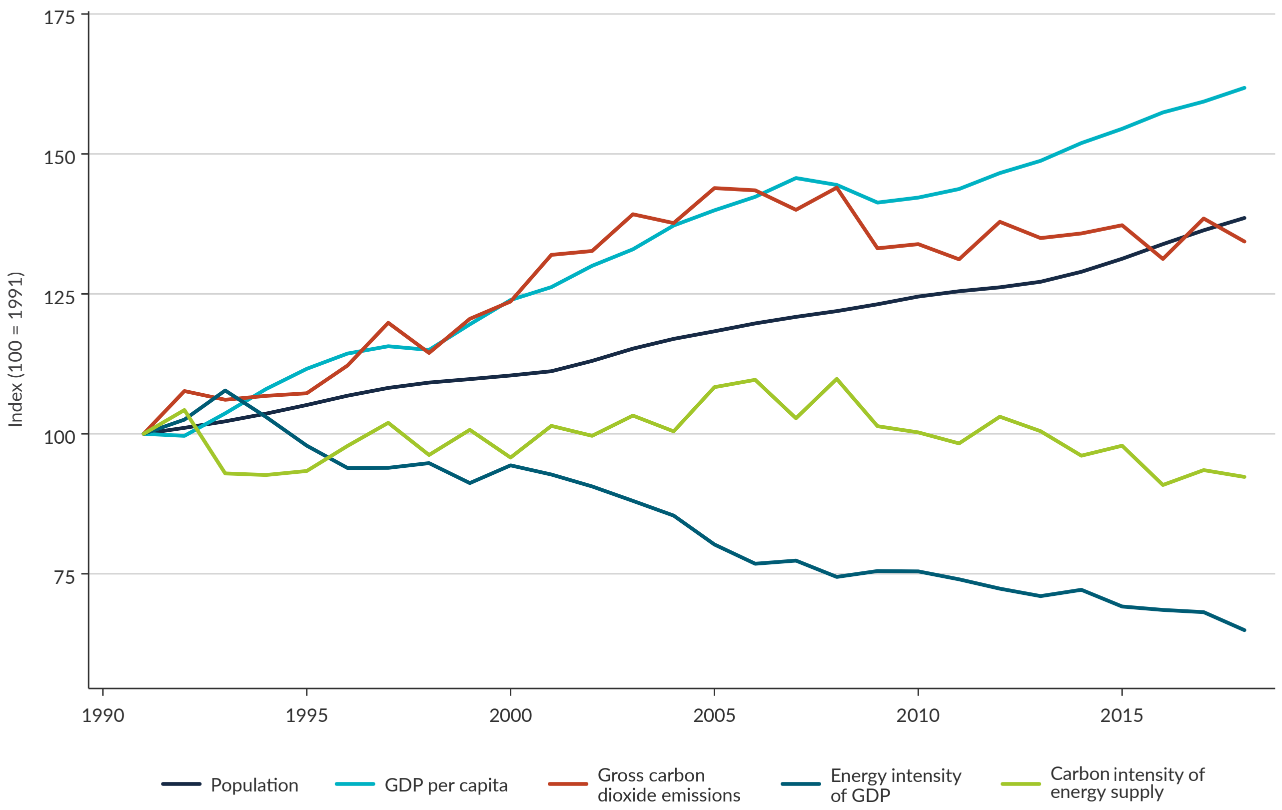
The increase in carbon dioxide emissions from light vehicles for 2009–18 was largely driven by strong growth in the total distance travelled by these vehicles – the overall distance travelled increased by 20 percent in the last decade. The increased travel was not offset by increased fuel efficiency in the light vehicle fleet during this time as this effect was much smaller (MoT, 2019).

Population growth in New Zealand has also driven the increase of our greenhouse gas emissions (as it does globally), particularly by driving economic growth and increasing total household consumption.

Increased pressures on gross carbon dioxide emissions from growth in GDP per person and population were lessened by decreases in the energy intensity of our economy. The energy intensity of GDP decreased by 31 percent between 2000 and 2018, and decreased by 14 percent in the last decade (MBIE, 2019a; Stats NZ, 2020c). Despite the decreases (and the high percentage of electricity generated from renewable sources) our energy intensity remains high – it was 18 percent above the OECD average in 2017, and the sixth highest of 37 OECD countries (MBIE, 2019a).

A decrease in the carbon intensity of our energy supply also contributed to reducing growth in emissions. Between 2000 and 2018 the carbon intensity of our energy supply decreased by 4 percent, but the decrease was 9 percent from 2009–18 (MBIE, 2019a). This was mainly due to more geothermal electricity generation from about 2010 (MBIE, 2019b).

Figure 8: Drivers of New Zealand's carbon dioxide emissions, 1991–2018



Data source: Ministry of Business, Innovation and Employment; Ministry for the Environment; Stats NZ

- Decreases in the energy intensity of our economy and a decrease in the carbon intensity of our energy supply contributed to reducing growth in gross carbon dioxide emissions.

METHANE EMISSIONS ARE MAINLY DRIVEN BY THE NUMBER AND TYPE OF LIVESTOCK

Methane emissions are driven by the economics of agriculture. The increased profitability of dairy farming (relative to sheep and beef) has resulted in conversions to dairy production, a larger national dairy herd, and increased methane emissions from dairy cattle. Increased livestock productivity (for the yield of milk and meat per animal) has also contributed, as higher productivity requires more feed per animal, which increases methane emissions (MfE, 2020d).

Higher emissions from a larger dairy herd and higher productivity have been offset by decreases in the number of beef cattle and sheep. Severe droughts, such as those in 2008, 2013, 2015, and 2016, can also drive down methane emissions as farmers are forced to reduce the number of livestock (MfE, 2020d).

Improving the capture of methane from landfills (managed waste disposal) has driven a decrease in emissions from this source, with a 25 percent reduction reported for 2009–18 (MfE, 2020d). This is despite more municipal waste being generated by our increasing population and rising GDP per person.

NITROUS OXIDE EMISSIONS ARE MAINLY DRIVEN BY LIVESTOCK

Nitrous oxide emissions were caused mainly by livestock dung and urine deposited onto pasture, but were also driven by the use of more synthetic nitrogen fertiliser – this increased by 673 percent from 1990 to 2018. More manure from more productive livestock also contributed to increased emissions (MfE, 2020d).

COVID-19 and greenhouse gas emissions

In an unprecedented move to eliminate a new coronavirus from New Zealand, the Government closed the borders and confined people to their homes for 29 days during the alert level 4 lockdown in March and April 2020. Essential work continued and supermarkets stayed open but schools, shops and workplaces closed. Many people lost their jobs and businesses, and those who could worked from home.

How did such a radical and sudden behaviour change affect greenhouse gas emissions?

During level 4, traffic volume in large urban areas dropped to an average of 19–25 percent of 2019 levels (NZTA, 2020). The distance heavy vehicles travelled decreased by up to 50–60 percent (compared to mid-March) but buses still ran to transport essential workers – sometimes with few or no passengers. Sea freight reduced, imports decreased by 21 percent, and exports decreased by 17 percent in April, compared to April 2019 (MoT, 2020). Domestic air travel restrictions and the closed border decreased air traffic volume by about 80 percent (ACL, 2020).

Large reductions in air pollutants were observed. In Auckland, nitrogen dioxide levels decreased by 34–57 percent and black carbon levels fell by 55–75 percent (Patel et al., 2020).

Globally, similar lockdowns cut carbon dioxide emissions to 2006 levels. At its peak during the lockdowns in early April, daily carbon dioxide emissions were estimated to have decreased by 17 percent from 2019 levels. Reductions in road and air traffic made the biggest contributions (Le Quéré et al., 2020).

By mid-year, it was estimated that annual global emissions for 2020 would be 4–7 percent lower than 2019 levels. Although this would be the largest annual decrease in greenhouse gases on record, global carbon dioxide emissions remain large, so even a decrease of this size would not be enough to significantly affect the accumulation of carbon dioxide in the atmosphere to limit warming to 1.5 degrees Celsius. For that to happen, this rate of decrease would need to continue year on year for the next decades (Le Quéré et al., 2020).

There is also a question of whether the reductions in emissions will be sustained. Previous economic crises have caused emissions to decrease in the short term but all rebounded except when the crises were driven by energy supply. For example, energy efficiency improved substantially and alternative energy sources were developed as a result of the oil crises of the 1970s and 1980s. The current decreases in emissions are unlikely to be lasting unless structural changes are made to the world's economic, transport, or energy systems (Le Quéré et al., 2020).

Transport and economic activity in New Zealand increased as restrictions on movement were eased in April and May. For the most part, daily life resumed on 9 June when New Zealand moved to level 1 (except for the border remaining closed). Traffic volumes returned to about 2019 levels 1 month into level 1, measuring up to 94 percent in Auckland, 96 percent in Wellington, and 100 percent in Dunedin. In Christchurch and Hamilton, level 1 traffic volumes exceeded 2019 traffic volumes by 4–5 percent (NZTA, 2020).

The emission reductions that will last longest are likely to be in tourism. Tourist activity makes up about 7 percent of the greenhouse gas emissions we produce (on an environmental-economic accounting basis), most of which is from air and land-based travel (Stats NZ, 2020b). Reductions in international tourism, however, may be partially offset by more domestic tourism as New Zealanders are encouraged to travel in their own backyard and support the recovery of local economies.

A lone car on the Auckland motorway during the early 2020 lockdown.

Photo: Stuart Mackay, NIWA

CHAPTER 3

Changes in our climate and environment are being observed

▸ Floodwaters encroach on roads, farmhouses, and paddocks.

Photo: Alan Blacklock, NIWA

Climate change has well and truly arrived in New Zealand and is affecting the climate where we live.

The annual average temperature in Aotearoa New Zealand continues to increase. Measurements between 1972 and 2019 showed increases in the annual average temperature at 28 of 30 sites, and at every site during winter. Daily average high and low temperatures also increased at many of the sites, and the growing season has lengthened.

Temperature extremes can cause serious risks to our health, and these have been changing. Warm days, where the daily high is above 25 degrees Celsius, very likely increased at nearly two thirds of sites. The annual number of heatwave days increased at more than half of all sites, while frost days decreased in many places.

The signals of changes to rainfall are also beginning to emerge. Annual rainfall either increased or decreased at 24 of 30 sites, and most of these also had changes to extreme rainfall. Changes to dry spells were observed, as well as changes to the frequency and intensity of drought.

The warmer atmosphere and changed rainfall is already translating to impacts on other parts of the physical environment, like our soils, oceans, and glaciers. The volume of ice in our glaciers has decreased, and changes to wildfire risk have been observed in some places. The changes are unmistakable in the oceans, which are rising, warming, and becoming more acidic.

(See Measuring and reporting trends and anomalies for information about how increases and decreases are reported.)

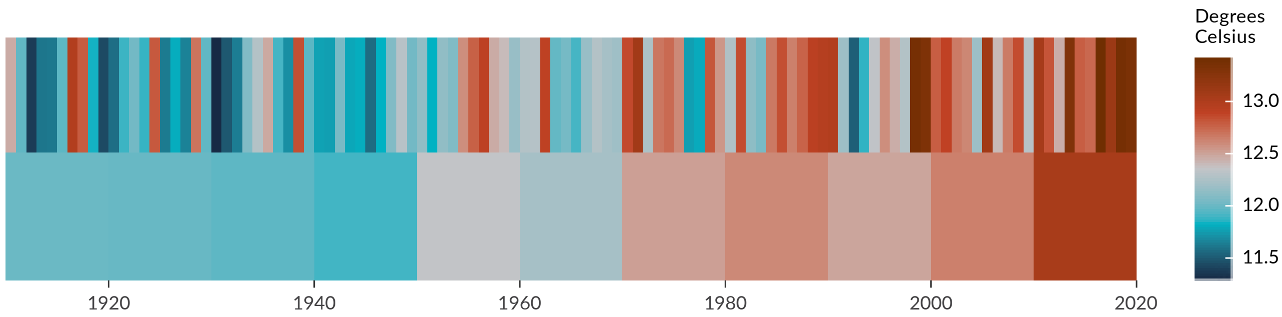
How New Zealand's climate is changing

TEMPERATURES ARE RISING NATIONWIDE

In 2019, the annual average land-surface temperature in New Zealand was the fourth highest since records began in 1909 (see figure 9). It has risen by 1.13 (± 0.27) degrees Celsius in these 111 years. (See indicator: Temperature.) Of the past 20 years, 16 have recorded above average temperatures compared with the average for the 1961–90 reference period. Overall, the national average temperature increased by 0.10 degrees Celsius per decade since 1909, but that rate was 0.31 degrees Celsius per decade in the past 30 years.

Evidence from sediments, pollen, and ice suggests it has been about 10,000 years since the average annual temperature in New Zealand was as high as it is today. The temperatures we are now experiencing are therefore likely to be near the top of the range that current ecosystems have experienced (MfE, 1997).

Figure 9: Annual and decadal average temperature between 1910 and 2019



Data source: NIWA

Note: Stripes on the top row show the annual average temperature for a year. Stripes on the bottom row show the average temperature by decade.

- 2010–19 was New Zealand's warmest decade on record.

Measuring and reporting trends and anomalies

Trends are classified as 'very likely' when there is a greater than 90 percent certainty of an increasing or decreasing trend. A 'likely' trend is greater than 66 percent certain and an 'indeterminate' trend is reported when there is not enough statistical certainty to say if a trend is going up or down. We report trends (for example, changes in temperature or rainfall over time) using likelihood categories describing the certainty of trends adapted from the Intergovernmental Panel on Climate Change (IPCC, 2014a).

Increasing or decreasing trends are calculated from all the sites where the trend was very likely or likely. Sites that had insufficient data were not included in the trend analysis. Note that *Our atmosphere and climate 2017* used a different framework for reporting trends. When comparisons between reports are made, it is based on the trend likelihood framework used for this report.

The 30 years from 1961 to 1990 are used in this report as a reference or baseline period from which to measure anomalies (data points above or below a standard reference) as recommended by the World Meteorological Organization (WMO, 2017). This provides a benchmark against which contemporary observations can be compared.

The reference period is different from the periods used in weather reports – these use climate normals. Climate normals are 30-year averages that give information about what we can expect on a given day now, given the climate is warming. Averages are currently based on the 1981–2010 climate normal period. The normal period is updated every 10 years, with the next update scheduled for the end of 2020.

Using data from 30 sites around New Zealand allows for an in-depth look at how the climate is changing in different parts of the country. From 1972 to 2019, the annual average temperature increased at 28 sites (the increasing trend was statistically very likely at 25 sites and likely at 3), and no decreasing trends were found. (See indicator: Temperature and Measuring and reporting trends and anomalies.) Nelson had among the fastest increases in annual average temperature – an average rate of +0.29 degrees Celsius per decade, along with Reefton (+0.25 degrees Celsius per decade) and Tara Hills in inland Canterbury (+0.24 degrees Celsius per decade).

Some sites have already experienced years with an average temperature well above the 1961–90 reference temperature. In 2013, the average annual temperature in Dannevirke was +1.73 degrees Celsius higher. This was the largest temperature annual average anomaly observed for the 16 sites with enough data to calculate anomalies.

The warming observed in New Zealand is consistent with global observations. Worldwide, recorded temperatures have risen 1.0 degrees Celsius above pre-industrial levels, and 19 of the 20 warmest years have occurred since 2001. The past 6 years have been the warmest since records began in 1880 (IPCC, 2018; NASA, 2020).

While 1.0 degrees Celsius of global warming may not sound like a big increase, this rise in global surface temperature is part of an enormous accumulation of extra energy in the climate system (Trenberth, 2020). The difference between today's climate and the climate during the last ice age (when large parts of Europe and North America were covered in ice) is 2–7 degrees Celsius, so changes that seem small can have major consequences (IPCC, 2013).

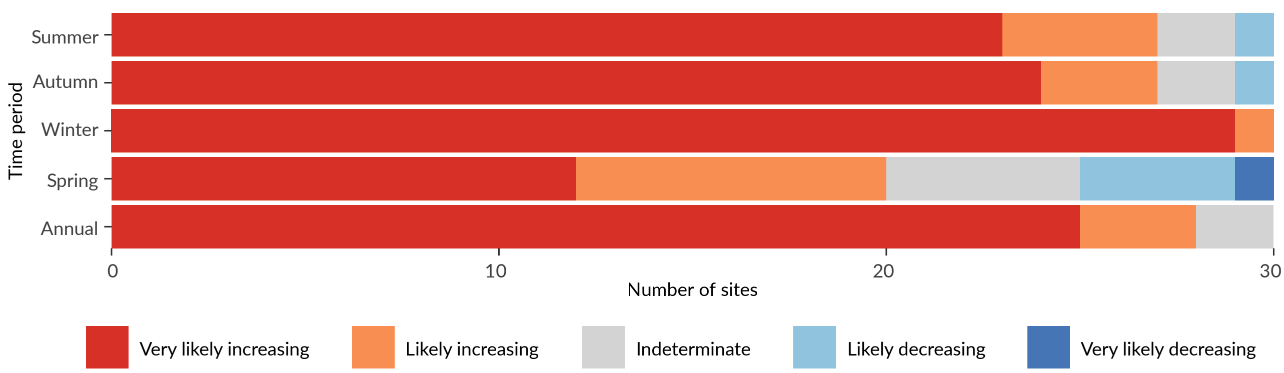
OUR SEASONS ARE CHANGING

Winters are becoming warmer – average temperatures increased at all 30 sites (the trend was statistically very likely at 29 sites and likely at 1 site, see figure 10). Between 1972 and 2019 winters at Tara Hills warmed at an average rate of +0.41 degrees Celsius per decade. This was one of the highest rates of change at any site in any season. Nelson and Gore were also among the sites that had rapid changes in winter temperatures, with average increases of +0.35 and +0.33 degrees Celsius per decade respectively.

Winter had the most sites with increasing trends, although many of the largest temperature anomalies were recorded in summer. The hot summer in 2018 was unprecedented in New Zealand's climate record. It resulted in average summer temperatures of more than 2 degrees Celsius above the 1961–90 baseline at 11 of the 30 sites, including Dannevirke, Nelson, and New Plymouth.

Changes in the seasons can affect our native plants, animals, and ecosystems, as well as how and when crops are grown. Changes can affect the flowering of some trees, when birds lay their eggs, and when species migrate. The timings and relationships that some mātauranga Māori is based on can also be affected. Warmer winters can mean less fuel needs to be burned to heat our homes. This could cause fewer emissions of air pollutants like particulate matter, the tiny particles in wood smoke. Warmer summers can increase heat stress (an inability to get rid of excess heat), which has serious health implications.

Figure 10: Trends in average temperature between 1972 and 2019

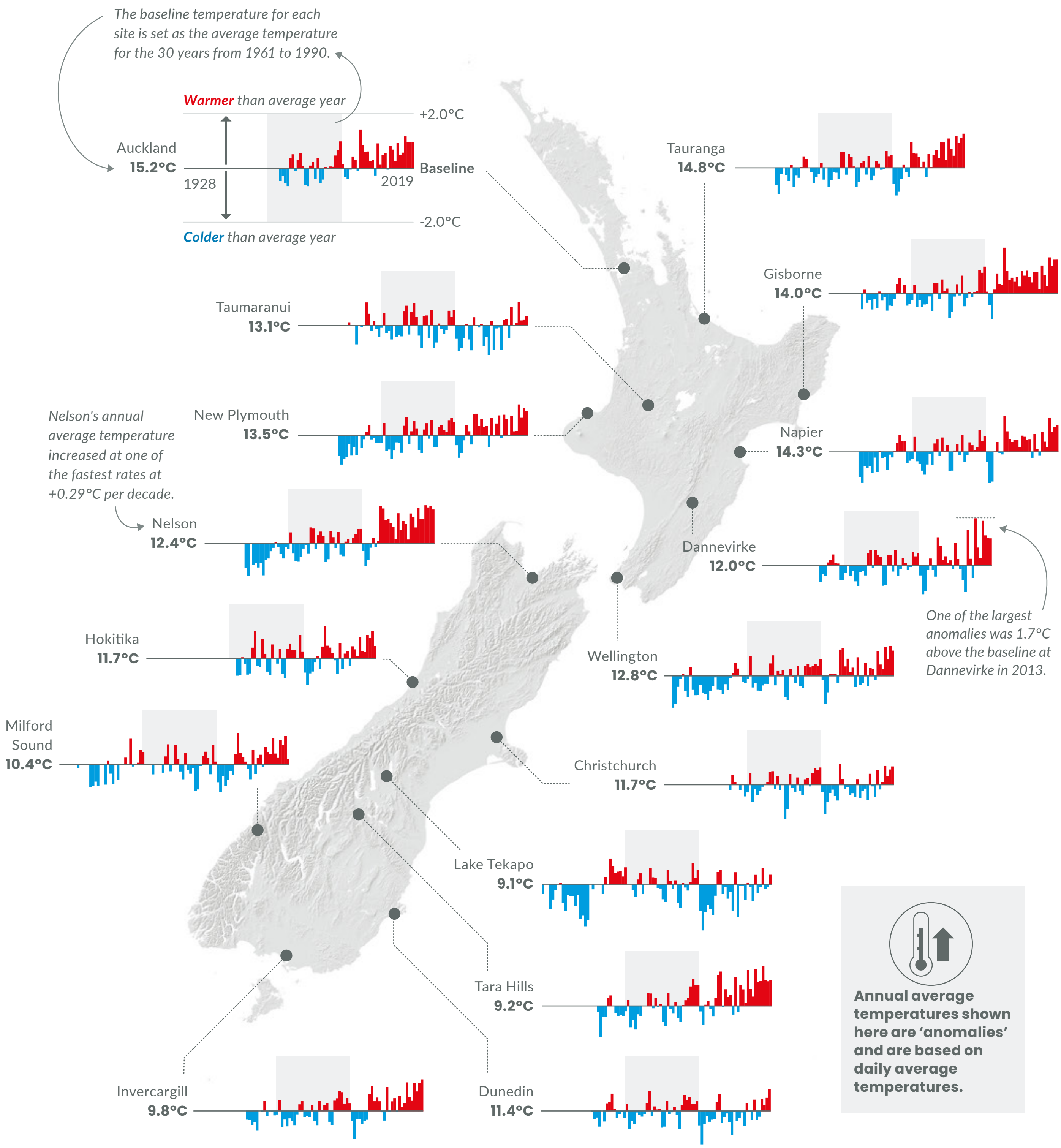


Data source: NIWA

‣ Average temperatures increased at most of the 30 sites across the country.

Average temperatures across New Zealand are increasing

Comparing annual average temperatures with the average for 1961–90 shows how temperatures are changing.



Note: Temperature records have different start dates. Only sites with enough data to calculate a baseline temperature are shown here.
Map data by Land Information New Zealand (CC BY 4.0)

Tohu and maramataka: observing and tracking changes in the environment

By interacting closely with local environments and processes over time, Māori developed a detailed knowledge of biophysical indicators or tohu (King, Tawhai, Skipper, & Iti, 2005). Tohu are passed down through kōrero tuku iho (stories of the past), karakia (prayers), pūrākau (legends), whakatauākī (proverbs), and waiata (songs) like this one:

Tīhore mai te rangi – clear the sky
Tīhore mai
Mao mao mao te ua – cease the rain
Whiti mai te rā – let the sun shine
E rere kōtare – fly kingfisher
Ki runga pūwharawhara – onto the astelia bush
Rūrū parirau – ruffle your wings
Kei mate i te ua – lest you catch a chill
E rere e noke – flee you worm
Mai tō pokorua – out of your burrow
Kei kī i te wai – lest it be filled with water
Ka mate i te ua – and you will drown.

Melbourne, 1978

In this waiata, Tāwhirimātea is asked specifically to stop the rain, clear the dark clouds, and let the sun shine. The waiata also contains a warning to the kōtare and noke (kingfisher and worm) about the consequences of failing to prepare and seek shelter. If we humans liken ourselves to kōtare and noke, the waiata can also be a warning to avoid the same failings.

The use of tohu is based on traditional principles that all things are connected through whakapapa (ancestral lineage). Through these layers of the past, tohu provide access to the memories of Māori ancestors and the state of the environment in their time. They can therefore be used to signal, monitor, and forecast changes in the natural environment.

Another method used by Māori for observing environmental changes is the maramataka. This stellar-lunar-ecological calendar is how Māori traditionally kept time as it divides a year into lunar months. The maramataka is a vast repository of mātauranga Māori (traditional knowledge) that aligns with the movements and phases of the moon (Weko, Roberts, & Clarke, 2006). It is used for deciding when to plant and harvest crops and indicates when to hunt and fish for specific animals. It also helps to indicate weather and seasonal changes (Harris, Matamua, Smith, Kerr, & Waaka, 2013; Tawhai, 2013).

There are many maramataka, and they vary from region to region. The appearance of the star Puanga or Rigel, for example, marks the start of Matariki (Māori New Year) in the far north, Taranaki, Whanganui, the South Island, and the Chatham Islands. In Te Urewera, Ngāi Tūhoe know that cold weather and frosts in Paengawhāwhā (April) are signs of a good year for kererū because the trees will produce plenty of fruit (Lyver, Jones, & Doherty, 2009).

Ātea a Rangi (star compass) in Hawke's Bay.

Photo: Andrew Caldwell/photonewzealand

DAILY MAXIMUM AND MINIMUM TEMPERATURES ARE CHANGING

Winter days and winter nights are warming in New Zealand (see figure 11). The maximum temperature in winter increased at all 30 sites, and the minimum winter temperature increased at 27 of the sites (increases and decreases include both very likely and likely statistical trends, see figure 12).

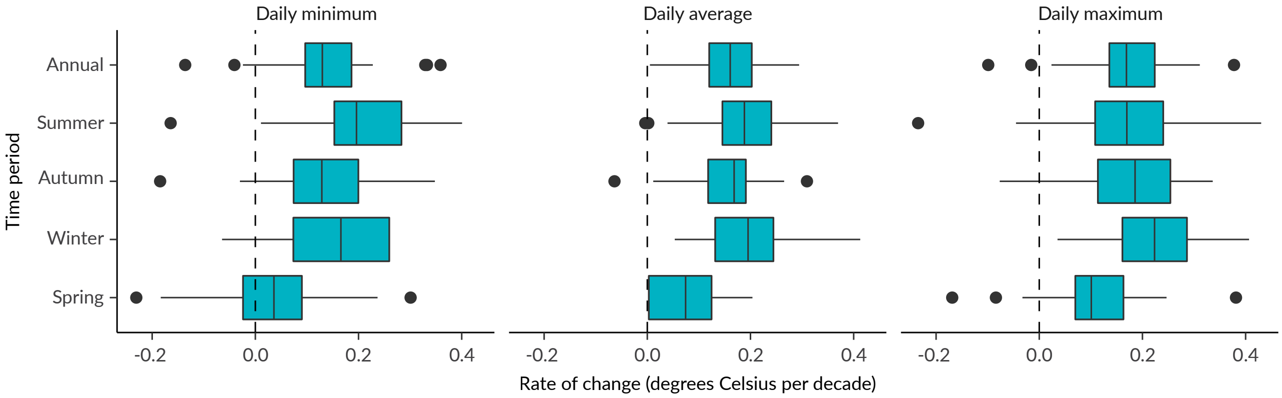
Changes in spring were more mixed – 25 sites had increasing maximum temperatures, but only 13 had increasing minimum temperatures. This contrasts with changes in seasonal rainfall (see Annual and seasonal rainfall is changing) where spring was the season when the most sites experienced changes.

One of the fastest increases in annual average maximum temperature occurred in Masterton, where an average rate of +0.38 degrees Celsius per decade was recorded. Some of the fastest increases in annual average minimum temperatures were recorded in Whangārei, Nelson, and Gisborne.

Maximum daily temperatures have strong influences on our day-to-day life and can affect human health, as well as ecosystems, agricultural systems, and water availability. These temperature measurements are sensitive to changes in siting and instrumentation.

Soaring maximum temperatures often make headlines, but changes to minimum temperatures have effects that may go unnoticed. Tropical nights, when the minimum temperature does not go below 20 degrees Celsius, increased by about half a night per decade in Whangārei and Tauranga on average. Elevated night-time minimum temperatures can be a health concern as people do not get a break from the heat (Murage, Hajat, & Kovats, 2017).

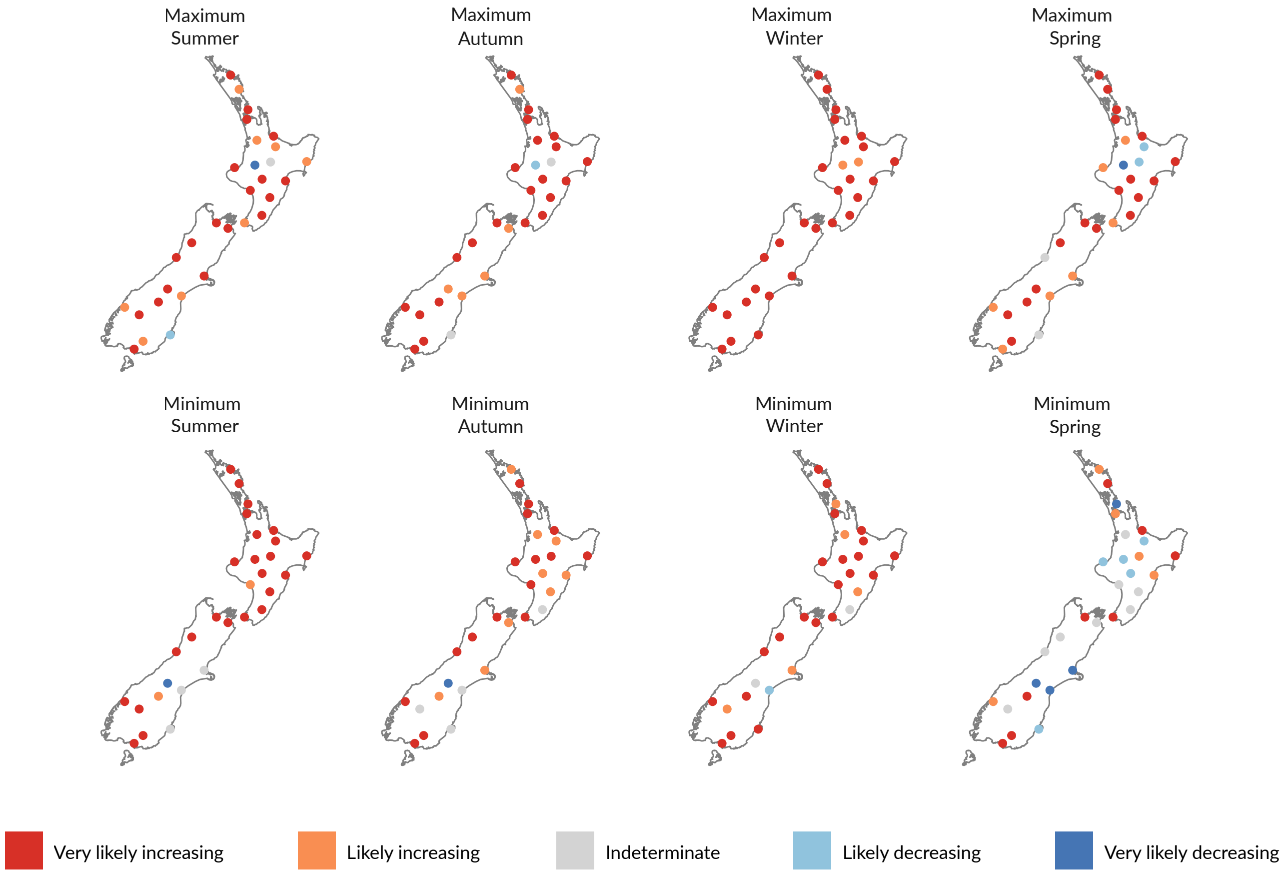
Figure 11: Rate of change in temperature between 1972 and 2019



Data source: NIWA

‣ Unlike summer, daily minimum temperatures in spring did not increase between 1972 and 2019.

Figure 12: Trends in daily minimum and maximum temperature between 1972 and 2019



Data source: NIWA

- Minimum and maximum daily temperatures increased at most of the 30 sites, although fewer trends were seen in spring minimum temperatures.

The temperature range widened at Lake Tekapo and Timaru, with decreases in minimum temperatures and increases in maximum temperatures recorded. This pattern could be linked to a reduction of cloudiness in the area, with more cooling happening at night. New Zealand is also strongly influenced by the surrounding marine environment, so these observations may be related to the cooler sea-surface temperatures found to the southeast of the South Island (Mullan, Stuart, Hadfield, & Smith, 2010). (See indicator: Sea-surface temperature.)

THE GROWING SEASON IS GETTING LONGER

Growing degree days is a measure that can be used to estimate the length of the growing season for agriculture and horticulture. The measure counts the total number of degrees Celsius that the average temperature is above a base temperature (commonly 10 degrees Celsius) each day. Growing degree days measure heat accumulation, which plants depend on for development, and can be used to predict plant and animal growth.

For 1972–2019, 27 of the 30 sites had an increasing trend in growing degree days (this includes both very likely and likely statistical trends). (See indicator: Growing degree days.) Lake Tekapo had a statistically likely decreasing trend for this period (this may be related to reduced cloudiness as discussed above).

THE NUMBER OF WARM DAYS AND HEATWAVE DAYS IS INCREASING

Average temperatures help define how a climate feels, but it is often the infrequent, extreme events like heatwaves that we notice most. These events are also where the most immediate impacts of changes to the climate are observed. Changes to the intensity and frequency of heatwaves, for example, may have much greater economic, social, and environmental impacts than changes in the average climate (Pearce et al., 2019).

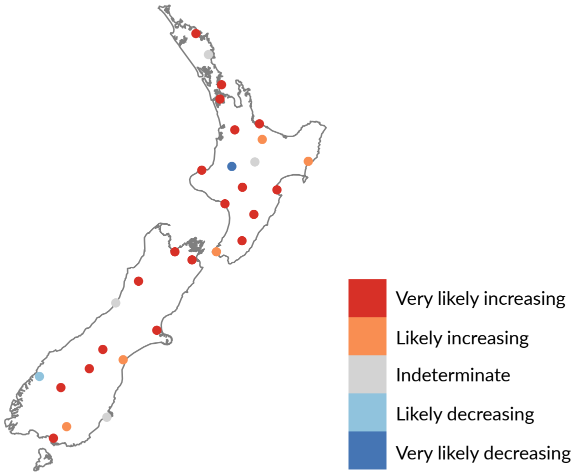
High temperatures can have health and safety implications for people who work and play outdoors, and for people like the elderly who are particularly sensitive to heat (Royal Society Te Apārangi, 2017). Heat can also affect infrastructure such as roading (like when your jandals stick to melted tar on the road) and increase the demand for electricity (because people use air conditioning). Plants, including crops, are affected by heat but their tolerances vary widely. Temperature extremes are likely to influence the range and survival of native and introduced species (Pearce et al., 2019).

The number of warm days (when the maximum temperature is above 25 degrees Celsius) is very likely to have increased at 19 of 30 sites and very likely to have decreased at only one site between 1972 and 2019. (See indicator: Frost and warm days and figure 13.) Among the sites with the largest average increases were Masterton (which gained a week per decade), Reefton (+5.0 days per decade), and Tauranga (+4.8 days per decade). A decrease was observed at Taumarunui, which recorded an average of 4.1 fewer warm days per decade.

The increase in the number of sites with trends in warm days is one of the biggest changes observed since *Our atmosphere and climate 2017* among the climate indicators used in this report. Five more sites (19 in total) observed a very likely increasing trend than the 14 sites that were observed between 1972 and 2016.

Heatwave days are a measure of when temperatures are significantly warmer than normal. In this report, heatwaves are defined as three or more consecutive days with a maximum temperature of more than 5 degrees Celsius above the monthly average for 1981–2010. Annual heatwave days is the total number of days in these heatwaves per year. Heatwaves can occur at any time of year – in winter they are known as warm spells.

Figure 13: Trends in annual number of warm days between 1972 and 2019



Data source: NIWA

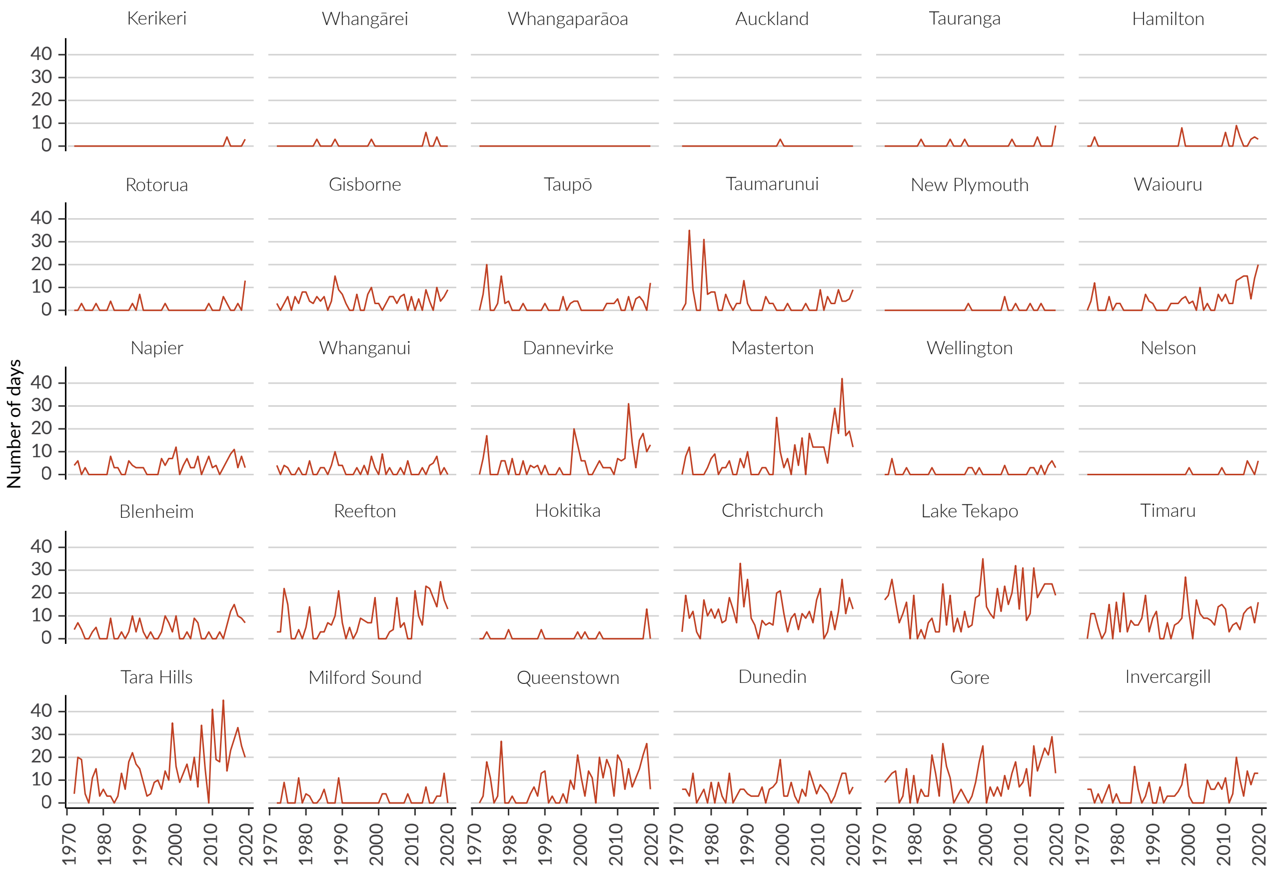
- The annual number of warm days increased across the country between 1972 and 2019.

Inland sites like Tara Hills, Lake Tekapo, Gore, and Masterton were among those with the most heatwave days between 1972 and 2019 (see figure 14). Coastal South Island sites like Christchurch and Timaru can also experience heatwaves, particularly when hot northwest winds blow across the Canterbury Plains.

A very likely increasing number of annual heatwave days occurred at 18 of 30 sites nationwide. Some of the fastest increases were at inland South Island locations. Heatwave days increased by 4.1 days per decade at Tara Hills, 3.0 days per decade at Lake Tekapo, 2.7 days per decade in Queenstown, and 3.2 days per decade in Masterton.

By season, more of the 30 sites had very likely increasing trends for annual heatwave days in summer (14) and autumn (18) than in winter (8) and spring (9, and 1 very likely decreasing trend).

Figure 14: Annual heatwave days, 1972–2019



Data source: NIWA

- Heatwaves were more common at South Island sites for 1972–2019.

FROSTS ARE BECOMING LESS COMMON AND THE DATES OF FROSTS ARE CHANGING

Our climate is not as cool as it used to be. A frost day occurs when the minimum air temperature is below zero degrees Celsius (rather than a day that has frost on the ground). For 1972–2019, 12 of the 30 sites had a very likely decreasing number of frost days. (See indicator: Frost and warm days.) Nelson and Tara Hills (with an average loss of 5 days per decade) had some of the fastest decreases.

Some places that once had frosts rarely no longer have any. Whangārei never recorded more than two frost days per year but a temperature below zero has not been recorded at this site since 1994. However, Lake Tekapo and Timaru are very likely to have had an increased number of frost days per year.

The dates of the first and last frosts have also changed (see figure 15). Some sites, including Waiouru, Taumarunui, Reefton, Nelson, Gore, Milford Sound, and Tara Hills now experience winter weather for a shorter time on average, with the first frost occurring later in the year and the last frost earlier. Four sites (Taupō, Blenheim, Timaru, and Lake Tekapo) had their first frost day occurring earlier and the last frost day later.

Some plants (including invasive species) cannot tolerate frost so fewer frost days may allow them to expand their range. Cold temperatures are critical for other species because they trigger processes like blossoming in fruit trees. Frost can also be beneficial in killing some insect pests.

Figure 15: First and last frost days, 1972–2019

Data source: NIWA

▸ The time between first and last frosts decreased (lines got closer) at several sites for 1972–2019.

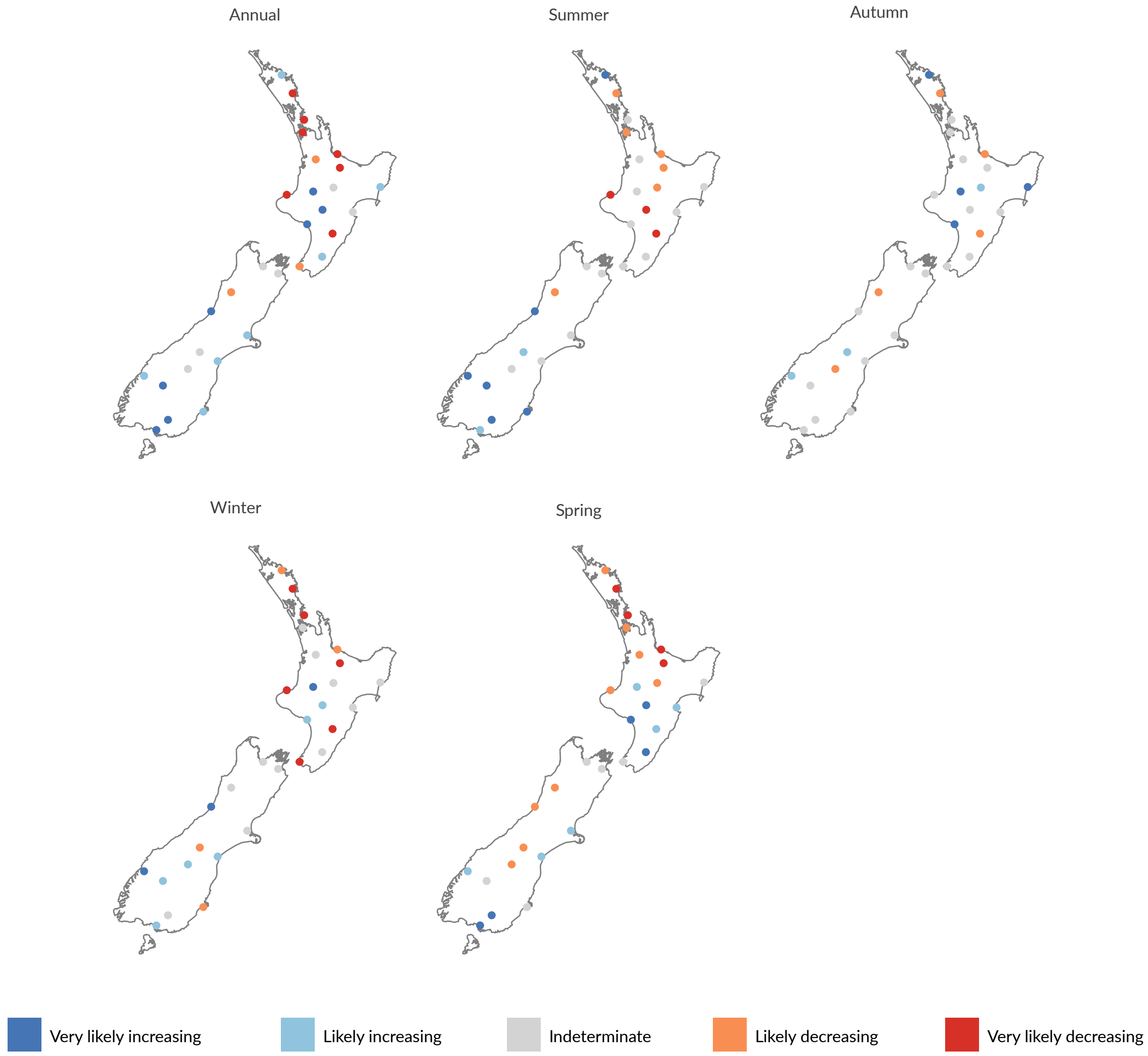
Rainfall is changing in many places

ANNUAL AND SEASONAL RAINFALL IS CHANGING

Almost half of the 30 sites had increasing trends for annual rainfall for 1960–2019 (increases and decreases include both likely and very likely statistical trends (see figure 16 and indicator: Rainfall). One third of the sites experienced less rainfall – many of these were in the northern half of the North Island. Southern South Island and west coast sites (including Milford Sound, the wettest of the 30 sites) had increased annual rainfall. Some of the drier sites – Tara Hills and Lake Tekapo – had different trends in different seasons.

Annual rainfall decreased by an average of 4.3 percent per decade in Whangārei, and 3.2 percent per decade in Tauranga, relative to the average rainfall over the entire period. These were among the largest decreases per decade. It increased by 2.8 percent per decade in Whanganui, 2.1 percent per decade in Milford Sound, and 1.3 percent per decade in Hokitika.

Figure 16: Trends in total rainfall between 1960 and 2019



Data source: NIWA

- Autumn had the fewest number of sites with increasing or decreasing trends compared with other seasons.

Changes in rainfall did not happen evenly across the year. There were increasing or decreasing trends in spring at 24 of 30 sites between 1960 and 2019. Spring is an especially important time of year for agriculture and horticulture. The fewest changes were observed in autumn, when 12 sites had increasing or decreasing trends, and the remaining sites had no detectable trend.

Most sites with increasing rainfall also had more intense rainfall – the rain fell in a shorter period of time rather than being spread out over the year. Most sites with decreasing rainfall had less intense rainfall (see Changes to extreme rainfall are mixed).

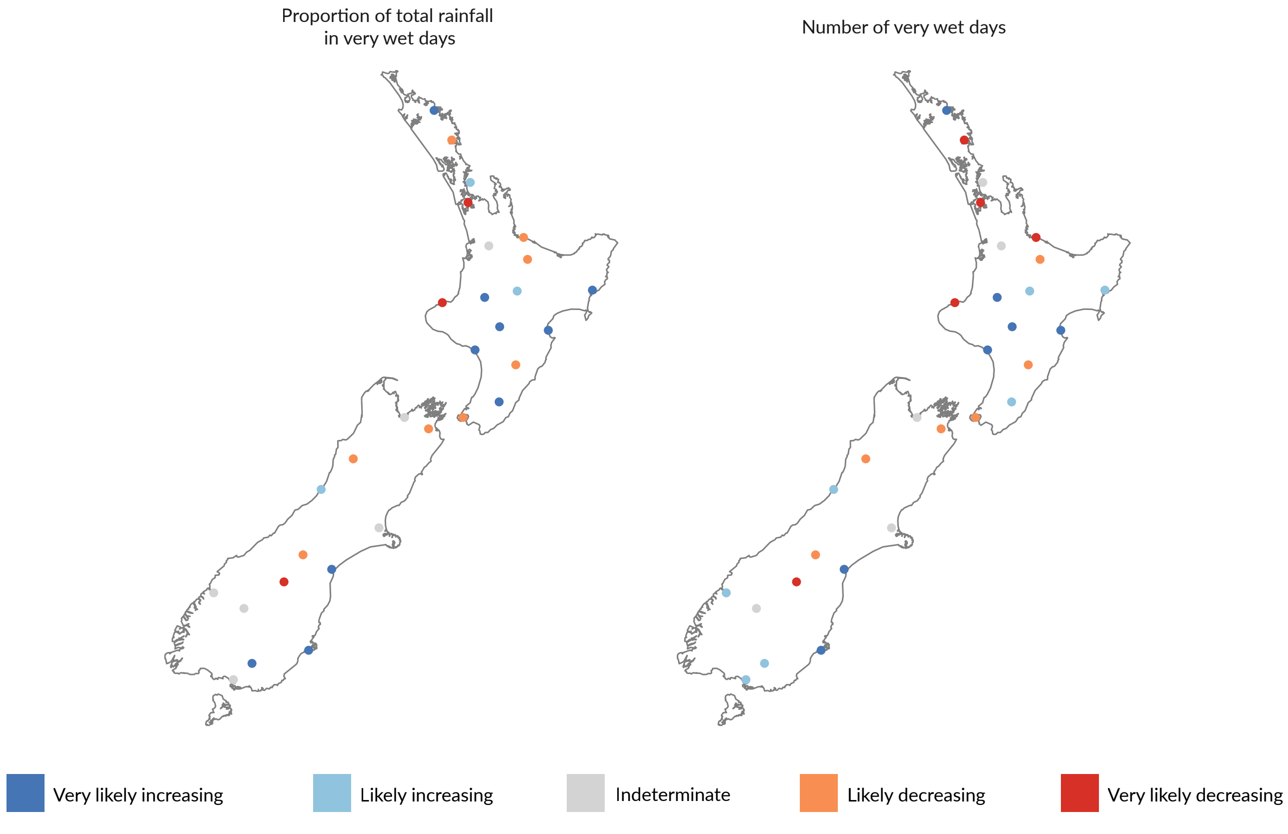
Rainfall influences which plants can grow in an area. Most ecosystems are sensitive to changes in precipitation (mostly rain and snowfall). Differences in the long-term baseline rainfall can affect the structure, composition, and diversity of ecosystems (Weltzin et al., 2003). The seasonal timing of rainfall can also have important implications for water supply and management, agriculture and irrigation, hydroelectricity generation, and river ecosystems.

CHANGES TO EXTREME RAINFALL ARE MIXED

Extreme rainfall events are variable by nature. Because a warmer atmosphere is a more energetic atmosphere (and can hold more water vapour), the water cycle is intensified. This can result in more frequent and intense rainfall. Although trends in the frequency and size of intense rainfall events have been observed, these events do not happen often, so a longer record of data is needed to increase confidence in these findings.

More rain falling in intense events can increase the risk of floods, landslides, streambank erosion, and sedimentation. Flooding from intense rainfall events can cause widespread damage to the infrastructure, social, and economic systems we rely on. Studies that examined recent floods for a link to climate change found that the warmer climate had increased the likelihood of some events – Golden Bay 2011 (Dean, Rosier, Carey-Smith, & Stott, 2013) and Northland 2014 (Rosier et al., 2015).

Figure 17: Trends in extreme rainfall between 1960 and 2019



Data source: NIWA

‣ Changes in extreme rainfall across New Zealand were mixed.

The proportion of total rainfall arriving in extreme events (downpours versus light rain) increased at 13 sites and decreased at 11 sites (increases and decreases include both likely and very likely statistical trends) (see figure 17 and indicator: Extreme rainfall). Timaru (+2.0 percent per decade), Kerikeri (+1.6 percent per decade), Napier (+1.5 percent per decade), and Dunedin (+1.4 percent per decade) had among the largest average increases. The proportion of rain falling in extreme events decreased by 1.6 percent per decade in New Plymouth.

The number of days with extreme rainfall increased at 14 sites and decreased at 11. Of the 25 sites with an increasing or decreasing trend, all but two had the same trend in the proportion of rainfall occurring in extreme events.

Floods release decades-old rubbish from a landfill

Ex-tropical cyclone Trevor hit New Zealand in March 2019, bringing extreme rainfall to the west coast of the South Island. Heavy rain closed part of State Highway 6, caused slips, and destroyed the Waiho River Bridge south of Franz Josef. Stretches of road were damaged over a distance of hundreds of kilometres. This weather event is estimated to have caused $3.81 million of damage in Westland (Westland District Council, 2019a).

A state of emergency was declared, residents and businesses were affected by power cuts, some homes were flooded or evacuated, and one person died (New Zealand Government, 2019a). Stop banks and farmland were damaged, and the floodwaters tore through a disused landfill beside Fox River, exposing rubbish from previous decades (Westland District Council, 2019b).

The effects were widespread. About 135,000 kilograms of rubbish was washed 21 kilometres downstream through Westland Tai Poutini National Park to the Tasman Sea and strewn over 64 kilometres of coastline. Litter in the marine environment is recognised as a global concern – flooding can deliver it deep onto the sea floor and threaten these marine ecosystems (Pierdomenico et al, 2019).

Westland District Council began the massive clean-up operation but handed it over to the Department of Conservation (DOC) in June 2019. (DOC is responsible for the national park, which is also part of Te Wāhipounamu South West New Zealand World Heritage Area). The New Zealand Defence Force also provided assistance.

The clean-up effort, called Operation Tidy Fox, coordinated hundreds of volunteers from across New Zealand and overseas and acted as a receiving point for financial support. Nearly 1,000 volunteers gave their time between June and August 2019, collecting over 134,000 bags of rubbish from the riverbed and coast (DOC, 2019).

Subsequent floods continue to release more rubbish. A feasibility study is underway to estimate the cost of sealing the landfill to stop more pollution. More intense and frequent extreme weather events may increase the risk to landfills that are vulnerable to storms and flooding (New Zealand Government, 2019b; Office of the Prime Minister's Chief Science Adviser, 2019).

Fox River landfill, which it is believed was closed in 2001, is one of between 110 and 163 closed landfills (compared to 2–3 active landfills) that are vulnerable to the effects of climate change such as sea-level rise (Simonson & Hall, 2019).

Volunteers collect rubbish from Fox riverbed.

Photo: Department of Conservation

DRY SPELLS ARE BECOMING MORE FREQUENT IN MANY PLACES

Auckland experienced its longest dry spell in early 2020, which finally ended after 47 days (NIWA, 2020). The average length of dry spells in Auckland between 1960 and 2019 was 10 days.

In this report a dry spell is defined as a period of 7 or more consecutive dry days when less than 1 millimetre of rain is recorded on each day. Annual dry spell days is the total number of days in these dry spells in a year. Note that some towns and cities use different time periods depending on their climate. Longer or more frequent dry spells coupled with shortened wet spells or warmer temperatures can lead to drought.

The total number of dry spell days per year increased at 13 of the 30 sites and decreased at 9 sites between 1960 and 2019 (increases and decreases include both very likely and likely statistical trends, see figure 18). Almost all sites with an increasing annual number of dry spell days (most of which were in the North Island and particularly the northern half) also had increasing trends for the number of dry spells. Six of the 9 sites with decreasing trends in the number of dry spell days, and 8 of the 11 sites with decreasing number of dry spells were in the South Island (particularly the lower half) where annual rainfall increased at many sites.

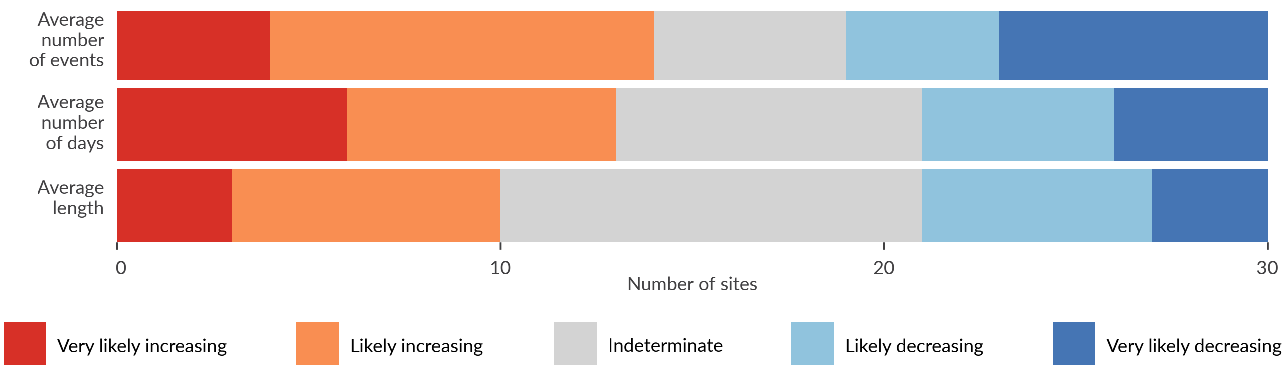
DROUGHTS ARE BECOMING MORE FREQUENT IN SOME AREAS

A drought is a prolonged and marked shortage of moisture compared to what is expected. Drought is caused by a lack of rain but high temperatures can contribute because they accelerate evaporation and water loss from soil, vegetation, and waterways. Therefore, high temperatures, low rainfall, and more of the rain falling heavily (with consequently longer dry intervals) can quickly lead to drought conditions.

One method used to detect and monitor drought is the standardised precipitation-evapotranspiration index (SPEI) (WMO and Global Water Partnership, 2016). Because SPEI accounts for the influence of temperature and precipitation on drought it is useful for studying climate change because both are affected. SPEI can also be applied for different time periods (like the past 3, 6, or 12 months) to provide information about the frequency and intensity (drought severity divided by its duration) of droughts.

More of the 30 sites had increasing trends for frequency and intensity of short-term drought than sites that had decreasing trends (as measured using the 3-month SPEI) for 1972–2019. (Increases and decreases include both very likely and likely statistical trends, see figure 21 and indicator: Drought). Thirteen of the 30 sites had an increased frequency of short-term drought, and the frequency decreased at 9 sites. Hamilton's 3-month SPEI values for example, dipped into short-term extremely dry conditions six times in the past 10 years (see figure 19). Blenheim and Dunedin were among the sites with the largest increases in the frequency of short-term drought.

Figure 18: Trends in dry spells between 1960 and 2019



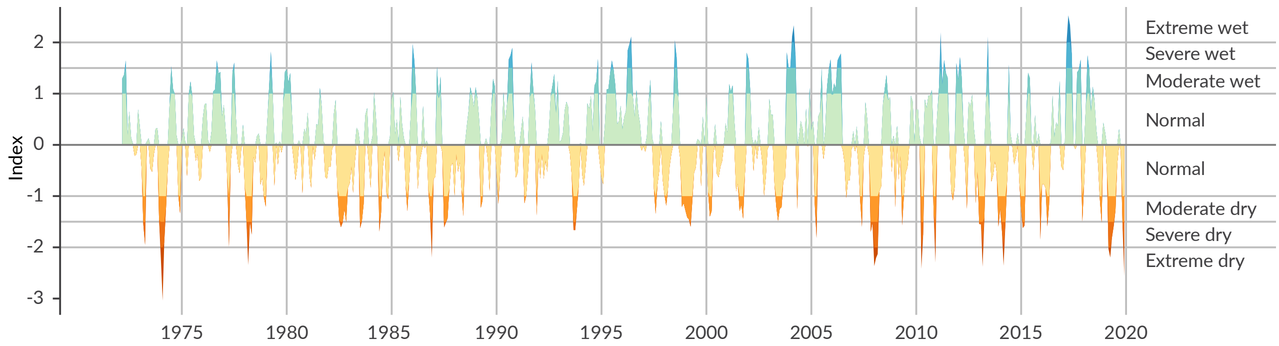
Data source: NIWA

▸ The average number of dry spell days and number of events changed at many sites.

The intensity of short-term drought increased at 14 sites, 11 of which were in the North Island. Of these 14 sites, 4 (Auckland, Waiouru, Reefton, and Lake Tekapo) had increasing trends in severity but not duration. This indicates that the drought intensification at those places was likely to be related more to increased severity than increased length. Auckland and Wellington had some of the largest increases in intensity. Nine sites had decreased short-term drought intensity, and of these, 7 were in the South Island.

New Zealand does not typically experience the droughts of a year or more that occur in other parts of the world, but long-term drought (measured using the 12-month SPEI) increased in frequency at 13 sites and decreased at 5 of the 30 sites. Also, more sites had decreases in severity and intensity than increases.

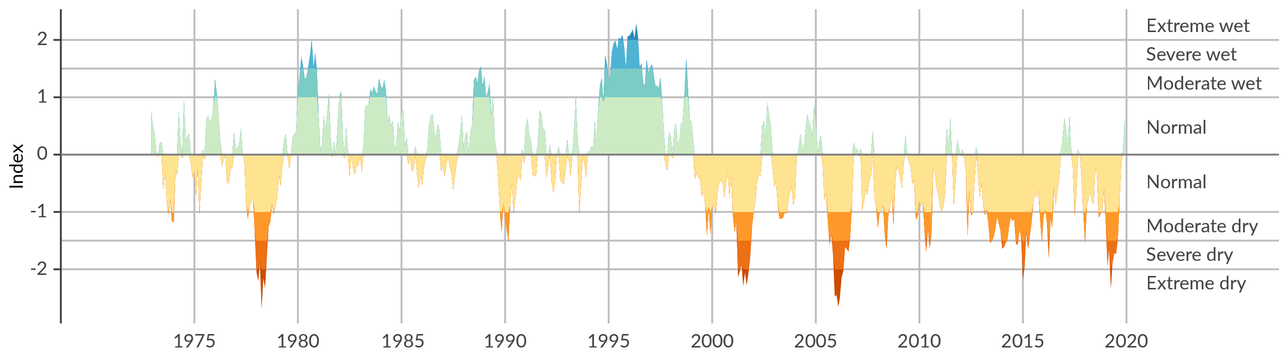
Figure 19: 3-month standardised precipitation-evapotranspiration index (SPEI) Hamilton, 1972 to 2019



Data source: NIWA

- 3-month SPEI can identify short-term drought – in Hamilton there were six periods of extremely dry conditions for 2010–19.

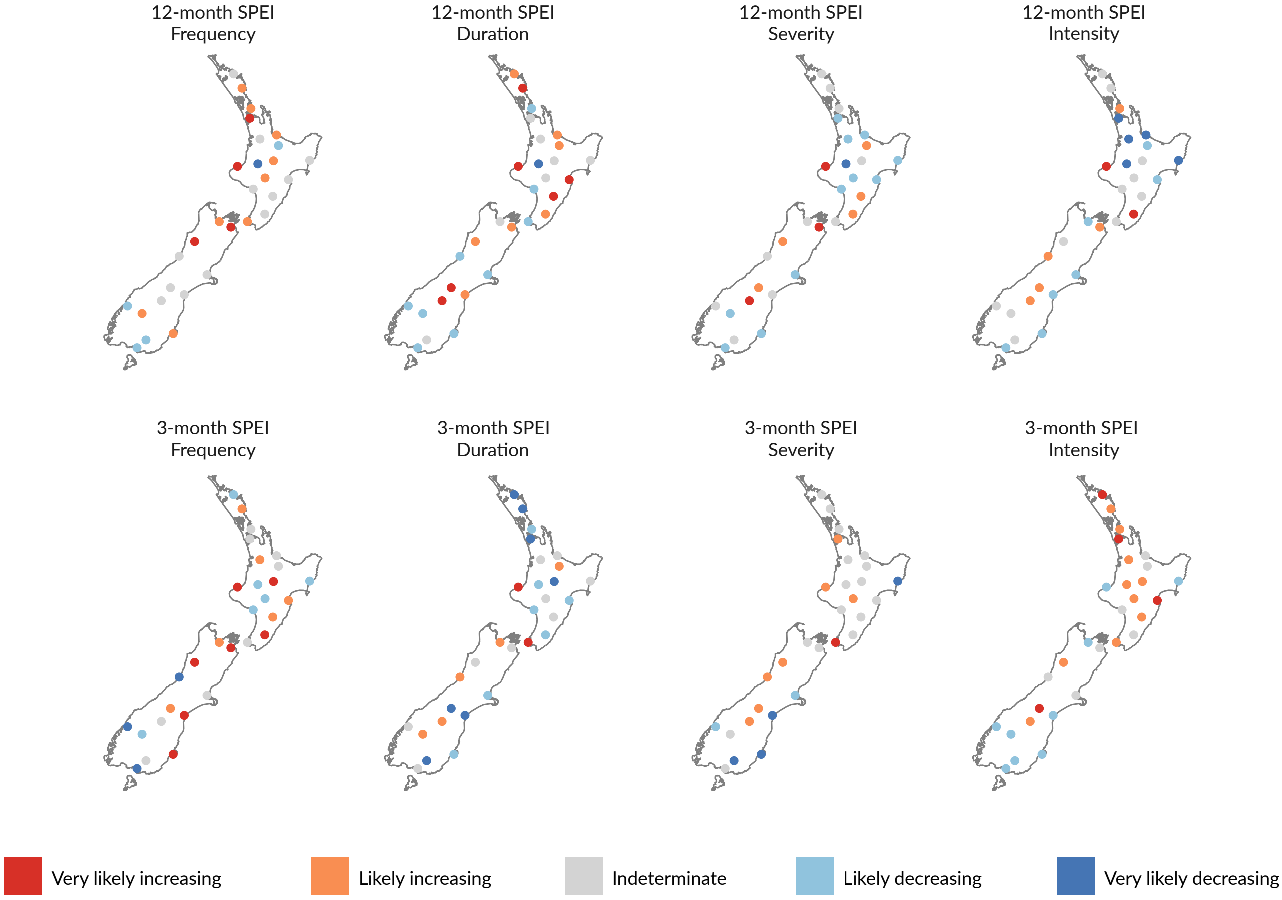
Figure 20: 12-month standardised precipitation-evapotranspiration index (SPEI) Reefton, 1972 to 2019



Data source: NIWA

- 12-month SPEI can show long-term drought. Reefton has had several periods of moderate to extremely dry conditions.

Figure 21: Trends in drought frequency, duration, severity, and intensity based on standardised precipitation-evapotranspiration index (SPEI) between 1972 and 2019



Data source: NIWA

- Short and long-term drought became more frequent at almost half of all sites.

New Zealand's native plants typically have low drought resistance, and drought has caused the death of trees in all types of forest (Wyse, Macinnis-Ng, Burns, Clearwater, & Schwendenmann, 2013; Wyse, Wilmshurst, Burns, & Perry, 2018). Freshwater ecosystems can also be affected when less rain results in a reduced amount of stream habitat for fish and other freshwater species.

Long-term drought, such as that experienced in Reefton can be especially stressful for rural communities that rely on rain for drinking water, to grow crops, and water livestock (see figure 20). Urban areas can also be affected by drought. In summer 2020, widespread drought occurred in much of the North Island and parts of the South Island. Water storage dams for Auckland fell below half of their capacity and mandatory water restrictions were put in place. This is one of the most severe droughts to have occurred in this country since the early 20th century (NIWA, 2020).

EXTREME WIND HAS DECREASED ACROSS THE COUNTRY

Because New Zealand is a nation of islands in the roaring 40s, our country is frequently buffeted by strong winds. For 1980–2019, the annual maximum wind gust decreased at 11 of the 14 sites that had enough data to calculate a trend, and increased at 2 of the 14 sites (Gisborne and New Plymouth) (increases and decreases include both likely and very likely statistical trends). (See indicator: Extreme wind.)

The number of days where gusts were extreme for that location (was potentially damaging) decreased at 12 and increased at 2 sites. This observation is counter to climate projections that anticipate an increase in extreme wind speeds, especially in the South Island and the southern half of the North Island (MfE, 2018a).

The observed decrease in potentially damaging wind may be related to changes in the Southern Annular Mode (SAM), a climate oscillation that is associated with storm tracks being shifted towards or away from New Zealand. Since 1970, the wind belt has often been shifted to the south (the SAM has been in more positive phases), bringing an overall decrease in windiness over the country (see Climate varies naturally but natural variations may be changing too).

OTHER CLIMATE INDICATORS

Our climate is affected by, and affects, other indicators such as sunshine hours and carbon stocks in forests. These indicators were reported in *Our atmosphere and climate 2017* and have not been updated for this report.

Changes to the climate are changing the environment

OUR GLACIERS ARE MELTING

In 1997, the volume of ice in New Zealand's glaciers peaked for the 1977–2016 data record. (See indicator: Annual glacier ice volumes.) Only two decades later in 2016, 28 percent (15.5 cubic kilometres) of the ice had gone, enough to fill Wellington Harbour 12 times.

An unprecedented ocean-atmosphere heatwave in the summer of 2017–18 resulted in the loss of about 3.8 cubic kilometres of glacier ice in the Southern Alps. This was the largest amount of loss in a single year since 1962 (Salinger et al., 2019). New research has linked years with the highest levels of ice loss to human-caused greenhouse gas emissions, finding that global warming made the extreme ice loss observed in 2018 at least 10 times more likely (Vargo et al., 2020).

The volume of ice in New Zealand's glaciers is strongly influenced by temperature and snowfall. Changes to the accumulation and melting of ice affects the volume of water downstream, which influences the ecology and health of waterways. Water for hydroelectric generation, cultural values, tourism, and agriculture can all be affected.

SEA LEVELS ARE RISING

Sea level is rising as ice sheets and glaciers melt, and because water expands when it warms. New Zealand's mean relative sea level (based on four long-term monitoring sites in Auckland, Wellington, Lyttelton, and Dunedin) rose 1.81 (±0.05) millimetres per year on average since records began more than 100 years ago. (See indicator: Coastal sea-level rise.)

Not only are sea levels rising, but they are rising faster. The average rate of sea-level rise at the four sites for 1961–2018 was twice the average rate between the start of New Zealand records and 1960.

Globally, mean sea level has risen more than 7 centimetres in just 25 years according to satellite data. The loss of ice from the large Greenland and Antarctic ice sheets has accelerated the rate of global sea-level rise – the rate for 2006–15 was about two and a half times the rate for 1901–90 (IPCC, 2019).

OCEANS ARE WARMING

Water around the New Zealand coast warmed by 0.2 degrees Celsius per decade on average from 1981 to 2018 as measured by satellite. (See indicator: Sea-surface temperature.) Higher rates of warming were observed off the South Island's west coast in the Tasman Sea between 2002 and 2018 (Chiswell & Grant, 2018). Faster warming has also been recorded to the east of the Wairarapa coast since 1981, although the rate of warming varies. Less warming has occurred to the southeast of the South Island (Sutton & Bowen, 2019).

The rate of warming in the upper ocean has accelerated globally since 1991 (Cheng, Abraham, Hausfather, & Trenberth, 2019). There is growing evidence that only a small amount of sea-surface warming is needed to affect the stability of ice shelves in Antarctica, which could result in multi-metre rises in sea level over the coming centuries (Turney et al., 2020).

OCEANS ARE BECOMING MORE ACIDIC

Higher concentrations of carbon dioxide in the air is also making the world's oceans more acidic. About 30 percent of global human-emitted carbon dioxide was absorbed by the oceans between 1994 and 2007 (Gruber et al., 2019).

Ocean surface water has become 26 percent more acidic (a decrease of 0.1 pH units) since the beginning of the industrial era (IPCC, 2014a). Subantarctic waters off the coast of Otago became 7 percent more acidic in the 20 years from 1998 to 2017. (See indicator: Ocean acidification.) More acidic seawater can affect ocean biodiversity, particularly species like corals, shellfish, and coralline algae (Kroeker et al., 2013).

THE RISK OF WILDFIRES IS CHANGING

The cool, moist environment in many of New Zealand's forests is a natural barrier to burning. In one version of the legend, Mahuika the Māori fire deity, discovered this as she tried to preserve her sparks using the native rātā, hīnau, kahikatea, rimu, and miro trees without luck (Best, 1924). But when the weather is dry for long periods, bushfires can sweep through our forests and grasslands (Kitzberger et al., 2016).

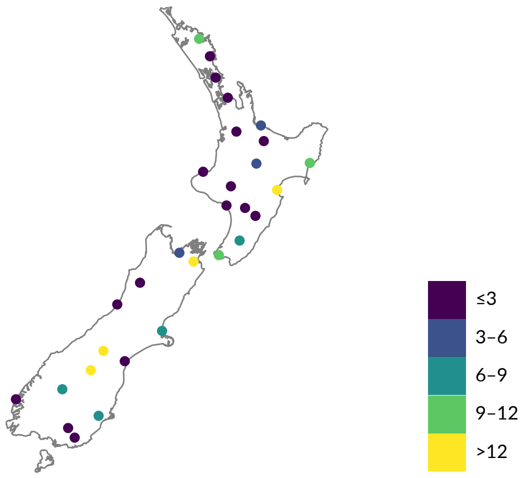
NIWA (National Institute of Water and Atmospheric Research) operates the fire weather system for Fire and Emergency New Zealand. Using four weather variables, fuel moisture data, and fire behaviour indices, fire danger in New Zealand is categorised into five levels: low, moderate, high, very high, and extreme. When fire danger is very high or extreme, large fire outbreaks are possible, and may require considerable effort to control.

For 1999–2019, 16 of the 30 sites had an annual average of 3 days or less with very high or extreme fire danger (see figure 22 and indicator: Wildfire risk). By contrast, Tara Hills, Lake Tekapo, and Blenheim all had an annual average of more than a month's worth of days per year with very high or extreme fire danger.

Six of 28 sites where trends could be calculated (Napier, Lake Tekapo, Queenstown, Gisborne, Masterton, and Gore) had a very likely increasing trend in days with very high or extreme fire danger between 1997 and 2019. Six sites (Blenheim, Christchurch, Nelson, Tara Hills, Timaru, and Wellington) had very likely decreasing trends.

Fire is still possible at places that do not have a large number of days with very high to extreme fire danger. Nelson and Dunedin, for example, have a relatively low yearly average (4 and 8 days per year, respectively for 1999 to 2019) compared to other sites, but had large wildfires nearby in 2019.

Figure 22: Annual average number of very high and extreme fire risk days, 1999–2019



Data source: NIWA

- **Tara Hills, Blenheim, Lake Tekapo, and Napier had the highest average number of days per year with very high or extreme fire danger.**

More bushfires could radically change our land. Unlike Australia, few New Zealand ecosystems have evolved with fire and most are not adapted to it. Most of our native trees cannot survive even a low-intensity fire (Tepley et al., 2018). Burned habitat can also affect many of our native animals.

The smaller trees and shrubs that are first to grow in burned spaces are also more prone to burning. Coupled with other factors like the loss of seed sources or invasive plants, burned forests may take centuries to recover, and recovery may be prevented in some areas (Tepley et al., 2018).

When vegetation is removed by burning, soil erosion increases. This can increase the risk of flash floods and affect water supplies by filling reservoirs with sediment and debris. Also, when soot from bushfires lands on snow and glaciers, it forms a dark layer that causes the absorption of more heat and faster melting.

The effects on air quality and human health can also be severe and occur far away from the fire itself. The Australian bushfires of 2019–20, for example, reduced visibility throughout this country and helped cause levels of tiny particles (PM_{10}) to exceed national air quality standards in four regions: Auckland, Bay of Plenty, Waikato, and Tasman (MfE, 2020a).

CLIMATE VARIES NATURALLY BUT NATURAL VARIATIONS MAY BE CHANGING TOO

The world's climate is influenced by natural patterns of change (oscillations) that operate globally or regionally on timescales ranging from months to millennia. New Zealand's weather and climate is most influenced by three oscillations: El Niño Southern Oscillation (with El Niño, La Niña, and neutral phases), Interdecadal Pacific Oscillation, and Southern Annular Mode (SAM). (See indicators: El Niño Southern Oscillation, Interdecadal Pacific Oscillation, and Southern Annular Mode.)

Although these oscillations are natural, they can be influenced by the greenhouse gases we are putting into the atmosphere. Recent work has found that El Niño events may be shifting – central Pacific El Niño events were more common in the past 30 years than any period in the previous 400 years. At the same time Eastern Pacific El Niño events were less frequent, but were more intense (the most intense in the 400 year record) when they did occur (Freund et al., 2019).

Models project an increase in strong Eastern Pacific El Niño events and the extreme weather they bring (Cai et al., 2018). More work is needed to pull out the recent trends from the long-term natural variations of this climate oscillation.

The SAM oscillation, which indicates how storm tracks shift towards or away from New Zealand, has been changing. Damage to the ozone layer has been associated with more positive SAM phases since 1970, which are associated with winds and storm tracks that are shifted away from this country. Recent research has found that this pattern has paused and slightly reversed since 2000 because the level of ozone is increasing (Banerjee, Fyfe, Polvani, Waugh, & Chang, 2020). Greenhouse gas emissions, however, continue to push SAM towards its positive phase and make future changes uncertain.

CHAPTER 4

Climate change and our wellbeing

Growing and harvesting potatoes.

Photo: photonewzealand

Our wellbeing and the things that matter most to us in life will be affected more and more by changes in the climate. We are only beginning to understand how wellbeing and climate change are connected.

Many of our activities produce greenhouse gases, which are changing the climate. These changes can affect the things that matter most to us in life. This is like when a house shifts on its foundations – the movement reduces the stability of the walls, roof, and plumbing and ultimately reduces the wellbeing and prosperity of the people who live in it.

Things that form the core of our wellbeing – our physical and mental health, a secure income, a pristine natural environment, even our identity – can be affected by changes to the climate.

In some areas, impacts on things that contribute to our wellbeing are already being observed. For example, the areas where some species live have shifted, including some species that are considered taonga. But in many areas, the ways climate change could affect various aspects of our wellbeing, like our mental health or security is only beginning to be explored in New Zealand.

Despite relatively little study to date, many of the things that contribute to our wellbeing are vulnerable to the environmental changes that are likely as the climate warms. Documented evidence as well as studies that give an indication of what to watch for, are presented here to show how wellbeing is already being affected or is likely to be affected in the future.

WELLBEING AND ASSESSMENT FRAMEWORKS

The people, places, and things that make a person feel safe, happy, healthy, and satisfied all contribute to wellbeing. Our wellbeing can suffer if the things that matter most to us are degraded. These could be health and happiness for ourselves and those we love, places that ground us and we draw identity from, or the feelings of purpose and hope that get us through tough times.

The New Zealand Treasury's Living Standards Framework identifies 12 domains that contribute to wellbeing, and is used by the Government to track changes in wellbeing. While there are other frameworks, components of the Living Standards Framework are used here to discuss both observed effects and expected changes to wellbeing. Although information is not currently available about how climate change affects every domain (housing for example) it is expected to affect all aspects of wellbeing in the future.

Living Standards Framework domains	Wellbeing component and section title
▸ Health ▸ Time use	**Health:** Health effects of climate change
▸ Income and consumption ▸ Jobs and earnings ▸ Housing	**Material:** Climate change impacts on material wellbeing
▸ Environment	**Environment:** Climate change threatens ecosystems
▸ Social connection ▸ Subjective wellbeing ▸ Cultural identity ▸ Knowledge and skills	**Social and cultural relations:** Our social and cultural relations are affected by climate change
▸ Civic engagement and governance ▸ Safety	**Engagement and governance:** Climate change is becoming part of the way we engage and govern

Health effects of climate change

WARMER WEATHER AND EXTREME EVENTS AFFECT PHYSICAL HEALTH

Higher temperatures affect people. For example, models indicate that when the temperature gets above 20 degrees Celsius in Christchurch and Auckland a total of 14 heat-related deaths occur per year in adults older than 65 years. Higher temperatures also have risks for those who work outdoors (Royal Society Te Apārangi, 2017). In some parts of New Zealand higher temperatures have been linked to an increased risk of Salmonellosis infection, and may lead to reduced food safety (Lal, Hales, Kirk, Baker, & French, 2016; Royal Society Te Apārangi, 2017). Warmer winters, however, may reduce winter illness and deaths but this has not yet been observed in New Zealand.

We can expect other health impacts that are related (at least in part) to climate change. Large-scale heatwaves have affected American and European populations during recent Northern Hemisphere summers. New Zealanders may experience similar events more regularly, with varying abilities to cope (Joynt & Golubiewski, 2019). Conditions that favour the introduction of disease-carrying species, like mosquitoes for dengue fever, are also a concern for health.

In 2019, the New Zealand Medical Association declared climate change to be a health emergency. This recognised the threats to health from higher temperatures and extreme weather, changing patterns of disease and potential social impacts.

A CHANGING CLIMATE CAN HAVE PROFOUND EFFECTS ON MENTAL HEALTH

Some people can experience feelings of hopelessness and frustration when the problem of climate change feels too big, too complicated, and completely overwhelming (Moser, 2009). These feelings of eco-anxiety or climate anxiety also relate to concern for future generations – as people become anxious about a climate disaster, their concern for the fate of their children and grandchildren increases (Albrecht, 2011). There is a growing awareness that young people are particularly at risk from eco-anxiety as they look at an uncertain future where their lives will be different to those of their parents and grandparents due to the effects of climate change (Fritze, Blashki, Burke, & Wiseman, 2008).

Experiencing severe weather events such as floods, storms, or droughts can be traumatic and can lead to anxiety and depression. People who are forced to move as a result of climate change have to leave familiar surroundings and in the process, break personal and cultural bonds, which can affect mental health (Stephenson et al., 2018)

The environment is at the heart of our identity as Kiwis – it shapes our economy, culture, and lifestyle. The degradation or alteration of familiar environments can therefore cause grief, a sense of loss, and anxiety. The impacts go further for some, with acute and chronic mental health effects that include strained social relationships, depression, suicide, substance abuse, loss of identity, as well as feelings of helplessness, fear, and fatalism (Clayton, Manning, Krygsman, & Speiser, 2017). These anxieties are likely to occur more often as awareness of the risks and consequences from climate change increases (Coyle & Van Susteren, 2011).

The effects on mental health were recognised by the New Zealand Psychological Society creating a Climate Psychology Taskforce in 2014. Its goal is to help practitioners address the anxiety, distress, depression, and post-traumatic stress that extreme weather and displacement can cause.

River forces a community to move tīpuna from a threatened urupā

When an encroaching river threatened their ancestral urupā (burial ground), a community near Wairoa took the difficult decision to dig up and move their tīpuna (ancestors) to a brand new site. So far 31 of the 53 tīpuna have been relocated.

“I could see the river coming closer and closer to our whānau. Initially I thought there was no way I was going to pick up our tīpuna and take them away, but the alternative was to see them floating down the river and I definitely didn’t want that,” says Karen Paku, Ngāti Kahungunu, who has been part of the team organising the move.

Natural movement and modifications to the riverbed have shifted the course of Te Wairoa Hōpūpū Hōnengenenge Mātangi Rau (Wairoa River) closer to Mātiti Urupā. Because it is situated on an outer bend of the river, the urupā is at a greater risk from ongoing erosion, particularly during larger floods. Despite wānanga (forums) with experts and research-based interventions such as building a barrier in the river and planting along the banks, the erosion continued.

“We realised that moving them was the only option. At that time we were quite scared that our tīpuna were going to be washed away so we had to move quite quickly. It was an anxious time because we couldn’t wait another winter – they were only about 4 metres from the river. It was really too close for comfort.”

A new urupā site near Huramua Marae was identified and the Huramua community came together to make the project happen. Different teams allowed people to work to their strengths in planning, fundraising, logistics, communications, and ahi kā (work behind the scenes including hospitality).

“We also had a cultural team who looked at what is tikanga (correct protocol) and the right way to do things. They taught us about opening a void with a karakia (prayer) for our tīpuna to travel along, how the neighbours beside the route would have to shut their gates to maintain the integrity of the void, and to use another karakia to close the void. This was to keep us all safe.”

Many family members came back home to be part of the process. “It was a great opportunity to reconnect and strengthen our ties. We also reconnected to our people who had passed on. The night before someone was moving, we would sit down and talk about who they were, what they did in their life, and tell some funny stories about them. It’s important to keep that alive so our people today realise who their tīpuna were.”

Moving the first tīpuna in April 2019.

Photo: Huramua Community

Karen's whānau were the first to move their taonga (treasured ones). They used diggers to excavate the site and placed the remains in large plywood boxes for transportation. "We first had to consecrate the new ground, so that morning we got up before the first light at 4.00am for a ceremony led by local Anglican and Catholic clergy and other hāhi (religious leaders). There was a light drizzle that made everything seem a bit surreal. It was a very moving time."

Now that her family are safe at the new site, Karen is continuing to work with the Huramua Marae Trustees to help others with moves. Some families with graves further from the river have decided not to move their tīpuna yet.

"For me, I feel relieved, happy, excited – all of that mixed together. And when it rains in the winter, I know we're all ok, we're safe."

Several other marae along the river are facing similar issues, and hundreds of coastal urupā are at risk from rising sea levels and increasing storm events. With this in mind, the moves from Mātiti to Huramua are being documented in written and video form. The information will be made available for others who face the same issues with their urupā.

The people of Huramua Marae would like to acknowledge and thank everyone who has contributed to the project, including Hawke's Bay Regional Council, J R McKenzie Trust, Department of Internal Affairs, Ministry for Culture and Heritage Te Manatū Taonga, Ministry of Health, Te Puni Kōkiri, Ministry for the Environment, Te Uru Rākau, Wairoa District Council, Evans Funeral Services, many local businesses, and the people of Wairoa district.

RECREATION CAN BE AFFECTED

Climate change may affect our access to coastal areas and the opportunity to spend our leisure time there in the future. Sea-surface warming for example, is associated with increased wave power that shapes the coast (Reguero, Losada, & Méndez, 2019). This, along with heavy rain, can increase erosion and the risk of slips like the one at Cape Kidnappers that closed a popular walking track in January 2019 and prevented public access to views of a large gannet colony.

Flooding, which is projected to increase with climate change, damaged some of New Zealand's iconic Great Walks in the summer of 2019–20, including the Milford and Routeburn tracks. It also delayed the opening of a new one, the Paparoa Track. Coastal flooding due to sea-level rise has put 331 Department of Conservation assets (2 percent) and 119 visitor sites at risk (Tait, 2019).

Fox and Franz Josef glaciers in Westland are retreating and have become too dangerous for tourists to be guided onto them from their bases. This has ended almost 100 years of glacier guiding from the valley floor (Anderson, Kerr, & Milner, 2016). Access to the glacier for a guided walk now requires a helicopter but this affects the wilderness experience, increases cost, and is more emissions-intensive. The long-term sustainability of these tours is now in doubt (PCE, 2019).

Climate change impacts on material wellbeing

FINANCIAL COSTS AND OPPORTUNITIES FROM CLIMATE CHANGE

The ability to provide for ourselves, our whānau, and our community is vital to our wellbeing. Many parts of the New Zealand economy are exposed to a changing climate.

In 2018, the Reserve Bank of New Zealand reported that our financial system is exposed to climate risks through the sectors it lends to and insures (RBNZ, 2018).

Between 2007 and 2017 it is estimated that the contribution of climate change to floods and droughts alone cost New Zealanders $840 million in insured damages and economic losses (Frame et al., 2018). In response, some insurers have already adjusted insurance products and pricing to account for emerging climate risks (RBNZ, 2018). Some insurance companies have moved to risk-based pricing where premiums are higher in areas that are prone to hazards such as floods or earthquakes (Horne, Frith, & de Pont, 2019). Insurance cover may become difficult or impossible to acquire and properties may become difficult to sell in locations that are vulnerable to climate risks, especially coastal areas (Storey et al., 2017).

Some economic opportunities also exist. Recent reporting found that for 2009–19, companies with low greenhouse gas emissions had higher valuations and better performance on the New Zealand Exchange than their high-emitting counterparts (Bowley et al., 2019). The impacts of climate change in other parts of the world could also create market opportunities for New Zealand's primary industries (Frame et al., 2018).

EFFECTS ON INFRASTRUCTURE AND BUILDINGS

Climate change is likely to cause severe effects on the infrastructure we rely on to support our daily lives and routines. Some communities are already having to contend with impacts.

In Wellington, summer heat in 2017 dried the ground and put stress on old, brittle water pipes. This caused a record number of leaks (Lawrence, Blackett, Cradock-Henry, & Nistor, 2018). High temperatures can also cause issues for rail networks. Temporary speed restrictions are used in some places as a precaution in the event that tracks become dangerously misaligned from the heat (Metlink, n.d.). The highest of high tides is also causing flooding in some locations even when there are no waves or storm surges (see King tides show possible future sea levels).

New information from agencies and local authorities is improving our understanding of how sea-level rise may affect assets, communities, and businesses. With a sea-level rise of 0.5 metres for example, an extra 48,900 people (about the population of Nelson), 36,000 buildings, and 350 square kilometres of land across the country would be exposed to flooding during extreme events (Paulik et al., 2019).

PRIMARY INDUSTRIES ARE VULNERABLE TO INCREASED WEATHER EXTREMES AND CHANGING CONDITIONS

Because of their reliance on the environment, New Zealand's primary industries (including farming, forestry, and horticulture) are sensitive to changes in climate. While extreme events such as droughts, rainstorms, and heavy snowfalls can have devastating effects, other changes like alterations to the growing season are starting to be documented.

In interviews, kiwifruit growers noted longer and more variable spring weather. Changes in temperature and humidity over the course of a growing season can change the size, shape, and taste of fruit and affect the price a grower receives (Cradock-Henry, 2017).

Modelling found that almost half of the variability in annual pasture production was linked to the climate. Climate shifts towards the end of this century are likely to result in higher yields, with a shift in pasture production towards spring, but also higher risk of heat stress for animals and increasing water limitation (Ausseil et al., 2019).

Sauvignon Blanc grapes were expected to mature about two weeks earlier than normal in the 2017–18 growing season because of high summer temperatures. Flowering occurred in a shorter period and fruit set was exceptionally successful – this delayed the harvest (Salinger et al., 2019). These changes are in line with recent modelling that projects earlier flowering dates for wine grapes towards the end of the century (Ausseil et al., 2019).

Fish stocks are influenced significantly by variations in climate (see *Our marine environment 2019*). Fishing is a valuable part of our economy, and in 2019 New Zealand's commercial fish stocks were valued at $10.4 billion (Stats NZ, 2020a). There is evidence that warmer seas in summer are affecting fish – the reproduction of some species (such as snapper and hoki) appears to be affected by sea-surface temperature (MPI, 2017).

The impacts of climate change on fish stocks is a concern for New Zealand's fisheries and for Māori in particular. Māori own about 40 percent of the national fisheries quota and rely on the ocean for food through customary fishing (King, 2015).

The marine heatwave of 2017–18 was associated with the death of many salmon grown by aquaculture in the Marlborough Sounds (Salinger et al., 2019).

Climate change threatens ecosystems

ECOSYSTEMS ARE VALUABLE AND CONTRIBUTE TO WELLBEING

New Zealand's ecosystems are unique and have incomparable value. They also contribute to our wellbeing by providing benefits that range from the tangible (like drinking water) to the ethereal (like the melodious song of a bellbird). We also gain cultural benefits from nature, like a sense of identity and connection to place. The loss of biodiversity, especially taonga species, can negatively affect our wellbeing through changes or loss of culture, traditional practices, and language.

ABNORMALLY HIGH TEMPERATURES ARE DISTURBING NATIVE SPECIES

Native plants and animals are exposed to changes in the environment and although their resilience varies, many are already being affected by higher temperatures.

In the marine environment, high sea-surface and land temperatures and low wave heights during the 2017–18 marine heatwave led to the complete loss of rimurapa (bull kelp, *Durvillaea*) at some reefs in Lyttleton and a significant loss at four other sites. Rimurapa is a crucial part of the marine ecosystem. At the site where the kelp was lost, the invasive seaweed *Undaria* took its place and a dramatic decrease in mussels was observed (Thomsen et al., 2019). Rimurapa is a taonga species for South Island Māori. It is traditionally used to make pōhā (kelp bags) to preserve and transport tītī (mutton bird). In the past pōhā were also used to steam shellfish, carry water, and as flotation devices when inflated.

In Lake Wānaka, warmer surface water temperatures are likely to have contributed to a shift in the populations of phytoplankton to a species that prefers warmer temperatures. (Phytoplankon are microscopic algae that form the base of the food web). Higher temperatures have also allowed a non-native phytoplankton to survive winter in the lake (Bayer, Schallenberg, & Burns, 2016).

A changing climate can make other stresses worse. On Otago Peninsula, a study found that warming seas contributed to a reduction in the survival rates of hoiho (yellow-eyed penguins) – probably by reducing the number and size of the fish they feed on. Other factors including disease outbreaks, predators, and tourism also have a role in their declining population. If sea-surface temperatures remain high, conditions may limit the ability of the penguins to recover (Mattern et al., 2017).

Impacts like these are expected to continue in the future. A warmer climate, for example, may cause some native fish species to be lost from places they once inhabited. Alpine galaxias are native to mountain streams but are sensitive to temperature and cannot live in water that is too warm (Boddy & McIntosh, 2017). In the Waikato River, īnanga (one of the species caught as whitebait) were found to be smaller in spring and summer when the water was warmer (Goodman, 2018). Īnanga are an iconic species for New Zealanders and a taonga species for Māori.

CLIMATE CHANGE IS REDUCING THE AREAS WHERE SOME SPECIES CAN LIVE

There is some early evidence that the warming climate is affecting the ranges of some species. For example, the altitude range of two wētā species on Mount Taranaki moved higher, due in part to warmer temperatures. Their range is also determined by competition with other wētā (Bulgarella, Trewick, Minards, Jacobson, & Morgan-Richards, 2014).

Sightings of tropical and warm-water fish that are usually seen only in warmer water, were reported in New Zealand seas during the marine heatwave of 2017–18 (Salinger et al., 2019).

As the temperature continues to warm, it is likely that the areas where some species can live will be squeezed. Many native birds have already retreated into cooler parts of their former habitats because there are more predators (like possums, rats, and stoats) in the warmer lowland forests. As the area of cooler forests shrinks, the pressure from predators will increase further. Large birds like kiwi, whio and North Island kōkako are particularly at risk because of their limited ability to move into new areas. Kākā and kea, as well as smaller cavity-nesting birds like kākāriki, may be threatened too (Walker, Monks, & Innes, 2019).

EXTREME EVENTS ARE AFFECTING BIODIVERSITY

Droughts and floods are projected to increase in many parts of the country (see chapter 5: Looking ahead: future emissions and climate). Droughts have been found to dramatically decrease the body size of kōwaro (Canterbury mudfish), which have a conservation status of threatened (nationally critical) (Meijer, Warburton, Harding, & McIntosh, 2019). Droughts and floods have also been shown to affect breeding in īnanga (Goodman, 2018).

Flooding in 2009 reduced a population of scree skinks in the Canterbury high country by 84 percent. This lizard has a conservation status of nationally vulnerable. It took about 8 years for the population to recover naturally (Lettink & Monks, 2019).

TREE MASTING IS AFFECTED BY CLIMATE CHANGE

Masting occurs when trees produce and spread a large number of seeds in some years. A study in the Northern Hemisphere found that climate change eliminated the benefit that beech trees get from seed masting. European beech trees in England had more regular mast events – this benefited some of the animals that feed on the seeds because food was produced more regularly, and their populations increased. The larger number of animals eliminated any benefit to the trees from the masting strategy because there were more of them to eat the seed before it could grow into trees (Bogdziewicz, Kelly, Thomas, Lageard, & Hacket-Pain, 2020).

New Zealand trees like beech use the same masting strategy and some species including kākāpō cue their breeding around mast events. At higher elevations in the South Island, increased rainfall and warmer temperatures in summer have been linked to greater seed production from beech trees (Allen, Hurst, Portier, & Richardson, 2014). Years with large mast events are linked to higher numbers of introduced predators. This increases predation on native species and can require significant human intervention and resources to control.

Our social and cultural relations are affected by climate change

A SENSE OF IDENTITY AND CONNECTIONS CONTRIBUTE TO WELLBEING

The ability to express our identity and connect with others has a strong bearing on our overall wellbeing. Many things besides climate contribute to these aspects of wellbeing, which makes it difficult to isolate the effects of climate change. However, the strong interconnections between environment, identity, and social connection (particularly for Māori), make it likely that changes to the environment will also affect these aspects of our lives.

EFFECTS OF CLIMATE CHANGE ON MĀORI CULTURAL IDENTITY

The phrase mai i ngā maunga ki te moana, from the mountains to the sea, describes the range of effects that climate change is having on weather and temperature in New Zealand. The changes are having direct and indirect negative effects on Māori – from the loss of physical structures and resources, to impacts on the spiritual, physical, intellectual, and social values that are integral to the health and wellbeing of Māori identity.

When culturally significant land, taonga (treasured) species, and mahinga kai (food gathering sites) are lost or damaged due to changes in the climate, it severs the ancestral relationships that tangata whenua (people of the land) share with a place and a resource. It also affects tūrangawaewae, (place where one has the right to stand), mātauranga (knowledge), and tikanga (customs) that are linked to Māori culture and sense of being (Bond, Anderson, Henare, & Wehi, 2019; Te Hiku o te Ika Development Trust, 2018).

CLIMATE CHANGE IS AFFECTING THE ENVIRONMENT AND MAKING SEASONAL TOHU LESS RELIABLE

Māori are observing many changes in the environment. People from Te Waipounamu (South Island) report changes that include more frequent long summers and mild winters. Along with much of the rest of the country, temperatures have increased in the Murihiku (Southland) region. This is likely to have contributed to profuse flowering of Southern rātā (*Metrosideros umbellata*) on Motupōhue (Bluff Hill) that in turn caused bird and pest populations to expand rapidly (Skipper, 2018).

Because of local changes in climate, tītī (sooty shearwaters, a taonga species) are having to fly further to find food and are therefore away from their chicks for longer periods. Kingfish are also being caught in greater numbers along the east coast of Te Waipounamu. This species was unknown to early Ngāi Tahu (a South Island iwi). Kiwifruit are now grown in Invercargill, which was not known to be possible 30 years ago (Skipper, 2018).

In the far north of the North Island, one fisher noted, “Everything has its time… there’s time for fish, there was time for oysters, time for mussels. And it never altered until recently. I realised about two years ago things are changing. Things [plants] are blooming out of season. Fishing is all out of kilter. Mullet never came till winter and now you’ve got mullet coming any old time, sort of thing. It’s really changed.” (Te Hiku o te Ika Development Trust, 2018).

Believed to be due to changes to the climate, some tohu that have been used for generations can no longer be used in the same way (Skipper, 2018) (see Tohu and maramataka: observing and tracking changes in the environment). Changes in sea temperatures for example mean that kina are no longer fat and ready for the table when pōhutukawa traditionally bloom in summer (see *Our marine environment 2019*). What was once normal like gathering a feed of kina with whānau at Christmas time – is at risk of becoming a thing of the past.

CULTURALLY SIGNIFICANT PLACES ARE AT RISK

Places of special significance such as marae (meeting places) and urupā (burial grounds) situated near the coast or on floodplains are at increasing risk of flooding from sea-level rise and erosion (Deep South National Science Challenge, 2018).

Numerous Māori cultural heritage sites are situated in coastal low-lying areas. These places are deeply connected with Māori identity but are especially exposed to impacts from climate change because of their location (CCATWG, 2018). Hundreds of coastal urupā across the country are threatened by rising seas and more severe storms.

Some iwi are already experiencing these effects first-hand. At Ōkūrei Point in Maketū, a sacred burial site on a cliff-top collapsed onto the beach below, scattering human remains into the sand and sea. The site was possibly pre-European, dating back to the 1300s and one of the first burial sites in the area (Office of the Māori Climate Commissioner, 2019). In other areas, urupā at risk from flooding have had to be relocated (see River forces a community to move tīpuna from a threatened urupā).

EFFECTS ON TAONGA SPECIES ARE BEING REPORTED

Climate change is affecting our environment and the species that live here. Taonga species such as tuna (eels), kōura (crayfish), and kākahi (mussels) are central to the identity and wellbeing of many Māori. For generations these species have been the source of physical and spiritual sustenance for whānau, hapū, and iwi, and helped transfer customary practices and knowledge from one generation to the next.

Many communities are reporting that both the abundance and size of their taonga species are declining. South Island iwi Ngāi Tahu ki Murihiku noticed that the quality and health of tītī and tio (oysters) had declined substantially and that the decline seemed to be occurring in cycles aligned with the El Niño Southern Oscillation (MAF, 2011b). Recent research indicates that climate change may be having an effect on El Niño events (Freund et al., 2019).

In some parts of Te Waipounamu rivers are drying up in summer and causing stress or even loss of taonga species. Mahinga kai areas are also disappearing (Skipper, 2018).

In Horowhenua, Ngāti Raukawa ki te Tonga have noticed a decline in tuna, one of their most prized taonga. Anecdotal evidence and a decrease in the quantity and quality of the resource encouraged hapū to research the health and habitat of the tuna population. The research points to climate change affecting ocean currents, habitat, and the tuna food chain, all of which have an effect on the species' sensitive life cycle (MAF, 2011a).

MĀTAURANGA MĀORI COULD BE LOST

Mātauranga Māori is knowledge in its broadest sense. It is part of Māori culture, linked to Māori identity, and is considered by some as a unique part of the identity of all New Zealanders (Mead, 2012).

For many coastal communities, traditional mahinga kai customs such as collecting tītī with whānau, shelling mussels around the table with cousins, and setting the hīnaki (trap) to catch tuna with koro (grandad), are all treasured activities. They are deeply rooted in mātauranga, which connects whānau, hapū, and iwi to their tīpuna (ancestors).

Muttonbirding is one example. Hana Morgan, Awarua rūnanga chair said, "The minute I'm back on the Tītī Islands it's like … 'I'm back! I'm home again' … we think of our ancestors … they walked these tracks … we are not alone and you know that, and that's why it's so special." (Skipper, 2018).

Māori use te reo (Māori language) to express mātauranga and their perception and understanding of the physical environment – how it functions in part and as a whole (Harmsworth & Awatere, 2013; New Zealand Waitangi Tribunal, 2011). As renowned Ngāpuhi leader Sir James Henare said, "ko te reo te mauri o te mana Māori", the language is the core of our Māori culture and mana (New Zealand Waitangi Tribunal, 1989).

Because te reo is often closely associated with a place, there are risks to the integrity of te reo, tikanga (customs), and the intergenerational transfer of mātauranga from sea-level rise and the displacement of iwi or hapū who live near the coast.

Climate change can contribute to degradation in the mauri (life force) of ecosystems and taonga species, and jeopardise the mātauranga associated with them. When a taonga species is lost, the whakapapa (lineage or ties) between iwi, hapū, whenua (land), and taonga is severed.

The ability of tangata whenua to act as kaitiaki (guardians) over the taonga, and to engage in mahinga kai practices within their rohe (region) can also be degraded. Te reo me ngā tikanga (language and customs) and interactions between generations to share the mātauranga can also be reduced (MAF, 2011a).

Some whānau already feel that mātauranga related to traditional practice is in danger of being lost forever (Skipper, 2018).

MANAAKITANGA IS THREATENED BY CLIMATE CHANGE

Manaakitanga describes the responsibility of a host to care for whānau and manuhiri (visitors) through nurturing relationships and by providing shelter, food, and resources. The word is derived from mana-aki-tanga, meaning to behave in a way that enhances mana, with actions reflecting the prestige and authority of a whānau, hapū, or iwi.

For Māori, manaakitanga is a way of life that can be shown in many ways. In homes, workplaces, and everyday interactions, Māori people take great pride in caring for the wellbeing of others. Manaakitanga is especially important on a marae as the following whakatauākī shows, "Tangata takahi manuhiri, he marae puehu. A person who mistreats his guest has a dusty marae."

Tangata whenua usually do all they can to show generosity and kindness to their guests by sharing stories, singing waiata, and treating them to the local delicacies for which their area is known. Pāua (abalone), kina (sea-urchin), tuna, tītī and wild pork are all examples.

Climate change is likely to affect marae and customary harvesting grounds, and cause major shifts in how whānau practice manaakitanga. Coastal marae may become inaccessible due to increased flooding. A loss of taonga species would mean whānau were no longer able to provide local delicacies to manuhiri. A combination of these situations could see some whānau unable to manaaki on their marae as they have for generations. The inability to gather kaimoana also has economic consequences because this practice has always supplemented low incomes and diet (Patuharakeke Te Iwi Trust Board Inc, 2014).

ALL THESE CHANGES AND LOSSES ADD UP

As the climate continues to change, seasonal tohu become less reliable, places of special significance are affected, taonga species face increased risk of extinction, te mātauranga me ngā tikanga (knowledge and customs) are lost, and risks to the unique Māori values at the heart of our society grow.

Rising sea levels and flooding are threatening to inundate all 14 marae of an iwi in the north. Iwi in the east talk about soil erosion and roads being washed away. Iwi in the south talk of the health of tītī declining, and iwi in the west also talk about flooding (Climate Change Iwi Leadership Group, 2016).

Around the world, climate change poses threats and dangers to the survival of other indigenous communities (United Nations, 2007). Because of their dependence on and close relationship with the environment and its resources, indigenous people are among the first to be directly affected by climate change (United Nations, n.d.).

Climate change is expected to worsen the difficulties that are already being faced by indigenous communities. These include political and economic marginalisation, loss of land and resources, human rights violations, discrimination, and unemployment (United Nations, n.d.). All these interacting challenges will test the resilience, adaption, and survival of Māori and indigenous communities more than ever before.

Māori identity and wellbeing is threatened by climate change

Te whenua, te wai, and taonga species are being affected by climate change, which threatens traditional practices connected to Māori identity and wellbeing.

The timing of tohu are changing

Traditional tohu are used to help forecast changes in the natural environment. They are becoming less reliable, and this is affecting planting, daily decision-making, and activities like resource gathering and hunting.

Culturally significant places are at risk of being damaged

Many marae and urupā are threatened by flooding and erosion from sea-level rise and extreme weather events.

The loss of taonga species

Taonga species are central to Māori identity and wellbeing. A warming climate is affecting where some species can live, their numbers, and size.

Ability to manaaki is threatened

Manaakitanga is a way of life and is especially important on marae where local delicacies are offered generously to manuhiri. Climate change threatens the reliability of tohu, abundance of kai, and sometimes the marae itself.

How Māori wellbeing is connected to te taiao

Taha tinana: physical wellbeing
- rongoā
- mahinga kai

Taha wairua: spiritual wellbeing
- karakia
- waiata

Taha hinengaro: mental wellbeing
- mātauranga
- tikanga

Taha whānau: social wellbeing
- manaakitanga
- whanaungatanga

Adapted from Durie, 1985

Mātauranga may not be passed on

Losing traditional resources from the moana, awa, and ngahere is not just a loss in the present. It affects future generations because the tikanga and mātauranga Māori associated with the resource and the practices around its harvest and use would also be lost.

Glossary

awa: river | **kai:** food | **karakia:** prayer | **mahinga kai:** food gathering place | **manaakitanga:** the practice of hospitality | **manuhiri:** visitors | **marae:** cultural gathering centre | **mātauranga:** knowledge | **moana:** ocean | **ngahere:** forest | **rongoā**: medicinal plants | **taonga species:** treasured species | **tikanga:** customary protocols | **tohu:** environmental indicator | **urupā:** burial grounds | **wai:** water | **waiata:** songs | **whanaungatanga:** socialisation | **whenua:** land

Climate change is becoming part of the way we engage and govern

EFFECTS ON COMMUNITIES AND LOCAL GOVERNMENT

Wellbeing is enhanced when we feel we have a say in the institutions and decision-making that governs our day-to-day lives. Climate change can create difficult trade-offs and raise new legal and ethical questions that society and governing institutions need to grapple with.

Many regions, cities, and towns are now incorporating the current and projected impacts of climate change in their planning. In Hawke's Bay for example, planning has begun to understand the risks and management options for dealing with coastal hazards, including sea-level rise. More resilient communities can be created by consulting with people early and developing options for managing the effects before they are needed (HBRC, 2016).

NATIONAL SECURITY

All aspects of wellbeing are threatened by a reduction in safety and security. Preparations for potential climate-related effects have already begun in this country.

The Ministry of Defence, for example, has identified climate change as "one of the greatest security challenges for New Zealand Defence in the coming decades". The Defence Force has already begun planning for more humanitarian, disaster relief, and stability operations in the Pacific region to help New Zealand's Pacific Island neighbours who will be increasingly affected by rising sea levels, drought, and stronger tropical cyclones (MoD & NZDF, 2019).

Rising seas have already immersed at least eight low-lying islands in the Pacific Ocean. Migration caused by climate change is inevitable, and will affect the people who are displaced as well as the communities where they eventually resettle. (MoD & NZDF, 2018).

CLIMATE CHANGE RAISES LEGAL QUESTIONS

Local authorities must disclose hazard information on property land information memorandums (LIMs), including "any information they have about the implications of sea-level rise and coastal processes" (MfE, 2017). Both disclosure and failure to disclose this information can create legal issues for councils, which puts them in a difficult situation. In 2012, the Kāpiti Coast District Council placed information on projected erosion hazard risk on LIMs for properties deemed to be at risk from future sea-level rise. Following a legal challenge that contested the accuracy of the analysis and the adequacy of a public consultation process, the council removed the information (Filippova, Nguyen, Noy, & Rehm, 2019).

Other legal risks are increasingly experienced by company directors for not considering climate change risks alongside other financial risk because it "presents a foreseeable risk of financial harm to many businesses". Climate change litigation has also been increasing. In 2019, court proceedings were filed against seven New Zealand companies seeking injunctions to reduce their emissions (Chapman Tripp, 2019).

CLIMATE CHANGE RAISES ETHICAL QUESTIONS

Questions about allocating the costs related to sea-level rise are complex: who is responsible when buildings or homes become uninsurable, or people have to retreat from living close to the sea? There are also questions about the duty of councils to their communities: what level of engagement is sufficient to ensure the public has a voice in how they adapt for a climate-changed future? Further questions about intergenerational equity arise: what costs should people alive today be allowed to impose on future generations?

CHAPTER 5

Looking ahead: future emissions and climate

Fire on the Port Hills, Christchurch in February 2017.

Photo: Mark Hannah Photography

Temperature in New Zealand and globally is expected to continue to increase. Large reductions to emissions are needed to limit future warming.

Human activities have already caused the world's average temperature to rise by about 1 degree Celsius above its pre-industrial level. At the current rate of increase, global average temperature is likely to be 1.5 degrees Celsius above the pre-industrial level in the next 10–30 years.

Globally, high rates of greenhouse gas emissions are expected to continue. Deep cuts to global net carbon dioxide emissions would be needed (45 percent below 2010 levels by 2030, and net zero by 2050) to hold warming to below 1.5 degrees Celsius.

In New Zealand, greenhouse gas emissions are projected to decrease in the coming decades, but not at a fast enough rate to meet our 2030 goals under the Paris Agreement.

As the climate warms, profound changes are expected in New Zealand. Temperature is projected to increase across the country particularly in summer and autumn. Extreme rainfall, drought, and wildfire risk are expected to increase in many places.

Continued sea-level rise will put large amounts of coastal infrastructure at risk. Our oceans will continue to warm and acidify.

How emissions are projected to change

GLOBAL EMISSIONS AND REDUCTION TARGETS

How much more the climate changes in the future depends on how much more greenhouse gases the world adds to what is already in the atmosphere (IPCC, 2014a).

Globally, greenhouse gas emissions continue to rise. Before the COVID-19 pandemic, there was no sign of emissions peaking in the next few years. Worldwide, lockdowns in 2020 did reduce emissions, but because the reductions to date have not come from structural changes to our economic, transport, or energy systems, they are likely to be temporary (Le Quéré et al., 2020; UNEP, 2019) (see COVID-19 and greenhouse gas emissions in chapter 2).

There is a large and growing gap between projections of emissions (that continue to rise) and the level of emissions required to be tracking on the least-cost pathways to limit warming to 2 or 1.5 degrees Celsius above pre-industrial levels. To limit warming to 2 degrees Celsius, total global emissions must be about 25 percent lower than 2018 levels by 2030. To limit warming to 1.5 degrees Celsius, emissions must be about 55 percent lower by 2030 – this would require countries to increase the stringency of their Paris Agreement reduction goals fivefold (UNEP, 2019).

To limit warming to 1.5 degrees Celsius, net emissions of carbon dioxide globally must be at zero by 2050. Big reductions in other greenhouse gases would also be needed. If the global community settles for keeping warming to no more than 2 degrees, these reductions could be delayed by about two decades, but cannot be avoided (IPCC, 2018).

There are many different options for achieving these reductions and each country will develop its own mix. The scale of reductions needed will require profound changes to the way food, energy, and the goods and services we rely on are produced and supplied. According to the United Nations Environment Programme, transforming societies, economies, and governance institutions will require unprecedented efforts. The longer we delay in making the reductions, the deeper and faster they will have to be (UNEP, 2019).

NEW ZEALAND'S EMISSIONS AND REDUCTION TARGETS

Models of future greenhouse gas emissions in this country are used to report projected emissions under the United Nations Framework Convention on Climate Change.

These models indicate that 'with existing measures and policies', New Zealand's net greenhouse gas emissions are projected to peak in the mid-2020s before decreasing (see figure 23). The projected decrease is due to replanting forests that were harvested in the early 2020s and establishing new forests (MfE, 2019). These plantings will not reduce emissions unless the wood is preserved in long-lasting products like house framing after harvest.

The latest modelling was published in 2019 before the COVID-19 pandemic response. It therefore does not reflect changes to the economy or COVID-19 response policies that may alter future emissions.

Gross greenhouse gas emissions are projected to remain steady through the early 2020s and decrease by 11 percent by 2035. Emissions in 2035 would be 10 percent above New Zealand's gross emissions in 1990, but 10 percent less than with no measures to mitigate emissions (MfE, 2019).

Carbon dioxide emissions from transport are projected to be 14 percent lower in 2035 than levels estimated for 2020. Because vehicles are replaced slowly in this country, it will take longer here for the effects of improved fuel efficiency and more electric vehicles to affect our emissions than in other countries (MfE, 2019).

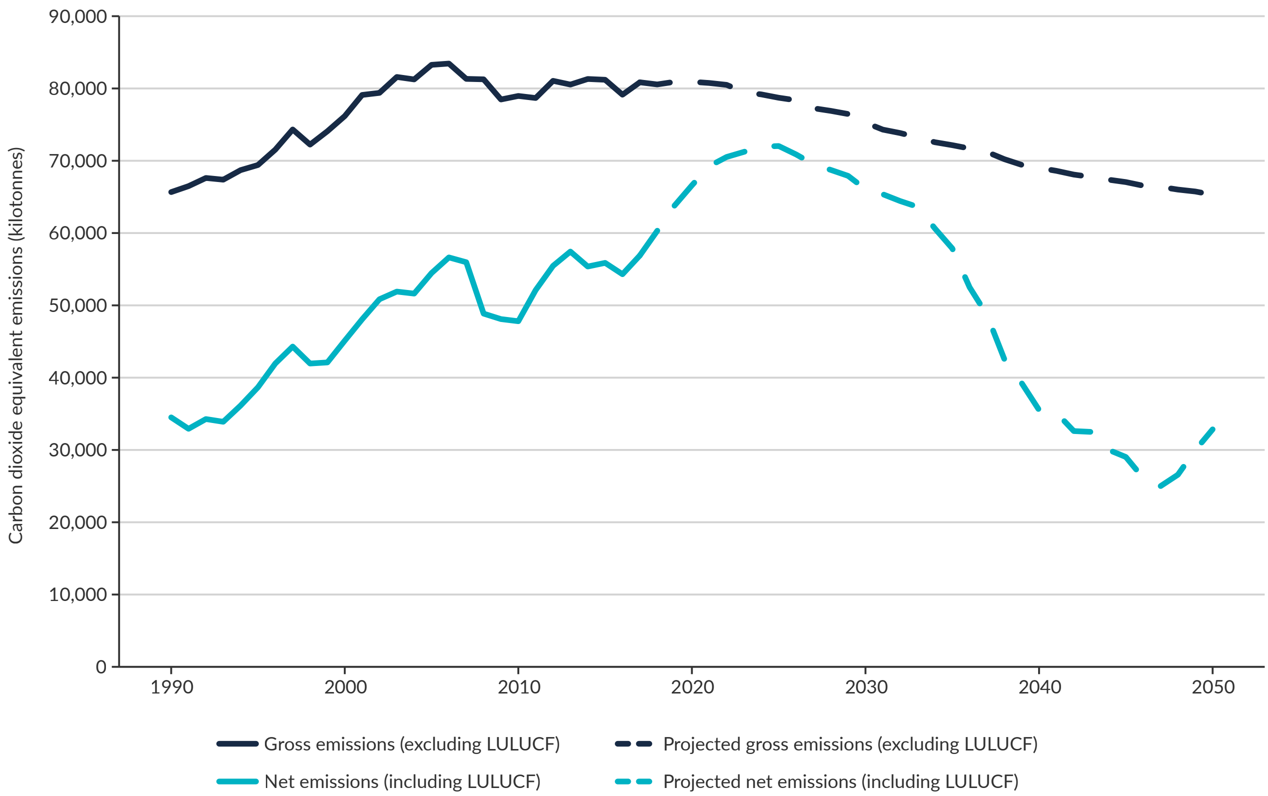
Gross emissions of methane are projected to be about 7 percent lower in 2035 than in 2020, and gross emissions of nitrous oxide are projected to be 7 percent lower (MfE, 2019).

To give the world a reasonable chance of limiting global warming to 1.5 degrees Celsius, the IPCC has calculated that net carbon dioxide emissions need to be brought to zero by 2050 globally. Agricultural methane emissions need to be reduced at the same time by about 24–47 percent relative to 2010 levels (IPCC, 2018). This global-scale information was used by New Zealand in 2019 to inform the domestic targets set in the Climate Change Response (Zero Carbon) Amendment Act.

New Zealand has committed to reduce its emissions by 30 percent relative to 2005 levels by 2030 under the Paris Agreement. This is our nationally determined contribution (NDC) – our country's ambition or target for reducing emissions. To achieve this emission reduction goal, there is a limited amount (or budget) of greenhouse gases that New Zealand can emit into the atmosphere between 2021 and 2030. Projections are that under current policies, cumulative emissions, and removals of all greenhouse gases over this period will be 707 million tonnes, which is 18 percent higher than the emissions budget set through the NDC of about 601 million tonnes (MfE, 2020b). (The NDC specifies that this budget can be met by actions in New Zealand, but international carbon markets can be used additionally.)

More information about New Zealand's greenhouse gas emission projections and progress towards the emissions targets is available from New Zealand's Fourth Biennial Report under the United Nations Framework Convention on Climate Change.

Figure 23: New Zealand's gross and net greenhouse gas emissions
from 1990–2017, with projections to 2050



Data source: New Zealand's Fourth Biennial Report under the United Nations Framework Convention on Climate Change

Note: The gross and net emissions (including land use, land-use change, and forestry – LULUCF) projections to 2050 were prepared using New Zealand's 2019 Greenhouse Gas Inventory 1990-2017 data.

- New Zealand's emissions are projected to decrease with existing measures.

ACTIONS TO REDUCE EMISSIONS WILL AFFECT OUR EVERYDAY LIVES

As well as a changing climate, we can expect to experience effects from the ways we address our emissions. The actions we take (or don't take) will affect many parts of our lives – including the economic, social, and cultural systems we participate in every day. Some parts of our economy will incur losses during a transition to a low-emissions future even if it is fair and well-planned. New opportunities and positive changes will also occur, such as savings in energy costs, improved health, cleaner air, reduced traffic congestion, and benefits for biodiversity (MfE, 2018b).

The longer the world delays emission reductions, the steeper and faster the reductions must be to stay in the agreed temperature range. Delayed reductions also cause faster short-term climate change with greater impacts to people and the environment, including our native biodiversity. Delays give us less time to adapt to the changes. Later reductions may defer costs in the near-term but have potentially higher costs and risks, and less flexibility in how we make the rapid reductions when they can no longer be deferred (IPCC, 2018).

How climate is projected to change

PROJECTIONS FOR FUTURE GLOBAL CLIMATE

The disturbance of climate change is not like a recession where a recovery eventually returns the economy to the level it was at before. Adding long-lived greenhouse gases to the atmosphere is like turning a ratchet. Stopping these emissions today would stop the ratchet from turning further, but because the gases will stay in the atmosphere for centuries or more, the ratchet will not be unwound. Even with no more carbon dioxide emissions, we will not go back to an undisturbed climate or even the climate we grew up with.

Climate models and projections

Sophisticated computer models are tools that are used to explore what may happen to the climate in the future. They are based on the laws of physics and maths and equations that describe the dynamics of the climate system.

Future climate scenarios are called projections rather than predictions, as they are only indications of what we can expect, rather than specific forecasts. The scenarios are generally based on different concentrations of greenhouse gases in the atmosphere and calculate the warming and other environmental effects they are likely to cause. Projections usually include scenarios that assume a rapid reduction in emissions as well as scenarios that assume a continued rise in emissions for the rest of the century.

Information about Earth's climate in the past is used to improve our understanding of the climate system and to test and improve climate models. The climate has changed naturally over millions of years, with ice ages and warm periods occurring. Records of these changes (including the concentration of carbon dioxide present in the atmosphere at the time) are laid down in sediments and ice and can be collected by researchers, including New Zealand teams studying the seafloor off Antarctica. This information gives us increased confidence in the outputs of the climate models.

Climate research has shown that the last time carbon dioxide levels were as high as they are now was about 3 million years ago and temperatures were 1.8–3.6 degrees Celsius warmer than in pre-industrial times (Burke et al., 2018). At this time trees grew in Antarctica and seas were at least 20 metres higher (Grant et al., 2019; Rees-Owen et al., 2018). This information cannot be used as a straightforward guide to the future, but it helps us better understand the impacts from changes that are similar to those happening now.

Short-lived gases with strong warming effects (such as methane) also contribute. Emissions of these gases make the climate warmer in the short term, and add to the total amount of warming the world experiences.

It is estimated that human activities have caused the world's average temperature to rise by about 1 degree Celsius above its pre-industrial level. At the current rate of increase, the global average temperature is likely to reach 1.5 degrees Celsius above the pre-industrial average temperature between 2030 and 2052. A rise of 3.4 to 3.9 degrees Celsius is projected by the end of the century if current policies continue (IPCC, 2018; UNEP, 2019).

Even if all the current emissions reduction commitments and goals (conditional and unconditional) are met by the international community, the average global temperature is likely to be 3 degrees Celsius warmer than the pre-industrial temperature by the end of this century (IPCC, 2018).

This amount of warming is projected to increase the likelihood of severe, pervasive, and irreversible impacts for people and ecosystems (IPCC, 2014a). Heatwaves and extreme rainfall are projected to become more frequent and intense in many places. Average global sea level is expected to continue to rise and at a faster rate, for many centuries. Ninety-nine percent of tropical corals could be lost with warming of 2 degrees Celsius (IPCC, 2018).

It is virtually certain that the extent of permafrost will decrease. Previously frozen areas may then start emitting carbon dioxide and methane, which would contribute to more climate change. (This is known as a positive feedback loop.) Irreversible changes such as species extinctions and melting of the Greenland ice sheet are also expected (IPCC, 2014a).

Recent research has found that most communities around the world can expect to soon experience climates that are more similar to a different city than their own current climate. For example, in 2050 the climate of Auckland is projected to be more similar to that of Sydney in 2020 than it is to its climate today (Bastin et al., 2019). By 2060 (about the time when a 25-year-old today will be retiring) most of the world's population can expect an average climate that is unfamiliar to them now. What is expected to be a normal climate in 2060 is so extreme that it would occur only once every 44 years on average today (Frame, Joshi, Hawkins, Harrington, & De Roiste, 2017).

More information about global climate change, risks, and impacts is available from the Intergovernmental Panel on Climate Change (IPCC).

PROJECTIONS FOR NEW ZEALAND'S FUTURE CLIMATE

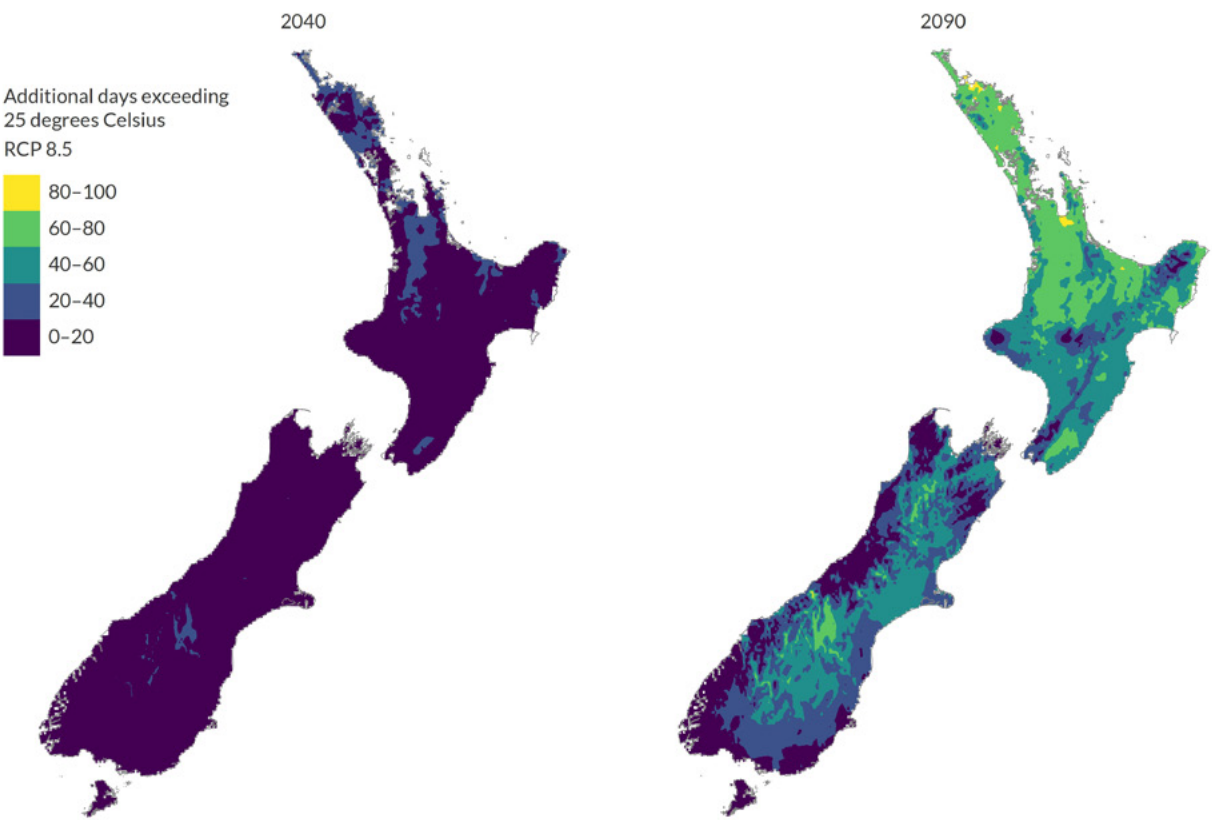
The continued accumulation of greenhouse gases in the atmosphere is projected to have increasing effects on New Zealand's climate.

Higher temperatures are expected across the country. Warm days (where the maximum temperature is 25 degrees Celsius or higher) are projected to occur four times as often in Auckland in 2090 if global emissions continue to increase throughout the 21st century (see figure 24). These days would still increase by 55 percent if emissions are reduced in line with limiting warming to below 2 degrees globally (MfE, 2018a).

Changes to rainfall are also expected – in general, wet areas are expected to get wetter, and dry areas drier (see figure 25). We can also expect more stress on water resources from both of these situations.

Extreme rainfall events are projected to become more common in many areas. What was once a rare, extreme event for us may become common for our children and grandchildren. In the Wellington region for example, projections for future climate point to more intense extreme, rare rainfall events. These events will have broad impacts including slips, landslides, reduced stream habitat quality, and effects on urban drainage and transport systems (Pearce et al., 2019).

Figure 24: Additional number of warm days compared to 1995

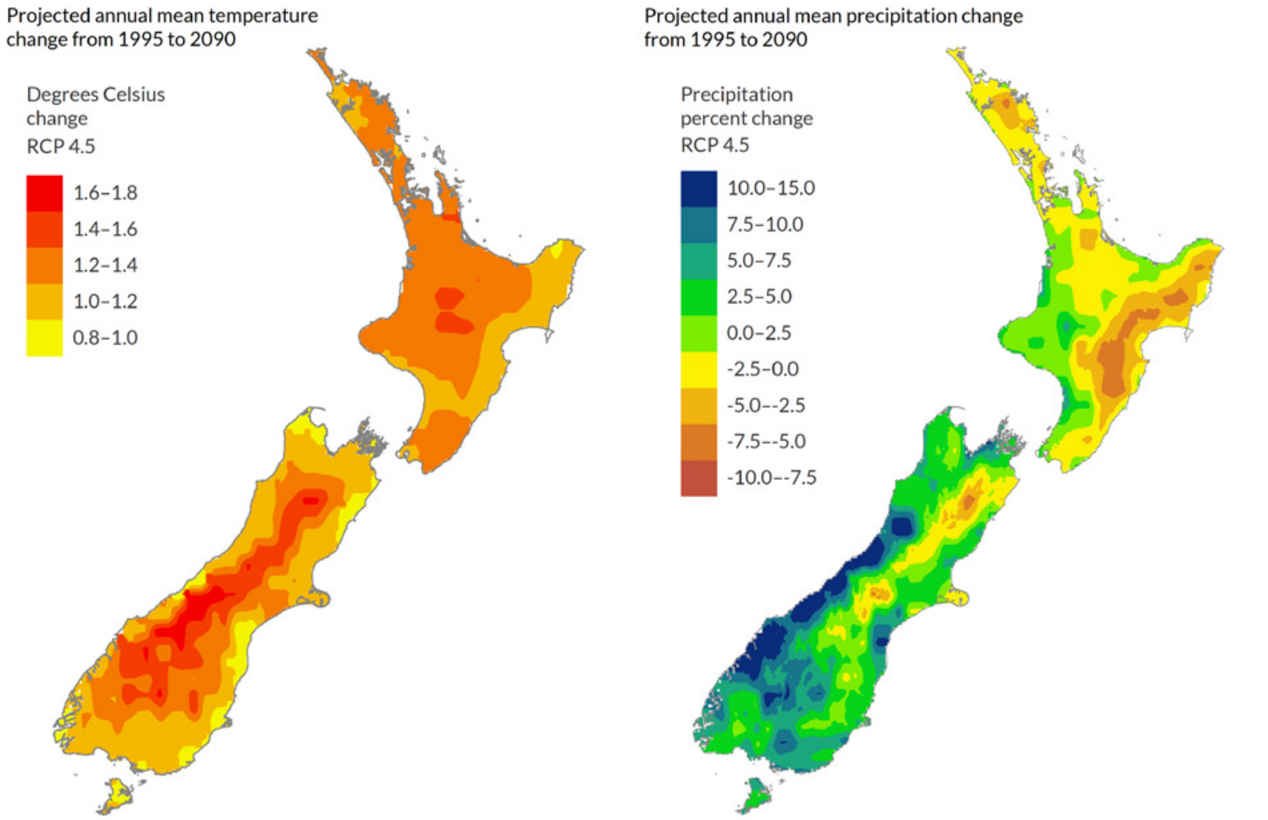


Data source: NIWA

Note: These projections are based on the IPCC Representative Concentration Pathway (RCP) 8.5 emissions scenario. Other emissions scenarios are available for RCP 2.6, RCP 4.5, and RCP 6.0.

▸ Warm days (above 25 degrees Celsius) are expected to increase across the country under the high emissions scenario (RCP 8.5).

Figure 25: Temperature and precipitation climate change projections for New Zealand



Data source: NIWA

Note: These projections are based on the IPCC Representative Concentration Pathway (RCP) 4.5 emissions scenario. Other emissions scenarios are available for RCP 2.6, RCP 6.0, and RCP 8.5.

- Average annual mean temperature is projected to rise across the country (left). Precipitation is projected to increase on the west coast of the South Island, and decrease along the east coast and Northland.

Droughts are projected to increase in severity and frequency in many areas due to a combination of rising temperatures and changes to rainfall. This will be most pronounced in areas that are already drier, like many eastern areas (MfE, 2018a). Longer periods of drought could affect native forests by causing trees to die, shifting the makeup of a plant community towards more drought tolerant species, and increasing the risk of wildfires.

Sea levels in New Zealand are projected to be 0.5 metres higher than the baseline level for 1986–2005 between 2060 and 2110, and will continue to rise for several centuries (MfE, 2017). The timeframe for this rise depends on future emissions, as well as how quickly polar ice sheets respond to rising temperatures.

The implications for coastal areas are serious but people are still attracted to living near the sea. In many cities throughout the world, population increase and building continues in some zones that are at risk from sea-level rise. In the Auckland region from 2010 to 2013 for example, some construction occurred in low lying areas that may eventually be affected by sea-level rise. The population was also estimated to have increased in these coastal areas between 2001 and 2013 (Golubiewski, Balderston, Hu, & Boyle, 2019).

Observed changes to wildfire risk have been mixed (see The risk of wildfires is changing), but days with very high or extreme fire danger are projected to increase by an average of 70 percent by 2040, due to hotter, drier and windier conditions. The largest increases are projected for Wellington and coastal Otago, where fires do not generally occur. A doubling (to around 30 days for Wellington) or even tripling (to around 20 days for coastal Otago) of the number of days per year with very high or extreme fire danger is possible (Watt et al., 2019).

More information can be found in the Climate change projections for New Zealand report produced by NIWA.

Cumulative and cascading effects

The effects of climate change will be felt most acutely when they overlap and build on each other. These are known as cumulative effects. Some examples include a heatwave and drought happening at the same time or a storm surge adding to raised sea levels and making coastal flooding worse.

Cumulative effects can also occur when climate change adds to other changes to the environment. For example, excess nutrients in rivers and lakes can cause algae blooms, but these blooms become more likely when water is warmer. In 2019, flooding on the Fox River on the west coast of the South Island washed through a disused landfill, exposing decades of rubbish and washing it downstream (see Floods release decades-old rubbish from a landfill).

The increasing frequency of climate-related extreme events makes them more likely to co-occur and cause cumulative effects. This increased risk will be a challenge to our resilience and ability to recover, especially as we are only beginning to understand how and where the events are likely to occur.

Climate change can also have cascading effects, where one climate impact can affect many aspects of our society. Heavy rain and floods for example, can affect wastewater services, road networks, and power and water supplies. These effects all have links to the safety of individuals as well as the quality of life and economic activity of an area. This may cause people to leave the area, particularly if the impacts become more common and access to insurance decreases. The effects then cascade to put greater pressure on councils – with fewer residents left to pay rates, services for those who remain can be reduced (Lawrence et al., 2018).

Impacts from droughts can also ripple through regions and affect the environment, the health of a community, and the economy. Areas that rely on rainwater for drinking and other uses like pasture growth can be especially hard hit.

Climate change will not affect New Zealand in isolation. Life in this country is not separate from the activities and the effects of climate change that are projected to occur around the world. International connections that could be affected include the Pacific Island nations that we have strong relationships with, as well as trading partners, trade routes, international aid assistance, and migration. Our wellbeing can also be threatened by overseas events that have cascading impacts to our economy and security including climate-driven conflicts, water scarcity, and food insecurity.

Overall, a warming climate is projected to create uncertainty and increase risk. The Ministry for the Environment has commissioned the first national assessment of the risks that climate change poses to New Zealand, to meet the requirements in the Zero Carbon Amendment to the Climate Change Response Act (CCRA). See First national climate change risk assessment for Aotearoa New Zealand webpage on the Ministry for the Environment website for more information about the specific risks and changes expected from climate change.

Future national climate change risk assessments will be carried out regularly by the Climate Change Commission. As required by the CCRA, the Government must deliver a national adaptation plan within 2 years from the publication of the national climate change risk assessment.

Towards a better understanding of our climate

▸ NIWA's atmospheric research station at Lauder, Central Otago.

Photo: Dave Allen, NIWA

Making good decisions today

WE KNOW WHY CLIMATE CHANGE IS HAPPENING AND WHAT FURTHER CHANGES ARE LIKELY

The data and insights highlighted in this report demonstrate some of the physical changes and broad-scale effects that are already being observed in Aotearoa New Zealand (see chapter 3: Changes in our climate and environment are being observed). The observations of increasing temperatures and changes to rainfall show that climate change is no longer a far-off threat but is affecting us and our environment here and now.

This report also sets out the sources of New Zealand's greenhouse gas emissions that are contributing to climate change, and the high-level forces that are driving emissions (see chapter 2: Our activities are driving emissions). Our activities and the choices we make every day can produce or reduce greenhouse gas emissions. At all levels from central to local government and businesses to communities, iwi, families, and individuals, we are continually making decisions that affect the climate.

Knowledge of Earth's systems and how they affect our lives is progressing, with further data collection, analysis, and investigation continuing across a wide range of subjects. Using tools like climate models, scientists can estimate the most likely range of impacts for different aspects of climate change. Projections from these models show how different emissions scenarios for the future are likely to cause further changes to the climate, with impacts on our environment, society, and culture, and ultimately on our wellbeing.

MANAGING UNCERTAINTY IN DECISION-MAKING

While our understanding of the climate is comprehensive, it will never be perfect. The climate system itself is complex, and so are the ecological and human systems it interacts with. There will always be some uncertainty surrounding any decision related to climate change.

We come across uncertainty in the decisions we make every day, from the mundane (can I get away without a jacket today?) to the life altering (should I start a new career?). While we rarely have all the information we need to act with absolute certainty, we also rarely have so little information that we cannot make a decision.

Part of the enterprise of science is to understand variability and uncertainty so what is significant can be distinguished from the noise. Science recognises that every measurement carries an uncertainty, and methods such as statistical analysis can be used to manage it for decision-making.

Our understanding has advanced to a point where it is straightforward to use our knowledge of uncertainty and risk to make many decisions. For example, taking into account the risk of where flooding is likely to occur more regularly in the future can help us make better decisions about where to build new roads.

PLANNING FOR A CHANGING FUTURE

The ways we choose to act require careful planning and evaluation well in advance of being needed. This can help make the best use of the time and resources that are available now, and because some interventions take a long time to have an effect. Well-planned actions can also increase the openings for other benefits to be incorporated. These could include new economic opportunities or reduced emissions of greenhouse gases. If left too late, the options can be limited and more costly.

Good planning can also help ensure there are no unintended consequences from the actions we take today. Planting pine trees to store carbon, for example, is often cited as an effective strategy for reducing carbon dioxide in the atmosphere. But if the trees are planted in a place where rising temperatures will increase the risk of extreme wildfires, this may not be a sensible long-term strategy for that location.

An improved understanding of how our climate is likely to change, and the effects of those changes, can also help us to be more resilient. This information is especially important at a local level, where adaptations to climate change need to be designed and implemented by the communities affected.

We can develop flexible and innovative plans and responses that allow us to adjust and adapt as the future plays out. The challenge is making the right decisions today that give the next generation the same opportunities to make the right decisions tomorrow.

Gathering the knowledge we need

LISTENING TO THE VOICES OF TE AO MĀORI

In New Zealand we are fortunate to have a vast repository of local knowledge – mātauranga Māori. It dates back hundreds of years and is therefore an invaluable source of information for identifying changes in te taiao (the environment) and helping us understand how it is changing (see Tohu and maramataka: observing and tracking changes in the environment).

Mātauranga Māori and science are independent views of te taiao and use different methodologies to progressively add observations and knowledge over generations. Their relationship has been likened to a braided river with channels that cross and uncross on the journey downstream (Macfarlane & Macfarlane, 2019). When the 'channels cross' there is an opportunity for these knowledge systems to come together and provide new ways of thinking and alternate pathways to explore.

There are challenges to bringing mātauranga Māori into the environmental reporting system, which has traditionally focused on the collection and analysis of quantitative data. This report has gone further than previous reports in the Environmental Reporting series in showing that mātauranga Māori can relate and offer different perspectives on data collection, use, and wellbeing. More listening and more work is needed to further combine these views of te taiao.

SOME THINGS WE CAN ONLY LEARN WITH TIME

The complexity of the climate system means it can take time for observations related to climate change to be confirmed statistically. For infrequent events like extreme rainfall, it can take several decades for clear signals to emerge. Robust observation systems and long-term datasets are therefore crucial to provide reliable, quality data. This allows us to detect and understand the trend of important changes. Quality data is also crucial for understanding how actual observed changes are tracking with climate projections and whether any adjustments in the projections are needed.

New Zealand has some of these long-term data sets as part of the data system. For example, coastal sea level and air temperatures have been measured since around the turn of the 20th century. Carbon dioxide concentrations have been measured at Baring Head since 1972. Data sets like these that span 50–100 years are invaluable national assets.

SOME THINGS WE CAN ONLY LEARN BY WORKING TOGETHER

The need for a more connected environmental monitoring system is highlighted by the chain of links from our activities and emissions to the changing climate, to impacts on our social, environmental and economic systems. New Zealand is already on a journey to improve environmental monitoring and ensure data gathering is prioritised and consistent across the many communities that observe, collate, and steward data.

The journey requires a shift in the system and a holistic understanding of the way environmental data is collected in New Zealand. It is essential that we understand:

- why we collect data (legislation, internal obligations, and national direction and regulation)
- the barriers and incentives (investment, governance, data management systems, standards, and frameworks)
- the roles and responsibilities (those who collect and use the data).

The challenges go well beyond this report, but better data is critical for ensuring a more useful, relevant, and robust evidence base for conversations about climate change and the environment. The Parliamentary Commissioner for the Environment, the Ministry for the Environment, and Stats NZ agree that systemic changes are needed to advance environmental reporting.

Further research to understand the links between climate change and wellbeing at local, regional, and national scales would also be beneficial. This knowledge would help us to better prepare and respond to the ways that climate change will impact our lives.

SOME THINGS WE CAN LEARN USING NEW APPROACHES

Beyond traditional data collection approaches, there is also significant potential to use new technology, such as drones or low-cost sensors. The popularity of smartphones also means that many of us now walk around with a data capture device (the humble camera and GPS receiver) wherever we go, and can be active participants in gathering scientific data.

Citizen science initiatives (that often use smartphones to collect data) have a much larger reach than traditional monitoring because many more people can be involved. Those who are involved also learn more about the places where they live by making observations. Citizen science collaborations can also increase the trust in data and findings and create a stronger base for decision-making (see King tides show possible future sea levels).

Climate change will affect all aspects of our environment and our lives. The scale and complexity of the challenge will require the use of all the knowledge available to us. There is a need for social scientists to work more alongside biologists, modellers, and other physical scientists. Going further than working across disciplines, however, the size and complexity of climate change offers an opportunity to draw on all knowledge systems.

King tides show possible future sea levels

The highest of all tides are called king tides. They occur a few times a year when the orbits of the Earth, sun and moon align and create high tides that are even larger than spring tides. King tides can cause flooding in the same places where the higher sea level caused by climate change would be expected to occur. Since king tides are actual events, they provide a more accurate picture of how water moves across a landscape than computer models.

The King Tides Project was begun to document the effects of king tides around the world to help planners, scientists and policymakers study and prepare for future sea-level rise. The Auckland King Tides Project enables local people to share their photographs of places around the city during king tides, so others can see the effects.

The king tides of today may well become normal sea level in the future. Documenting these currently rare events is helping to demonstrate what raised sea levels would be like in New Zealand. The information gathered is also beginning to be used by councils and organisations such as surf clubs that have buildings, roads, and other infrastructure close to the coast.

See King Tides Auckland for more information.

Blue sky flooding from a king tide on Tamaki Drive, Auckland, March 2020.

Photo: King Tides Auckland

Additional information

Dark clouds over the Auckland suburbs of Ellerslie and Panmure.

Photo: Sky View Photography

About Our atmosphere and climate 2020

REPORTING UNDER THE ENVIRONMENTAL REPORTING ACT 2015

Under the Environmental Reporting Act 2015 (the Act), the Secretary for the Environment and the Government Statistician must produce regular reports on the state of our environment.

Under the Act, a report on a domain (marine, freshwater, land, air, and atmosphere and climate) must be produced every 6 months and a whole-of-environment (or synthesis) report every 3 years. Each domain report has now been published once (see the Environmental reporting section on the Ministry for the Environment website for the full list). The most recent synthesis report, *Environment Aotearoa 2019*, was published in April 2019. The previous atmosphere and climate report was *Our atmosphere and climate 2017*.

Our atmosphere and climate 2020 continues the second cycle of domain reporting. It updates *Environment Aotearoa 2019* and *Our atmosphere and climate 2017* by presenting new data and insights.

As required by the Act, state, pressure, and impact are used to report on the environment. The logic of the framework is that pressures cause changes to the state of the environment and these changes have impacts. The reports describe impacts on ecological integrity, public health, economy, te ao Māori, culture, and recreation to the extent that is possible with the available data.

Suggesting or evaluating any responses to environmental impacts is out of scope under the Act. Therefore, this report does not cover the work that organisations and communities are doing to mitigate the issue. It does provide an update on the most recent data about the state of the atmosphere and climate. The evidence in this report is a basis for an open and informed conversation about what we have, what we are at risk of losing, and where we can make changes. For the first time in the Environmental Reporting series, information about drivers of environmental change and future outlooks are included.

INFORMATION FOR THIS REPORT COMES FROM MANY SOURCES

Data, upon which this report is based, came from many sources including Crown research institutes and central government. Further supporting information was provided using a 'body of evidence' approach. This is defined as peer reviewed, published literature, and data from reputable sources. This also includes mātauranga Māori and observational tools used to identify changes in an ecosystem.

All the data used in this report, including references to scientific literature, was corroborated and checked for consistency. A panel of independent scientists advised on and reviewed the content of the report.

SUPPORTING INFORMATION IS AVAILABLE

This report is supported by other products that are published by the Ministry for the Environment and Stats NZ:

- Environmental Indicators: Atmosphere and climate – summaries, graphs, interactive maps, and data that are relevant to the state, pressures, and impacts on the atmosphere and climate.
- Data tables are available on the Ministry for the Environment's data service, and technical reports on the Ministry for the Environment's website.

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References

Airport Corporation Ltd (ACL). (2020). Flight arrivals/departures at New Zealand airports. Retrieved July 29, 2020, from www.acl-international.com

Ajtić, J., Connor, B. J., Lawrence, B. N., Bodeker, G. E., Hoppel, K. W., Rosenfield, J. E., & Heuff, D. N. (2004). Dilution of the Antarctic ozone hole into southern midlatitudes, 1998-2000. *Journal of Geophysical Research: Atmospheres*, *109*(D17), 1–9. https://doi.org/10.1029/2003JD004500

Albrecht, G. (2011). Chronic environmental change: emerging 'psychoterratic' syndromes. In I. Weissbecker (Ed.), *Climate Change and Human Well-Being* (pp. 43–56). New York, United States of America: Springer. https://doi.org/10.1007/978-1-4419-9742-5

Allen, R. B., Hurst, J. M., Portier, J., & Richardson, S. J. (2014). Elevation-dependent responses of tree mast seeding to climate change over 45 years. *Ecology and Evolution*, *4*(18), 3525–3537. https://doi.org/10.1002/ece3.1210

Anderson, B., Kerr, T., & Milner, A. (2016). Alpine processes. In P. Jellyman, T. Davie, C. Pearson, & J. Harding (Eds.), *Advances in New Zealand Freshwater Science* (pp. 73–98). Christchurch, New Zealand: New Zealand Freshwater Sciences Society.

Ausseil, A., van der Weerden, T., Beare, M., Teixeira, E., Baisden, T., Lieffering, M., … Noble, A. (2019). *Climate change impacts on land use suitability*. Manaaki Whenua Contract Report: LC3573. Lincoln, New Zealand: Manaaki Whenua.

Banerjee, A., Fyfe, J. C., Polvani, L. M., Waugh, D., & Chang, K. L. (2020). A pause in Southern Hemisphere circulation trends due to the Montreal Protocol. *Nature*, *579*(7800), 544–548. https://doi.org/10.1038/s41586-020-2120-4

Bar-On, Y. M., Phillips, R., & Milo, R. (2018). The biomass distribution on Earth. *Proceedings of the National Academy of Sciences of the United States of America, 115*(25), 6506–6511. https://doi.org/10.1073/pnas.1711842115

Bastin, J-F., Clark, E., Elliott, T., Hart, S., van den Hoogen, J., Hordijk, I., … Crowther, T. W. (2019). Understanding climate change from a global analysis of city analogues. *Plos One*, *14*(7), e0217592. https://doi.org/10.1371/journal.pone.0217592

Bayer, T. K., Schallenberg, M., & Burns, C. W. (2016). Contrasting controls on phytoplankton dynamics in two large, pre-alpine lakes imply differential responses to climate change. *Hydrobiologia*, *771*(1), 131–150. https://doi.org/10.1007/s10750-015-2625-2

Best, E. (1924). The Polynesian method of generating fire. *The Journal of the Polynesian Society*, *33*(130), 87–102.

Boddy, N. C., & McIntosh, A. R. (2017). Temperature, invaders and patchy habitat interact to limit the distribution of a vulnerable freshwater fish. *Austral Ecology*, *42*(4), 456–467. https://doi.org/10.1111/aec.12463

Bogdziewicz, M., Kelly, D., Thomas, P. A., Lageard, J. G. A., & Hacket-Pain, A. (2020). Climate warming disrupts mast seeding and its fitness benefits in European beech. *Nature Plants*, *6*(2), 88–94. https://doi.org/10.1038/s41477-020-0592-8

Bond, M. O., Anderson, B. J., Henare, T. H. A., & Wehi, P. M. (2019). Effects of climatically shifting species distributions on biocultural relationships. *People and Nature*, *1*(1), 87–102. https://doi.org/10.1002/pan3.15

Bowley, A., Harvey-Green, A., Leadbeater, C., Henry, M., Hooper, G., Simpson, J., … Walton, J. (2019). *The Carbon Report*. New Zealand Equity Research. Retrieved from https://investmentnews.co.nz/wp-content/uploads/The-Carbon-Report-2019-12-05-Counting-Carbon-Costs-Climate-Change-and-NZX-Companies.pdf

Bulgarella, M., Trewick, S., Minards, N., Jacobson, M., & Morgan-Richards, M. (2014). Shifting ranges of two tree weta species (*Hemideina spp.*): competitive exclusion and changing climate. *Journal of Biogeography*, *41*(3), 524–535. https://doi.org/10.1111/jbi.12224

Burke, K. D., Williams, J. W., Chandler, M. A., Haywood, A. M., Lunt, D. J., & Otto-Bliesner, B. L. (2018). Pliocene and Eocene provide best analogs for near-future climates. *Proceedings of the National Academy of Sciences of the United States of America, 115*(52), 13288-13293. www.pnas.org/cgi/doi/10.1073/pnas.1809600115

Cai, W., Wang, G., Dewitte, B., Wu, L., Santoso, A., Takahashi, K., … McPhaden, M. J. (2018). Increased variability of eastern Pacific El Niño under greenhouse warming. *Nature*, *564*(7735), 201–206. https://doi.org/10.1038/s41586-018-0776-9

Chapman Tripp. (2019). *Climate change risk – implications for New Zealand company directors and managed investment scheme providers*. Legal opinion, The Aotearoa Circle. Retrieved from https://chapmantripp.com/media/r30jdd05/climate-change-risk-legal-opinion-2019.pdf

Cheng, L., Abraham, J., Hausfather, Z., & Trenberth, K. E. (2019). How fast are the oceans warming? *Science*, *363*(6423), 128–129. https://doi.org/10.1126/science.aav7619

Chiswell, S., & Grant, B. (2018). *New Zealand coastal sea surface temperature*. NIWA Client Report: 2018295WN. Wellington, New Zealand: National Institute of Water and Atmosphere Ltd (NIWA).

Clayton, S., Manning, C., Krygsman, K., & Speiser, M. (2017). *Mental Health and Our Changing Climate: Impacts, Implications, and Guidance*. Washington, D.C.: American Psychological Association, and ecoAmerica.

Climate Change Adaptation Technical Working Group (CCATWG). (2018). *Adapting to climate change in New Zealand*. Wellington, New Zealand.

Climate Change Iwi Leadership Group. (2016). *NZ ETS review submissions 2016 priority matters part 1: mitigation*. Retrieved from https://www.mfe.govt.nz/sites/default/files/media/NZETS_reviewstage1%20-%20Climate%20Change%20Iwi%20Leaders%20Group%20180.pdf

Coyle, K. J., & Van Susteren, L. (2011). *The psychological effects of global warming on the United States: And why the U.S. mental health care system is not adequatly prepared*. National Forum and Research Report. Virginia, United State of America: National Wildlife Federation.

Cradock-Henry, N. A. (2017). New Zealand kiwifruit growers' vulnerability to climate and other stressors. *Regional Environmental Change*, *17*(1), 245–259. https://doi.org/10.1007/s10113-016-1000-9

Dean, S., Rosier, S., Carey-Smith, T., & Stott, P. (2013). The role of climate change in the two day extreme rainfall in Golden Bay, New Zealand, December 2011. *Bulletin of the American Meteorological Society*, *94*(9), 61–64.

Deep South National Science Challenge. (2018). *Tangoio Climate Change Adaptation Decision Model: A process for exploring adaptive pathways for Tangaio Marae*. NIWA Client Report: 2018242HN. Hamilton, New Zealand: National Institute of Water and Atmospheric Research Ltd (NIWA).

Department of Conservation (DOC). (2019). Operation Tidy Fox ending Sunday with a record number of volunteers [Press release]. Retrieved from https://www.doc.govt.nz/news/media-releases/2019/operation-tidy-fox-ending-sunday-with-a-record-number-of-volunteers

Durie, M. H. (1985). A Māori perspective of health. *Social Science & Medicine*, *20*(5), 483-186.

Filippova, O., Nguyen, C., Noy, I., & Rehm, M. (2019). *Who cares? Future sea level rise and house prices* (Vol. 96). Working Paper: 4/2019. Wellington, New Zealand: School of Economics and Finance, Victoria Business School. https://doi.org/10.3368/LE.96.2.207

Frame, D., Joshi, M., Hawkins, E., Harrington, L. J., & de Roiste, M. (2017). Population-based emergence of unfamiliar climates. *Nature Climate Change*, *7*(6), 407–411. https://doi.org/10.1038/nclimate3297

Frame, D., Rosier, S., Carey-Smith, T., Harrington, L., Dean, S., & Noy, I. (2018). *Estimating financial costs of climate change in New Zealand, an estimate of climate change-related weather event costs*. Wellington, New Zealand: National Institute of Water and Atmospheric Research (NIWA), New Zealand Climate Change Research Institute.

Freund, M. B., Henley, B. J., Karoly, D. J., McGregor, H. V., Abram, N. J., & Dommenget, D. (2019). Higher frequency of Central Pacific El Niño events in recent decades relative to past centuries. *Nature Geoscience*, *12*(6), 450–455. https://doi.org/10.1038/s41561-019-0353-3

Friedlingstein, P., Jones, M. W., O'Sullivan, M., Andrew, R. M., Hauck, J., Peters, G. P., … Zaehle, S. (2019). Global Carbon Budget 2019. *Earth System Science Data*, *11*, 1783–1838. https://doi.org/10.5194/essd-11-1783-2019

Fritze, J. C., Blashki, G. A., Burke, S., & Wiseman, J. (2008). Hope, despair and transformation: climate change and the promotion of mental health and wellbeing. *International Journal of Mental Health Systems*, *2*, 1–10. https://doi.org/10.1186/1752-4458-2-13

Gaffney, O., & Steffen, W. (2017). The Anthropocene equation. *The Anthropocene Review*, *4*(1), 53–61. https://doi.org/10.1177/2053019616688022

Golubiewski, N. E., Balderston, K., Hu, C., & Boyle, J. (2019). Auckland's Exposure to Sea Level Rise: Part 1 - Regional Inventory. In N. E. Golubiewski (Ed.), *Auckland Climate Change Risk Assessment – 2019*. Retrieved from: https://knowledgeauckland.org.nz/media/1085/tr2019-017-aucklands-exposure-to-sea-level-rise-part-1-regional-inventory-final.pdf

Goodman, J. M. (2018). *Conservation, ecology and management of migratory galaxiids and the whitebait fishery. A summary of current knowledge and information gaps*. Nelson, New Zealand: Department of Conservation.

Grant, G. R., Naish, T. R., Dunbar, G. B., Stocchi, P., Kominz, M. A., Kamp, P. J. J., … Patterson, M. O. (2019). The amplitude and origin of sea-level variability during the Pliocene epoch. *Nature*, *574*(7777), 237–241. https://doi.org/10.1038/s41586-019-1619-z

Gruber, N., Clement, D., Carter, B. R., Feely, R. A., van Heuven, S., Hoppema, M., … Wanninkhof, R. (2019). The oceanic sink for anthropogenic CO_2 from 1994 to 2007. *Science*, *363*(6432), 1193–1199. https://doi.org/10.1126/science.aau5153

Harmsworth, G. R., & Awatere, S. (2013). Indigenous Māori knowledge and perspectives of ecosystems. In J. Dymond (Ed.), *Ecosystem services in New Zealand: conditions and trends*. Lincoln, New Zealand: Manaaki Whenua Press.

Harris, P., Matamua, R., Smith, T., Kerr, H., & Waaka, T. (2013). A Review of Māori Astronomy in Aotearoa-New Zealand. *Journal of Astronomical History and Heritage*, *16*(3), 325-336.

Hawke's Bay Regional Council (HBRC). (2016). *Clifton to Tangoio Coastal Hazards Strategy 2120: Coastal Hazard Assessment*. Napier, New Zealand.

Horne, A., Frith, N., & de Pont, O. (2019). Risk under the microscope - a sea change in pricing property insurance. *Cover to Cover*, (17). Retrieved from https://www.minterellison.co.nz/our-view/risk-under-the-microscope-a-sea-change-in-pricing-property-insurance

Intergovernmental Panel on Climate Change (IPCC). (2007). Climate Change 2007: The Physical Science Basis. In S. Solomon, D. Qin, M. Manning, Z. Chen, M. Marquid, & K. Averyt (Eds.), *Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*. Retrieved from https://www.ipcc.ch/report/ar4/wg1/

Intergovernmental Panel on Climate Change (IPCC). (2013). *Information from Paleoclimate Archives*. In *Climate Change 2013: The Physical Science Basis: Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* (pp. 383–464). https://doi.org/10.1017/CBO9781107415324.013

Intergovernmental Panel on Climate Change (IPCC). (2014a). Climate Change 2014: Synthesis Report. *Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge, United Kingdom and New York: Cambridge University Press.

Intergovernmental Panel on Climate Change (IPCC). (2014b). Drivers, Trends and Mitigation. In *Climate Change 2014: Mitigation of Climate Change. Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* (pp. 351–412). https://doi.org/10.1017/cbo9781107415416.011

Intergovernmental Panel on Climate Change (IPCC). (2018). *Global warming of 1.5°C*. Masson-Delmotte, V. P., Zhai, H. O., Pörtner, D., Roberts, J., Skea, P. R., Shukla, A., Pirani, W., Moufouma-Okia, C., Péan, R., Pidcock, S., Connors, J. B. R., Matthews, Y., Chen, X., Zhou, M. I., Gomis, E., Lonnoy, T., Maycock, M., Tignor, & T., Waterfield (Eds.). In Press.

Intergovernmental Panel on Climate Change (IPCC). (2019). *IPCC special report on the ocean and cryosphere in a changing climate*. Pörtner, H.-O., Roberts, D. C., Masson-Delmotte, V., Zhai, P., Tignor, M., Poloczanska, E., Minternbeck, K., Nicolai, M., Okem, A., Petzold, J., Rama, B. &Weyer, N. (Eds.). In Press.

Joynt, J. L. R., & Golubiewski, N. E. (2019). *Development of the Auckland Heat Vulnerability Index*. Auckland Council Technical Report: TR2019/012. Auckland, New Zealand: Auckland Council.

King, D. N. (2015). The climate change matrix facing Māori society. In R. A. C. Nottage, D. S. Wratt, J. F. Bornman, & K. Jones (Eds.), *Climate change adaptation in New Zealand: future scenarios and some sectoral perspectives* (pp. 100–111). Wellington, New Zealand: New Zealand Climate Change Centre.

King, D., Tawhai, W., Skipper, A., & Iti, W. (2005). *Anticipating local weather and climate outcomes using Māori environmental indicators*. NIWA Client Report: AKL-2005-129. Auckland, New Zealand: National Institute of Water and Atmospheric Research Ltd (NIWA).

Kitzberger, T., Perry, G. L. W., Paritsis, J., Gowda, J. H., Tepley, A. J., Holz, A., & Veblen, T. T. (2016). Fire–vegetation feedbacks and alternative states: common mechanisms of temperate forest vulnerability to fire in southern South America and New Zealand. *New Zealand Journal of Botany*, *54*(2), 247–272. https://doi.org/10.1080/0028825X.2016.1151903

Kroeker, K. J., Kordas, R. L., Crim, R., Hendriks, I. E., Ramajo, L., Singh, G. S., … Gattuso, J. P. (2013). Impacts of ocean acidification on marine organisms: Quantifying sensitivities and interaction with warming. *Global Change Biology*, *19*(6), 1884–1896. https://doi.org/10.1111/gcb.12179

Lal, A., Hales, S., Kirk, M., Baker, M. G., & French, N. P. (2016). Spatial and temporal variation in the association between temperature and salmonellosis in NZ. *Australian and New Zealand Journal of Public Health*, *40*(2), 165–169. https://doi.org/10.1111/1753-6405.12413

Lawrence, J., Blackett, P., Cradock-Henry, N., & Nistor, B. (2018). *Climate Change: the cascade effect. Cascading impacts and implications for Aotearoa New Zealand*. Wellington, New Zealand: Deep South Challenge.

Le Quéré, C., Jackson, R. B., Jones, M. W., Smith, A. J. P., Abernethy, S., Andrew, R. M., … Peters, G. P. (2020). Temporary reduction in daily global CO_2 emissions during the COVID-19 forced confinement. *Nature Climate Change*. https://doi.org/https://doi.org/10.1038/s41558-020-0797-x

Lettink, M., & Monks, J. M. (2019). Ecology of scree skinks (*Oligosoma waimatense*) in O Tu Wharekai Wetland, mid-Canterbury high country, New Zealand. *New Zealand Journal of Ecology*, *43*(1). https://doi.org/10.20417/nzjecol.43.6

Lyver, P. O. B., Jones, C. J., & Doherty, J. (2009). Flavor or forethought: Tuhoe traditional management strategies for the conservation of Kereru (*Hemiphaga novaeseelandiae novaeseelandiae*) in New Zealand. *Ecology and Society*, *14*(1). https://doi.org/10.5751/ES-02793-140140

Macfarlane, A., & Macfarlane, S. (2019). Listen to culture: Māori scholars' plea to researchers. *Journal of the Royal Society of New Zealand*, *49*:sup1, 48-57. https://doi.org/10.1080/03036758.2019.1661855

Mattern, T., Meyer, S., Ellenberg, U., Houston, D., Darby, J., Young, M., … Seddon, P. (2017). Quantifying climate change impacts emphasises the importance of managing regional threats in the endangered Yellow-eyed penguin. *PeerJ*, *5*, e3272. https://doi.org/10.7717/peerj.3272

McKenzie, R., Bernhard, G., Liley, B., Disterhoft, P., Rhodes, S., Bais, A., … Brogniez, C. (2019). Success of Montreal Protocol Demonstrated by Comparing High-Quality UV Measurements with "World Avoided" Calculations from Two Chemistry-Climate Models. *Scientific Reports*, 9, 12332, 1–13. https://doi.org/10.1038/s41598-019-48625-z

Mead, H. M. (2012). Understanding Mātauranga Māori. In D. Bean, T. Black, W. Collings, & W. Nuku (Eds.), *Conversations On Mātauranga Māori* (pp. 9–14). Retrieved from https://www.nzqa.govt.nz/assets/Maori/ConversationsMMv6AW-web.pdf

Meijer, C., Warburton, H., Harding, J., & McIntosh, A. (2019). Shifts in population size structure for a drying-tolerant fish in response to extreme drought. *Austral Ecology*, *44*(4), 658–667. https://doi.org/10.1111/aec.12709

Melbourne, H. (1978). Tihore Mai Te Rangi. Retrieved from http://www.folksong.org.nz/tihore/

Metlink. (n.d.). What delays trains. Retrieved June 18, 2020, from https://www.metlink.org.nz/getting-around/trains/what-delays-trains

Ministry of Agriculture and Forestry (MAF). (2011a). Adapting to a changing climate: case study 17: Managing impacts on tuna (eel) using a kaupapa *Māori approach*. Retrieved from https://www.biosecurity.govt.nz/dmsdocument/26842/direct

Ministry of Agriculture and Forestry (MAF). (2011b). Adapting to a changing climate: case study 33: Threats to *stocks of Tītī and Tio in the South Island*. Retrieved from https://www.fisheries.govt.nz/dmsdocument/26848/direct

Ministry of Business, Innovation and Employment (MBIE). (2019a). Energy balances. Retrieved 10 August, 2020, from https://www.mbie.govt.nz/building-and-energy/energy-and-natural-resources/energy-statistics-and-modelling/energy-publications-and-technical-papers/energy-in-new-zealand/

Ministry of Business, Innovation and Employment (MBIE). (2019b). *Energy in New Zealand 2019* (Vol. 15). Wellington, New Zealand.

Ministry for the Environment (MfE). (1997). *The state of New Zealand's environment 1997*. Wellington, New Zealand.

Ministry for the Environment (MfE). (2017). *Coastal hazards and climate change: guidance for local government*. Wellington, New Zealand.

Ministry for the Environment (MfE). (2018a). *Climate Change Projections for New Zealand: Atmosphere projections based on simulations from the IPCC fifth assessment, 2nd Edition*. Wellington, New Zealand.

Ministry for the Environment (MfE). (2018b). *The co-benefits of emissions reduction: An analysis*. Wellington, New Zealand.

Ministry for the Environment (MfE). (2019). *New Zealand's Fourth Biennial Report under the United Nations Framework Convention on Climate Change*. Wellington, New Zealand.

Ministry for the Environment (MfE). (2020a). About exceptional circumstances and how to apply. Retrieved from https://www.mfe.govt.nz/air/air-regulations/national-environmental-standards-air-quality/exceptional-circumstances-and

Ministry for the Environment (MfE). (2020b). New Zealand's projected greenhouse gas emissions. Retrieved 10 July, 2020, from https://www.mfe.govt.nz/climate-change/emissions-reduction-targets/projected-emissions

Ministry for the Environment (MfE). (2020c). *New Zealand's Greenhouse Gas Inventory 1990-2018 Snapshot*. Wellington, New Zealand.

Ministry for the Environment (MfE). (2020d). *New Zealand's Greenhouse Gas Inventory 1990-2018*. Wellington, New Zealand.

Ministry for Primary Industries (MPI). (2017). *Aquatic Environment and Biodiversity Annual Review 2017*. Wellington, New Zealand.

Ministry of Defence (MoD) & New Zealand Defence Force (NZDF). (2018). *The climate crisis: defence readiness and responsibilities*. Wellington, New Zealand.

Ministry of Defence (MoD) & New Zealand Defence Force (NZDF). (2019). *Responding to the climate crisis, an implementation plan*. Wellington, New Zealand.

Ministry of Transport (MoT). (2019). *Annual Fleet Statistics 2018*. Retrieved from https://www.transport.govt.nz/assets/Import/Uploads/Research/Documents/The-NZ-Vehicle-Fleet-Report-2018-web-v2.pdf

Ministry of Transport (MoT). (2020). Weekly COVID-19 Transport Indicators Dashboard - 25 May 2020. Retrieved August 31, 2020, from https://www.transport.govt.nz/mot-resources/covid-19-transport-indicators-dashboard/

Moser, S. C. (2009). More bad news: the risk of neglecting emotional responses to climate change information. In S. C. Moser, & L. Dilling (Eds.), *Creating a Climate for Change* (pp. 64–80). https://doi.org/10.1017/cbo9780511535871.006

Mullan, A. B., Stuart, S. J., Hadfield, M., & Smith, M. J. (2010). Report on the review of NIWA's "seven-station" temperature series. NIWA Information Series: 78. Wellington, New Zealand: National Institute of Water and Atmospheric Research Ltd (NIWA).

Murage, P., Hajat, S., & Kovats, R. S. (2017). Effect of night-time temperatures on cause and age-specific mortality in London. *Environmental Epidemiology, 1*(2). https://doi.org/10.1097/EE9.0000000000000005

National Aeronautics and Space Administration (NASA). (2020). Global temperature. Retrieved May 4, 2020, from https://climate.nasa.gov/vital-signs/global-temperature/

National Institute of Water and Atmospheric Research (NIWA). (2020). Auckland's drought most extreme in modern times. Retrieved from https://niwa.co.nz/news/aucklands-drought-most-extreme-in-modern-times

National Oceanic and Atmospheric Administration (NOAA). (2019). 2019 ozone hole smallest on record. Retrieved from https://research.noaa.gov/article/ArtMID/587/ArticleID/2566/2019-ozone-hole-smallest-on-record

National Oceanic and Atmospheric Administration (NOAA). (2020). Trends in atmospheric carbon dioxide. Retrieved July 24, 2020, from https://www.esrl.noaa.gov/gmd/ccgg/trends/

New Zealand Government. (2019a). Govt support for Westland floods recovery [Press release]. Retrieved from https://www.beehive.govt.nz/release/govt-support-westland-floods-recovery

New Zealand Government. (2019b). Minister announces multi-agency response to identify risks from legacy landfills [Press release]. Retrieved from https://www.beehive.govt.nz/release/minister-announces-multi-agency-response-identify-risks-legacy-landfills

New Zealand Transport Agency (NZTA). (2020). Weekly traffic count information. Retrieved July 22, 2020, from https://nzta.govt.nz/about-us/coronavirus-disease-covid-19-services-update/data-and-research/weekly-traffic-count-information

New Zealand Waitangi Tribunal. (1989). *Report of The Waitangi Tribunal on The Te Reo Māori Claim*. Wai 11. Wellington, New Zealand.

New Zealand Waitangi Tribunal. (2011). *Ko Aotearoa Tēnei*. Wai 262. Wellington, New Zealand.

Office of the Māori Climate Commissioner. (2019). Māori burial grounds under threat from rising seas increasing storm events. [Press release]. Retrieved from http://www.maoriclimatecommission.co.nz/media/maori-burial-grounds-under-threat-from-rising-seas-increasing-storm-events/

Office of the Prime Minister's Chief Science Adviser. (2019). Compromised landfills at risk during extreme weather [Press release]. Retrieved from https://www.pmcsa.ac.nz/2019/11/05/compromised-landfills-at-risk-during-extreme-weather/

Organisation for Economic Co-operation and Development (OECD). (2017). OECD Environmental Performance Reviews: New Zealand 2017. Paris, France: OECD Publishing. http://dx.doi.org/10.1787/9789264268203-en

Organisation for Economic Co-operation and Development (OECD). (2019). Carbon dioxide emissions embodied in international trade. Retrieved from https://www.oecd.org/sti/ind/carbondioxideemissionsembodiedininternationaltrade.htm

Organisation for Economic Co-operation and Development (OECD). (2020). OECD Statistics. Retrieved August 12, 2020, from https://stats.oecd.org/

Parliamentary Commissioner for the Environment (PCE). (2019). *Pristine, popular... imperilled? The environmental consequences of projected tourism growth*. Wellington, New Zealand.

Patel, H., Talbot, N., Salmond, J., Dirks, K., Xie, S., & Davy, P. (2020). Implications for air quality management of changes in air quality during lockdown in Auckland (New Zealand) in response to the 2020 SARS-CoV-2 epidemic. *Science of the Total Environment*, *746*, 141129. https://doi.org/10.1016/j.scitotenv.2020.141129

Patuharakeke Te Iwi Trust Board Inc. (2014). *Patuharakeke Hapū Environmental Management Plan 2014*. Whangarei, New Zealand.

Paulik, R., Stephens, S., Wadhwa, S., Bell, R., Popovich, B., & Robinson, B. (2019). Coastal flooding exposure under future sea-level rise for New Zealand. *Prepared for The Deep South Science Challenge*. NIWA Client Report: 2019119WN. Wellington, New Zealand: National Institute of Water and Atmospheric Research (NIWA).

Pearce, P., Fedaeff, N., Mullan, B., Rosier, S., Carey-Smith, T. & Sood, A. (2019). *Wellington Region climate change extremes and implications*. NIWA Client Report: 2019134AK. Auckland, New Zealand: National Institute of Water and Atmospheric Research Ltd (NIWA).

Pierdomenico, M., Casalbore, D., & Chiocci, F. L. (2019). Massive benthic litter funnelled to deep sea by flash-flood generated hyperpycnal flows. *Scientific Reports*, *9*(1), 1–10. https://doi.org/10.1038/s41598-019-41816-8

Rees-Owen, R. L., Gill, F. L., Newton, R. J., Ivanović, R. F., Francis, J. E., Riding, J. B., ... Lopes dos Santos, R. A. (2018). The last forests on Antarctica: Reconstructing flora and temperature from the Neogene Sirius Group, Transantarctic Mountains. *Organic Geochemistry*, 118, 4–14. https://doi.org/10.1016/j.orggeochem.2018.01.001

Reguero, B. G., Losada, I. J., & Méndez, F. J. (2019). A recent increase in global wave power as a consequence of oceanic warming. *Nature Communications*, *10*(1), 1–14. https://doi.org/10.1038/s41467-018-08066-0

Reserve Bank of New Zealand (RBNZ). (2018). *Financial Stability Report, November 2018*. Wellington, New Zealand.

Rosier, S., Dean, S., Stuart, S., Carey-Smith, T., Black, M., & Massey, N. (2015). Extreme rainfall in early July 2014 in Northland, New Zealand - Was there an anthropogenic influence? *Bulletin of the American Meteorological Society*, *96*(12), 35–40. https://doi.org/10.1016/j.jmatprotec.2009.09.029

Royal Society Te Apārangi. (2017). *Human Health Impacts of Climate Change for New Zealand: Evidence Summary*. Wellington, New Zealand.

Salinger, M. J., Renwick, J., Behrens, E., Mullan, A. B., Diamond, H. J., Sirguey, P., ... Sutton, P. J. (2019). The unprecedented coupled ocean-atmosphere summer heatwave in the New Zealand region 2017/18: drivers, mechanisms and impacts. *Environmental Research Letters*, *14*(4), 1-18. https://doi.org/10.1088/1748-9326/ab012a

Simonson, T., & Hall, G. (2019). *Vulnerable: the quantum of local government infrastructure exposed to sea level rise*. Wellington, New Zealand: Local Government New Zealand (LGNZ).

Skipper, A. (2018). Ka taki mai te māuru When the nor'wester howls. *Te Karaka*, *78*, 24–27.

Stats NZ. (2019). Environmental-economic accounts: 2019 (data to 2017). In *SEEA account*. Retrieved from https://www.stats.govt.nz/information-releases/environmental-economic-accounts-2019-data-to-2017

Stats NZ. (2020a). Environmental-economic accounts: 2020 – tables. In *SEEA account*. Retrieved September 1, 2020, from https://www.stats.govt.nz/information-releases/environmental-economic-accounts-2020-tables

Stats NZ. (2020b). Greenhouse gas emissions (industry and household): Year ended 2018. Retrieved September 1, 2020, from https://www.stats.govt.nz/information-releases/greenhouse-gas-emissions-industry-and-household-year-ended-2018

Stats NZ. (2020c). Gross domestic product (GDP). Retrieved August 10, 2020, from https://www.stats.govt.nz/indicators/gross-domestic-product-gdp

Stephenson, J., Orchiston, C., Saunders, W., Kerr, S., MacMillan, A., McKenzie, L., … Willis, S. (2018). *Communities and climate change: vulnerability to rising seas and more frequent flooding*. Motu Note: 29. Wellington, New Zealand: Motu Economic and Public Policy Research.

Storey, B., Noy, I., Townsend, W., Kerr, S., Salmon, R., Middleton, D., … James, V. (2017). *Insurance, housing and climate adaptation: current knowledge and future research*. Motu Note: 27. Wellington, New Zealand: Economic and Public Policy Research.

Sutton, P. J. H., & Bowen, M. (2019). Ocean temperature change around New Zealand over the last 36 years. *New Zealand Journal of Marine and Freshwater Research*, *53*(3), 305–326. https://doi.org/10.1080/00288330.2018.1562945

Tait, A. (2019). *Risk-exposure assessment of Department of Conservation (DOC) coastal locations to flooding from the sea: a national risk assessment of DOC assets, archaeological sites, recreation functional locations, destinations and ecosystem and species management uni* (Vol. 332). Wellington, New Zealand: Department of Conservation.

Tawhai, W. (2013). *Living by the Moon: Te Maramataka a Te Whānau-ā-Apanui*. Wellington, New Zealand: Huia publishers.

Te Hiku o te Ika Development Trust. (2018). *Te Hiku O Te Ika Climate Change Project. Project Summary Report for the Deep South National Science Challenge*. Wellington, New Zealand: The Deep South.

Tepley, A., Thomann, E., Veblen, T., Perry, G., Holz, A., Paritsis, J., … Anderson-Teixeira, K. (2018). Influences of fire–vegetation feedbacks and post-fire recovery rates on forest landscape vulnerability to altered fire regimes. *Journal of Ecology*, *106*(5), 1925–1940. https://doi.org/10.1111/1365-2745.12950

Thomsen, M. S., Mondardini, L., Alestra, T., Gerrity, S., Tait, L., South, P. M., … Schiel, D. R. (2019). Local extinction of bull kelp (*Durvillaea spp.*) due to a marine heatwave. *Frontiers in Marine Science*, *6*(MAR), 1–10. https://doi.org/10.3389/fmars.2019.00084

Trenberth, K. E. (2020). Understanding climate change through Earth's energy flows. *Journal of the Royal Society of New Zealand*, *50*, 331-347. https://doi.org/10.1080/03036758.2020.1741404

Turney, C. S. M., Fogwill, C. J., Golledge, N. R., McKay, N. P., Sebille, E. van, Jones, R. T., … Cooper, A. (2020). Early Last Interglacial ocean warming drove substantial ice mass loss from Antarctica. *Proceedings of the National Academy of Sciences of the United States of America*, *117*(8), 3996-4006. https://doi.org/10.1073/pnas.1902469117

United Nations. (2007). *Climate change an overview.* Paper prepared by the Secretariat of the United Nations Permanent Forum on Indigenous Issues.

United Nations. (n.d.). The effects of climate change on indigenous peoples. Retrieved July 23, 2020, from https://www.un.org/development/desa/indigenouspeoples/climate-change.html

United Nations Environment Programme (UNEP). (2019). *Emissions gap report 2019.* Nairobi, Kenya. https://doi.org/10.18356/ff6d1a84-en

United Nations Framework Convention on Climate Change (UNFCCC). (2020). Greenhouse gas inventory data - detailed data by Party. Retrieved June 22, 2020, from https://di.unfccc.int/detailed_data_by_party

United Nations Population Division (UNPD). (2020). World population prospects 2019. Retrieved August 12, 2020, from https://population.un.org/wpp/Download/Standard/Population/

Vargo, L. J., Anderson, B. M., Dadić, R., Horgan, H. J., Mackintosh, A. N., King, A. D., & Lorrey, A. M. (2020). Anthropogenic warming forces extreme annual glacier mass loss. *Nature Climate Change*, *10*, 856-861. https://doi.org/10.1038/s41558-020-0849-2

Walker, S., Monks, A., & Innes, J. (2019). Thermal squeeze will exacerbate declines in New Zealand's endemic forest birds. *Biological Conservation*, *237*, 166–174. https://doi.org/10.1016/j.biocon.2019.07.004

Watt, M. S., Kirschbaum, M. U. F., Moore, J. R., Pearce, H. G., Bulman, L. S., Brockerhoff, E. G., and Melia, N. (2019). Assessment of multiple climate change effects on plantation forests in New Zealand. *Forestry*, 92, 1-15, https://doi.org/10.1093/forestry/cpy024.

Weko, F., Roberts, M., & Clarke, L. (2006). *Maramataka: the Māori Moon Calendar.* Research Report No. 283. Christchurch, New Zealand: Lincoln University.

Weltzin, J., Loik, M. E., Schwinning, S., Williams, D. G., Fay, P. A., Haddad, B. M., … Zak, J. C. (2003). Assessing the response of terrestrial ecosystems to potential changes in precipitation. *BioScience*, *53*(10), 941. https://doi.org/10.1641/0006-3568(2003)053[0941:ATROTE]2.0.CO;2

Westland District Council. (2019a). March storm remains costly for small council [Press release]. Retrieved from https://www.westlanddc.govt.nz/media-release

Westland District Council. (2019b). *Westland District Council Annual Report 2018/19.* Hokitika, New Zealand.

Willeit, M., Ganopolski, A., Calov, R., & Brovkin, V. (2019). Mid-Pleistocene transition in glacial cycles explained by declining CO_2 and regolith removal. *Science Advances*, *5*(4). https://doi.org/10.1126/sciadv.aav7337

World Meteorlogical Organization (WMO). (2017). *WMO Guidelines on the Calculation of Climate Normals*. WMO-No. 1203. Geneva, Switzerland.

World Meteorlogical Organization (WMO). (2019). *Scientific Assessment of Ozone Depletion: 2018*. Global Ozone Research and Monitoring Project – Report No. 58. Geneva, Switzerland.

World Meteorlogical Organization (WMO) and Global Water Partnership. (2016). *Handbook of drought indicators and indices*. Integrated Drought Management Programme (IDMP), Integrated Drought Management Tools and Guidelines Series 2 (No. 1173). Geneva, Switzerland.

Wyse, S. V., Macinnis-Ng, C. M. O., Burns, B. R., Clearwater, M. J., & Schwendenmann, L. (2013). Species assemblage patterns around a dominant emergent tree are associated with drought resistance. *Tree Physiology*, *33*(12), 1269–1283. https://doi.org/10.1093/treephys/tpt095

Wyse, S. V., Wilmshurst, J. M., Burns, B. R., & Perry, G. L. W. (2018). New Zealand forest dynamics: A review of past and present vegetation responses to disturbance, and development of conceptual forest models. *New Zealand Journal of Ecology*, *42*(2), 87–106. https://doi.org/10.20417/nzjecol.42.18