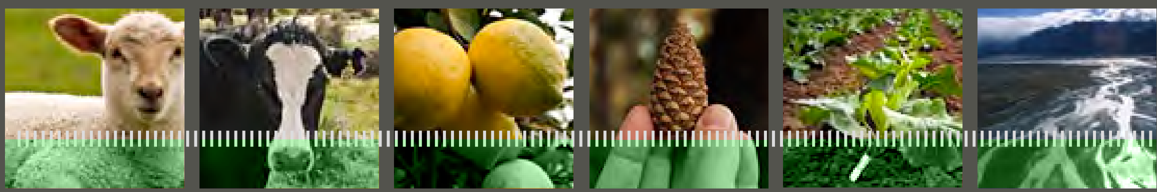
Sustainable Land Management and Climate Change (SLMACC)

Impacts of Climate Change on Land-based Sectors and Adaptation Options



Stakeholder Report

July 2012

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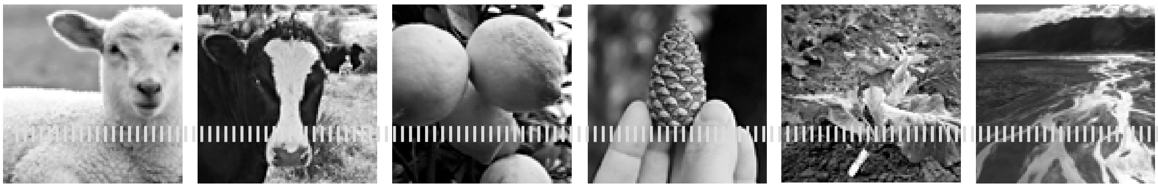

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Contents

Preface

Adaptation is a positive response to the prospect of climate change. This stakeholder report presents the key findings of the first comprehensive evaluation of climate change adaptation options in New Zealand for land-based sectors. The report integrates research and new analysis from a supporting technical report to present the state of adaptation knowledge in New Zealand.

Many adaptation solutions are already part of current management approaches. They allow land managers to continue to pursue existing objectives – albeit under changing conditions – and to be more resilient. They can also access more strategic options that further improve the resilience of businesses. In the event of more severe climate impacts, land-based sectors have recourse to more comprehensive 'transformational' solutions.

Adaptation solutions don't just help the land-based sectors cope with climate change: they consolidate and can improve their overall position. This report identifies solutions available to land management professionals in each sector. This comprehensive bank of knowledge will help the land-based sectors adapt to meet the challenges and capture the opportunities that lie ahead.

"This report identifies practical adaptation activities that are or can be part of day-to-day business, as well as those that build on the innovative drive of the land-based sectors."

Ma tini ma mano ka rapa te whai.

By many, by thousands, the work (project) will be accomplished.
Many hands make light work. Unity is strength.

Key messages

A changing climate

New Zealand's temperatures are warming, and its weather patterns shifting – trends consistent with those recorded around the globe. While a reliable water source – our surrounding oceans – will protect us from the severe aridity expected in some other parts of the world, it will not insulate land-based sectors from a more intense and variable climate. Temperatures will continue to warm, and carbon dioxide concentrations will increase. New Zealand's complex landscape and climate mean that there will be a range of positive and negative changes around the country.

"New Zealand's temperatures are warming, and its weather patterns shifting..."

Impacts on land-based sectors

Direct production impacts will present sectors with both opportunities and challenges. There will be a general shift toward more production variability, and changes in the timing of seasons. In some seasons and years, rising temperatures, carbon dioxide fertilisation and rainfall changes will increase yields.

At other times, changes in rainfall will cause production downturns more pronounced than anything currently experienced. Variability will be greater in the dry-land pastoral and arable sectors, which will experience more fluctuations in feed and crop yields. Water availability will oscillate between larger surpluses and deficits. All sectors are exposed to temperature-driven changes in seasonality of plant and crop responses.

The severity of impacts will vary by sector and region. Some impacts will be indirect. Risks and costs from extreme weather will increase across all sector groups, ranging from short-term inconveniences to longer-term operational restrictions. Such impacts will affect not just the production landscape, but also the water, processing and transport infrastructure that supports it.

Some secondary effects are difficult to quantify. Pests and diseases, as well as environmental responses like increasing erosion and nutrient runoff, are all possibilities. Similarly, there are some more obvious socio-economic implications – such as supply shocks – beyond the sectors. However, if positive impacts can be exploited, they could help drive regional growth.

The cumulative impacts of back-to-back climatic events are important for all sectors, but they are difficult to identify and anticipate. This is the least-understood, but potentially the largest, challenge for the sectors. Some have already experienced such a phenomenon in the sequence of droughts and extreme weather in 2007–2010.

Adaptation options

Importantly, New Zealand's land-based sectors have a comprehensive choice of adaptation solutions and are well-positioned to capture opportunities and meet the challenges ahead. This report provides a sector-by-sector breakdown of those options.

Some adaptation options – termed 'tactical' – are already part of day-to-day practice, and can help counter the low to moderate impacts expected in the future. Prime examples are increasing feed flexibility, adjusting cropping schedules and improving irrigation efficiency.

Land-based sectors also employ a number of existing technologies and practices that increase the climatic range they profitably operate in – termed 'strategic adaptation' in this report. These practices will counter expected moderate impacts, and some higher-level ones. Examples include diversifying production options in the sheep and beef sector, and finding new plantation sites for the forest sector.

More comprehensive adaptation changes – known as 'transformational' – may be best suited to extensive climate change and cumulative impacts or novel opportunities. These might include the regional concentration of a sector shifting, or changing infrastructure to respond to production changes or novel uses. They also require an adaptive process, with better monitoring, information development and thorough consultation. Sound working models, particularly in water resource management, forestry and farm-level change, already exist in New Zealand.

"Importantly, New Zealand's land-based sectors have a comprehensive choice of adaptation solutions and are well-positioned to capture opportunities and meet the challenges ahead."

Introduction

The New Zealand climate is changing, and will enter a new regime in the coming 30 years. Production conditions will be warmer and more variable than in the past. Rules of thumb may no longer work as well in the future, but existing skills and experience will stand land managers in good stead. There are clear benefits to acting now by taking long-term investment decisions which capture future opportunities.

This stakeholder report assesses the effects of a changing climate on New Zealand's land-based sectors, and options for responding to those changes. It also looks for ways that potential opportunities could be exploited. Most importantly, it asks – and answers – the question: "How are productive and profitable land-based sectors maintained under a changing climate in New Zealand?"

Methodology

Each sector review follows a general methodology (Figure 1) which blends two complementary approaches:

- Integrated reviews of existing scientific, professional and experiential knowledge.
- Advanced risk analysis, applying production modelling to individual production units under new climate modelling (Primary Sector Adaptation Scenarios).

The reviews employ the latest climate knowledge and scenarios within a planning horizon of 2030–49 for land-based sectors, although a longer-term view has been taken for forestry. General adaptation categories (Box 1) apply across all sectors. The reviews and analysis have been integrated into a detailed technical report, with further synthesis and evaluation used to create this stakeholder report.

How this report works

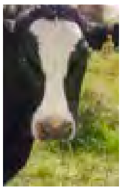
Each section of this report presents managers with information about impacts and a range of adaptation options relevant to their sector. Information notes provide an update on research into important areas for all sectors – regional climate change, carbon dioxide fertilisation and drought. Additional resources are presented, along with links between sections of the report. These are denoted by the various icons below. A cross-cutting section identifies impacts and adaptation options that affect all sectors. The next steps in adaptation are also identified. A glossary of common terms appears in Appendix 1.

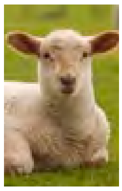

Information note

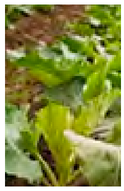

Linkages

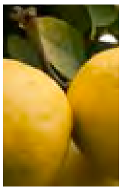

Additional resources

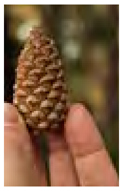
Sectors

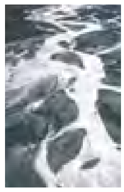

Dairy


Sheep & Beef


Broad acre cropping


Horticulture


Forestry


Water

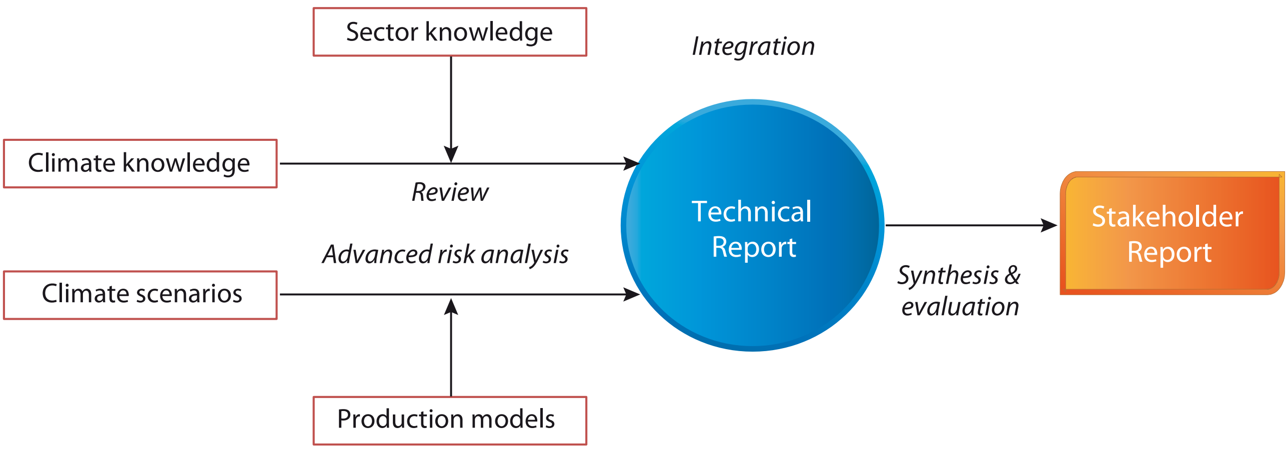
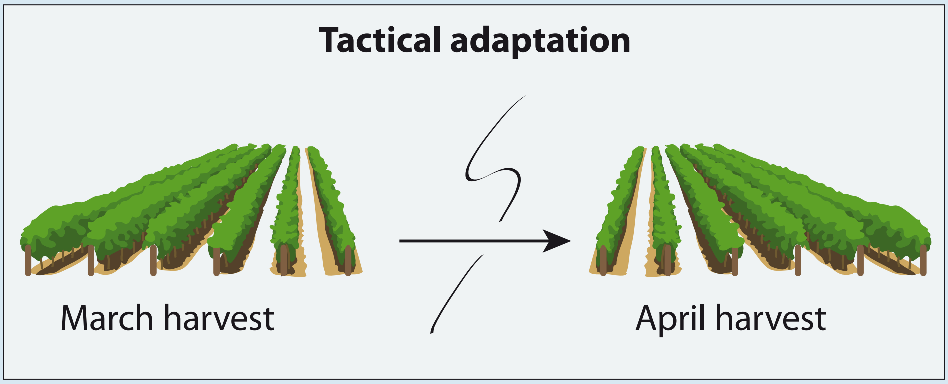
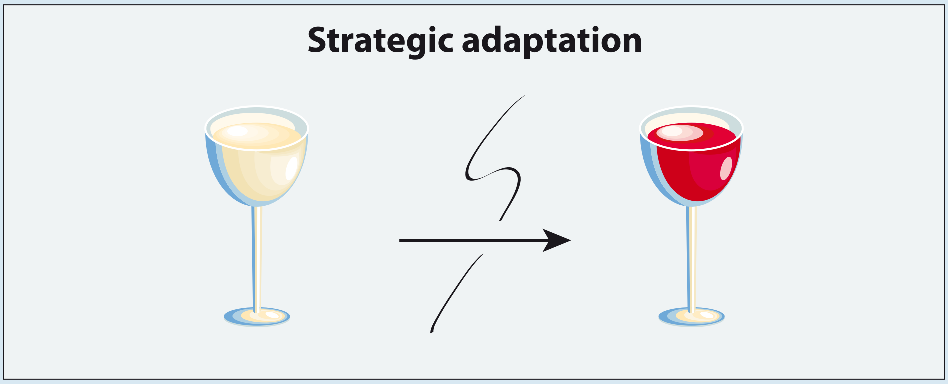


Figure 1. Methodology used to assess impacts and identify adaptation options.

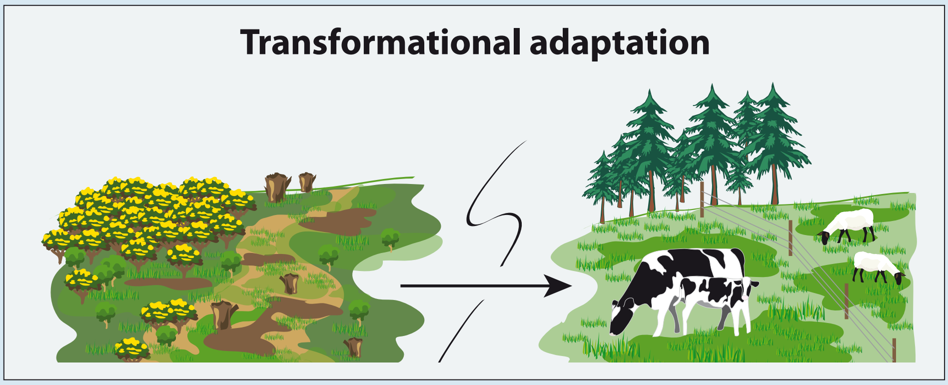
Box 1. Land-based sector adaptation categories.



1. Tactical adaptation modifies an existing production system using commonplace, contemporary management, allowing land managers to respond effectively to mild climate change. These options – such as altering timing of sowing and harvesting – are already familiar and relevant to operational managers today. Tactical approaches can be implemented immediately or the in the short- term.



2. Strategic adaptation involves shifting to other production systems, or making substantive changes to current ones, but still using familiar practices and technologies. This level of change may be warranted in the face of moderate to significant climate change, but could require capital investment in some cases. Detailed guidance may be needed from specialists, especially during planning stages. Strategic adaptation can involve planning and implementation in the medium term, such as changing cultivars in a viticulture operation, can involve planning 3–10 years ahead.



3. Transformational adaptation means developing completely new production systems, or even industries. It encompasses innovative technologies, as well as long-term planning, that balance uncertainties against the need for immediate action. This is the least well-defined level of adaptation, as it demands more novel approaches to land management. It may be a necessary response where climate changes preclude current practices. Transformational adaptation options are likely to evolve over the longer term and take 5–20 years or possibly more, to realise.

An in-depth review of adaptation concepts and the report's methodology is available:
Technical Report Chapter 1: Background
An Adaptation Toolbox has been developed for the land-based sectors, containing detailed information and resources to help these sectors prepare for climate change and is available from the Ministry for Primary Industries:
www.mpi.govt.nz

Regional climate change in New Zealand

Observed changes across New Zealand agree with those observed globally:

- The average land surface temperature has warmed by around 0.9°C over the last century.
- Sea surface temperatures around New Zealand have also warmed over the last 30 years, and weather systems have re-oriented to a more southerly origin.
- It is now formally accepted that these regional changes are linked to global warming and an enhanced greenhouse effect.

> ***"...the hydrological cycle will become more energetic..."***

Surrounding oceans influence New Zealand's climate in complex ways. These effects must be considered in any assessment of future climate change:

- Almost none of the country's rain comes from evaporation off the land. Instead, it is sustained by a large and constant supply of moisture from the surrounding ocean. Whereas warming makes continental land masses increasingly arid, New Zealand's large maritime 'water bank' will not empty in a warmer global environment.
- However, this means the hydrological cycle will become more energetic: more intense rain will fall less frequently. It is important that land managers monitor this shift to understand future growing conditions.
- In New Zealand, we cannot accurately predict climate change on small, local scales, because of the many micro-climates across the country. This is one reason why future climate estimates are expressed as 'probabilities', or a range of possible changes. It is also why accurate local observations are an important tool for land managers adapting to climate change.
- Entirely natural phenomena – such as El Niño, the Interdecadal Pacific Oscillation, as well as local factors – will continue to influence our climate into the future, in addition to climate change. Land-based sector managers must consider the two together, because it's this combination that determines future climate variability.
- In New Zealand, local trends can sometimes run counter to global change. This is a normal feature of our climatic environment. Nevertheless, when considered as a whole, observed shifts in New Zealand are consistent with the global signals of warming.
- Against a background of gradual change, changes to seasonality, along with more frequent droughts and floods, will be the most tangible threat to land-based sectors.

Expected future changes have their own regional and seasonal distribution, and levels of certainty (Table 1).

Table 1. Summary of climate change expected in New Zealand.

	Change	***Regional distribution***	***Level of certainty***
Temperature	Increase	Relatively uniform across the country	High
Annual and seasonal rainfall averages	Positive & negative Wide range	East (decrease) to west (increase) the dominant pattern	Change: High Estimates of direction and magnitude: moderate to low+
Major drought	Predominantly increasing in eastern regions	East (increase)-west (decrease) the dominant pattern	Moderate
Variability	More variability in seasonal rainfall patterns	No dominant pattern	Moderate
Extreme events	Increased magnitude of events	No dominant pattern	Moderate

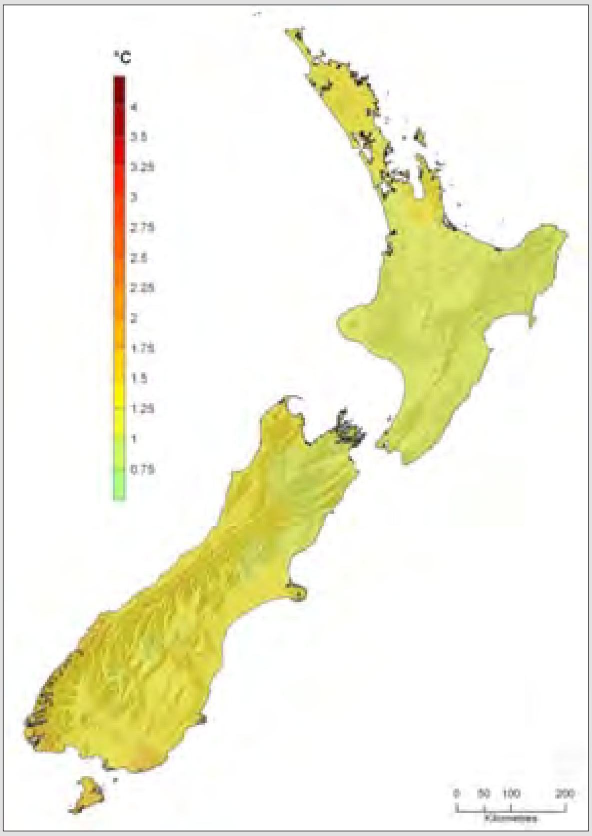
+ The range in rainfall projections and level of confidence varies by region and season.

Primary Sector Adaptation Scenarios

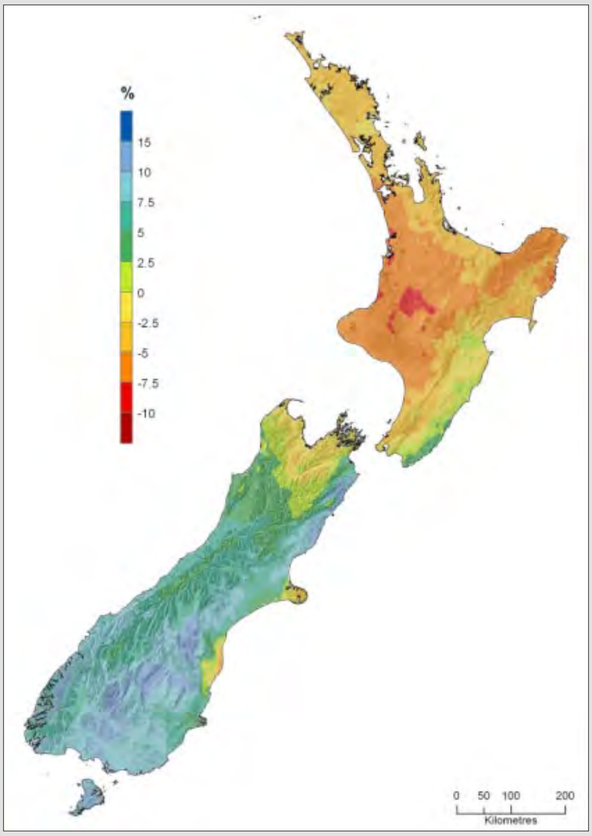
Computer models estimate what the world's future climate might look like. These are then translated to a national and regional level to understand impacts, and explore adaptation options using production models. New regional estimates have been developed for land-based sector modellers in New Zealand. These are consistent with the 'on-average' estimates used in the past. They also open up new opportunities to estimate shifts in seasonality and variability. This is important, because it expands the range of adaptation options that can be considered.

Two climate scenarios at 2030–2049 are used by land-based sector modellers. These cover some of the range expected in future New Zealand climate.

1. A high temperature scenario[1], which anticipates a +1.2°C change by 2040 (2030–49) from a 1980–99 baseline. Nationally, rainfall decreases by two per cent, but is subject to geographic and seasonal variability. For example, this scenario projects a wetter North Island summer rainfall pattern.



Annual temperature change

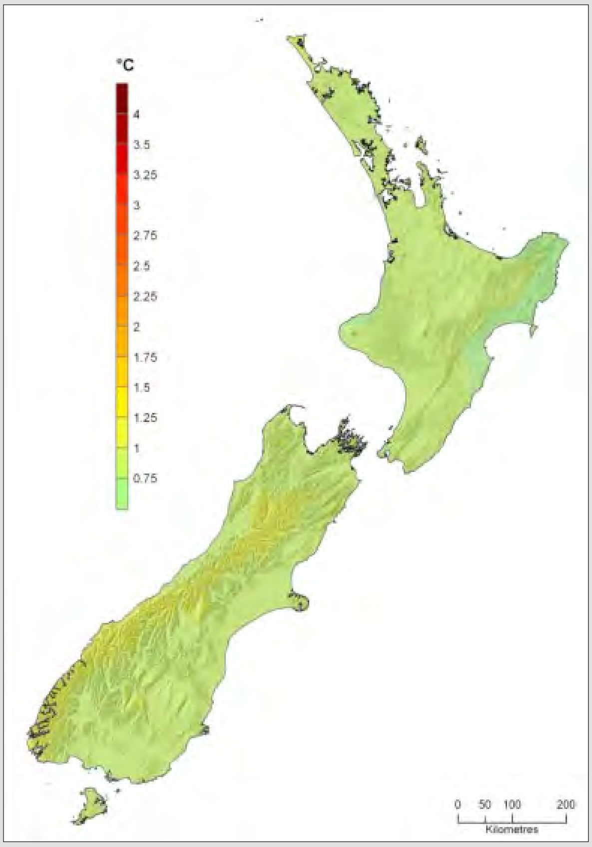


Annual rainfall change

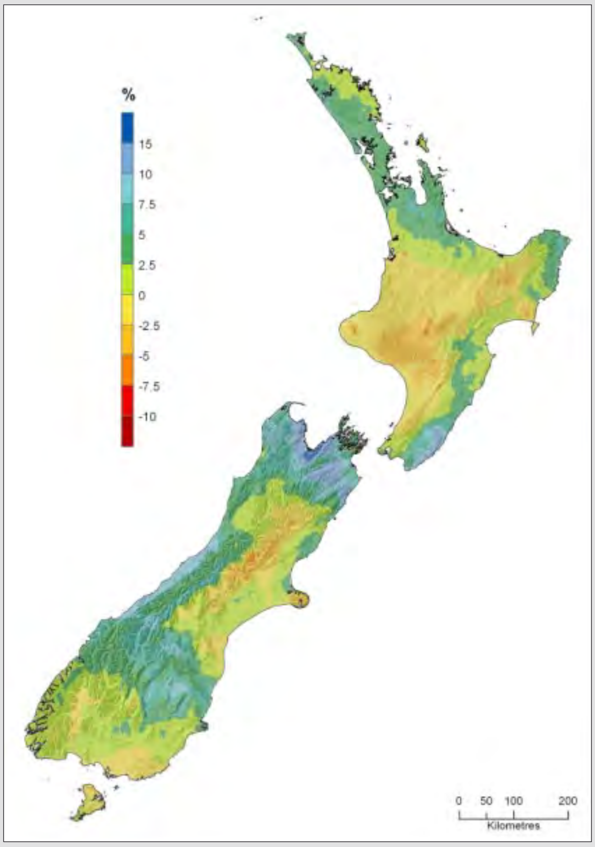
[1] Based on IPCC A2 emissions scenario

> *"New regional estimates have been developed for land-based sector modellers in New Zealand."*

2. A low temperature scenario[2], where there is a +0.89 °C change by 2040, with a national annual rainfall increase of three per cent*. The regional pattern is consistent with the 'more likely outcome' for New Zealand, with drier eastern and northern summers.



Annual temperature change



Annual rainfall change

*Small percentage changes in averages mask larger shifts in variability

[2] Based on IPCC B1 emissions scenario

A comprehensive assessment of climate change knowledge, focussing on land-based sector issues, is available:

Technical Report Chapter 2: Climate

Further information about climate change and projections can be found at:
www.niwa.co.nz

Climate data for New Zealand is downloadable at:
www.cliflo.niwa.co.nz

Local Government guidance manuals provide a synopsis of national projections and climate change knowledge at:
www.mfe.govt.nz

Studies of interest to land management professionals, including estimates of wind, drought and frost under climate change are available at:
www.mpi.govt.nz

Notes

Dairy (p17-23), Sheep & Beef (p25-31)
Forestry (p49-55), Broad acre cropping (p35-39)
Horticulture (p41-47)

Primary production under higher carbon dioxide

Increased carbon dioxide (CO_2) concentrations affect all land-based sectors. They mean higher potential growth of biomass for many key crops, pastures and trees in the future. This is known as 'CO_2 fertilisation'.

- Higher CO_2 concentrations stimulate plant photosynthesis and growth.
- Pasture, tree and crop varieties do not respond equally to changes in CO_2 concentrations. The effect is stronger in C3 plants (ryegrass, clover, wheat, kale) than C4 plants (maize, kikuyu).
- Plants close their stomata to cope with the increased CO_2, transpiring less water in the process. CO_2 fertilisation also stimulates more growth per unit of water, making plants less water-dependent.

In pre-industrial times – before around 1870 – atmospheric CO_2 concentrations averaged 280 parts per million (ppm). In early 2012, they measured 390 ppm. By the 2050s, those levels could climb to between about 475 and 565 ppm; and by the 2100s, to between 540 and 955 ppm.

The CO_2 fertilisation effect is well documented from greenhouse production systems, where the environment is controlled. Whether or not higher potential growth is achieved in the field depends on local climate conditions and management. Free Air CO_2 Enrichment Experiments have placed New Zealand at the forefront of research into fertilisation effects in the field. Important findings are that:

- Optimal plant growth occurs at higher temperatures under increased concentrations of CO_2.
- The strength of the effect depends on the amount of nitrogen (N) available for plants.
- Extreme heat and severe drought (deficits of around two to three weeks in duration) override the effect in pastures and crops.
- New research indicates potentially lower animal intake of forage grown in enriched CO_2 conditions, due to reduced palatability and digestibility.

Estimates of the net effect of CO_2 fertilisation vary widely. For New Zealand pastures, estimates range from 5 per cent to 30 per cent increases in above-ground biomass for a doubling of CO_2.

Implications and adaptation options

CO_2 fertilisation will exaggerate any increased variability under a changed climate. When droughts and heat waves are not restricting growth, more biomass production is possible.

Modelling indicates that forest production is also sensitive to CO_2 fertilisation, with large differences in radiata pine productivity under assumed constant and increased CO_2 concentrations (Figure 2).

These shifts in production variability pose management challenges. Important adaptation solutions across the sectors include:

- Stocking and crop rotation flexibility, to capture benefits and avoid losses.
- Appropriate cultivar and species selection.
- More efficient use of nitrogen, heightening the importance of current efforts to improve nitrogen use efficiency.
- Aggressive pruning and biomass management.

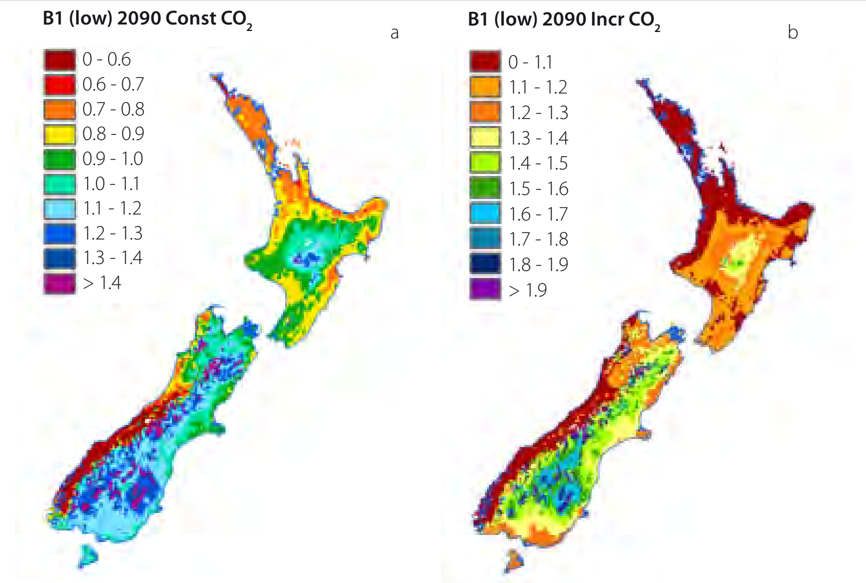


Figure 2. Future radiata pine productivity under (a) constant and (b) increasing CO_2 concentrations for the low Primary Sector Adaptation Scenario at 2090.

Sector-specific reviews of CO_2 fertilisation are in:
Technical Report: Chapter 4 Dairy; Chapter 5 Sheep & Beef; Chapter 6 Broad acre cropping; Chapter 7 Forestry.
An overview of the latest New Zealand research for pastures is available from the Ministry for Primary Industries:
www.mpi.govt.nz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DAIRY

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Primary production under higher carbon dioxide (p15)
Adapting to changes in drought (p32-33)
Water Resources (p57-65)
Sheep & Beef (for pastures p25-31)

Dairy

Key messages

- Production impacts on pasture-based dairy systems from a more variable climate are well understood. Positive and negative impacts vary with season and region.
- A whole-farm systems approach, which considers multiple stressors, is critical to understanding of climate impacts, and when examining the benefits and risks of adaptation options.
- Existing tactical options – widely published in rural training literature – offer New Zealand dairy farmers moderate to high degrees of adaptive capacity, effective in the face of moderate climate change. A good example is the use of conservation paddocks to improve feeding flexibility.
- The diversity of current New Zealand dairy farming systems means operators have options around the level of exposure to climate change they are prepared to accept. Irrigation, new pasture species, milk platform infrastructure, and pasture renewal can all help to reduce vulnerability further while enhancing production. However, costs and benefits must be carefully considered.
- The cost and availability of supplementary feed will be an important determinant of the industries response to climate change.

Introduction

New Zealand's climatic environment – assuming reliable rainfall and temperate seasons – is ideal for pasture-based dairy systems. This is evident in the performance of the dairy sector: in 2011/12, it earned NZ$13.9 b in exports – a significant contribution to New Zealand's GDP.

Pasture-based systems are directly dependent on climate. Those based on imported feed experience climate-related impacts indirectly – through increased costs in times of short supply. Many dairy systems are highly geared, which further increases vulnerability and makes climate change an emerging concern for the sector.

Dairying has already proven flexible in the face of both stresses and opportunities. Farmers have readily adjusted their economies of scale, and the sector has expanded rapidly in recent years. There is good knowledge about impacts and pasture productivity, but little has been done to extend this to the whole system and evaluate adaptation options. Currently, a narrow knowledge base tends to consider each climate driver in isolation.

The sector's understanding of the range of potential impacts needs to broaden and deepen. In particular, a collective response to climate change calls for a farm systems approach, so as to better appreciate which adaptation options are feasible.

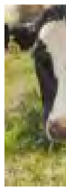
To better inform such a response, this study presents not just a review of current knowledge, but the results of targeted, whole-farm systems modelling at five representative regions (Northland, Waikato, Taranaki, Canterbury and Southland) under newly-developed Primary Sector Adaptation Planning Scenarios.

"Changes in seasonal timing of production, with shifts in spring break-even dates and, subsequently, planned calving dates."

Assessments show both positive and negative climate change impacts for the dairy sector. Some are already relatively well understood – others less so. The sector should ideally be prepared for these impacts, but not so rigidly that it cannot capitalise on any positive opportunities that also arise.

Impacts

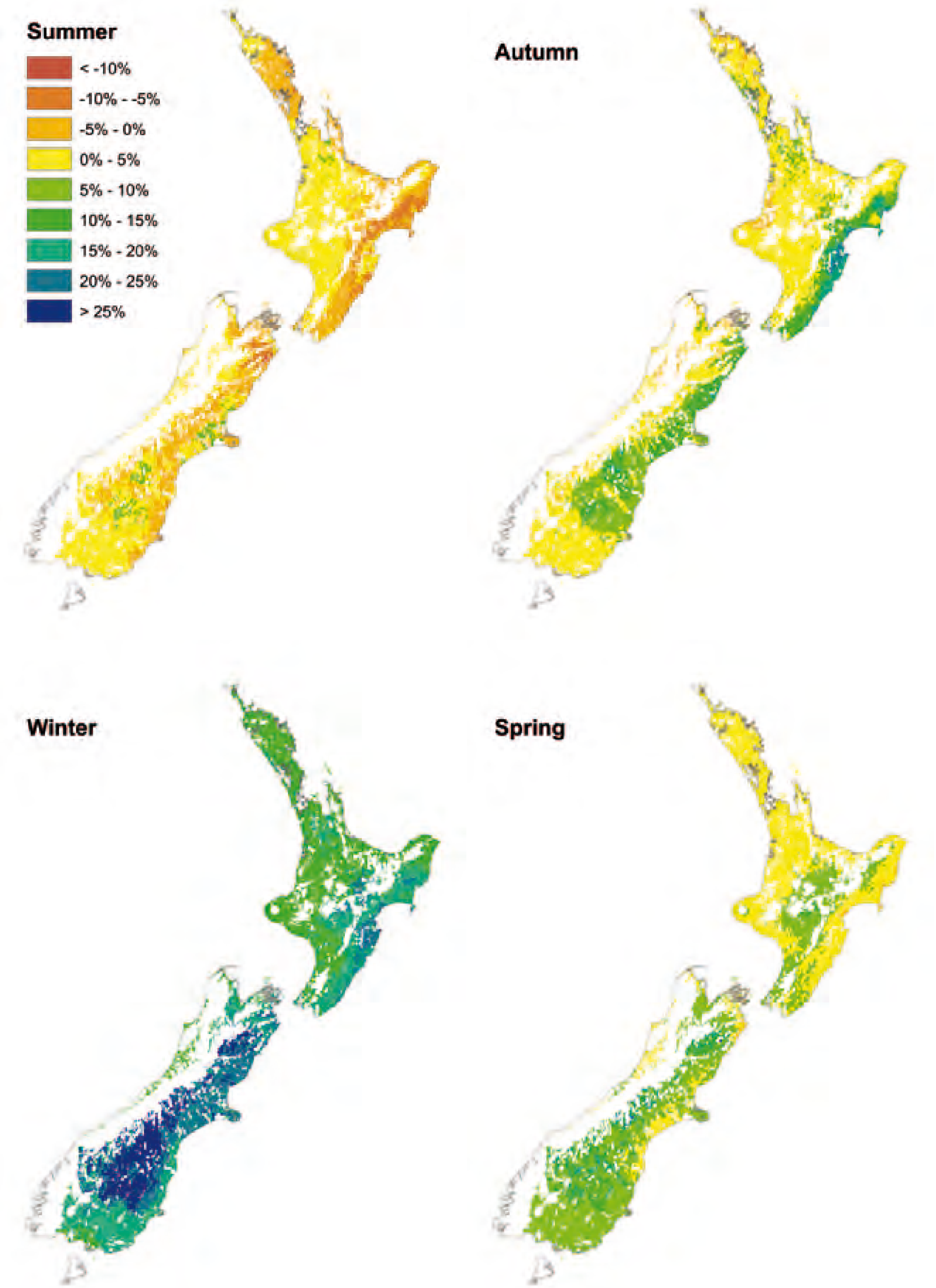
Potential changes in perennial ryegrass growth rates are already well understood in New Zealand. The combined effects of rainfall changes, temperature shifts and increasing CO_2 fertilisation will likely manifest as:



- Changes in seasonal timing of production, with shifts in spring break-even dates and, subsequently, planned calving dates.
- Increased seasonal growth rates during winter and spring, due to reduced temperature limitation.
- Shorter spring seasons, but with higher potential growth. More variable autumns and earlier summer onset, with more water deficiencies.
- Increase in growth rate variability, bringing additional feed deficits and higher surpluses.

These impacts have been deduced from detailed understanding of biological processes under a changing climate. They consider plant photosynthetic and respiration responses under warmer temperatures – as well as increases or decreases in rainfall, given existing pasture tolerances to moisture stress. They also consider CO_2 fertilisation, including key interactions with nitrogen.

Pasture growth under climate change has been studied extensively in New Zealand. Figure 3 is provided here, as it is a representative example of the results found in most previous modelling studies. Overall there is a positive impact on growth under climate change, but with important seasonal and regional differences. Past estimates like those shown in Figure 3 have not factored in year-to-year variability– and more importantly have not included any effect that adaptation options can have. Pasture growth changes are the main impact examined by the whole farm modelling study in this review. With improvements to the climate information and the use of the systems approach, it is possible to address the limitations of past studies and examine variability along with adaptation options.



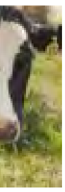


Figure 3. Percentage change in pasture production for 2030–49, compared with 1980–1999 given a mid-range climate scenario. Values include the influence of carbon dioxide fertilisation and assume no adaptation.

These anticipated changes signal a need for greater management flexibility because preparedness for both feed deficits and surpluses will be needed.

Warming temperatures are also expected to exacerbate a number of animal health and production issues. Cattle have a 'thermoneutral' zone – an optimal environmental temperature range in which animal heat production is minimal, and core body temperature normal. Beyond this range, cattle show a number of negative responses:

- Production – reduced intake and milk solids production.
- Clinical – pressure on rumen health.
- Reproductive – difficulties conceiving.

The thermoneutral zone is not tightly defined, because it depends on a range of cow variables such as age, breed, size, body insulation, milk yield, feed intake, diet composition, and prior acclimation. As a general rule of thumb, on days warmer than 25°C, New Zealand cattle may start to suffer heat stress, but this is not a rigid threshold. Internationally, estimates of the lower temperature vary widely from 5°C through to -30°C, below which cattle become stressed.

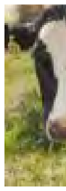
In the case of other potential impacts, our understanding is either incomplete, or inferred from overseas experience. Such impacts include:

- The possibility of genetic responses which provide animals and pastures with a degree of natural resilience to factors like rising temperatures.
- Shifts in the botanical composition and forage quality of pastures in warmer climates, with increasing weediness. Higher temperatures favour C4 grasses such as kikuyu, and accelerated pasture development with associated seasonal reduction in dry matter digestibility.
- An increase in pests and diseases in a warming, more humid climate. Pest and disease impacts are yet to be studied systematically, but in principle, such conditions can increase pest populations and change disease vectors (spreading mechanisms) for common pasture pests like black beetle. They also have ramifications for the pathology of facial eczema, including the areas at risk.
- Reduced cold stress in dairy cows, due to warming temperatures. Most inferences for New Zealand have – so far – been based on beef cattle.
- The prospect of drought-induced feed deficits, and their consequences for animal health and welfare.
- Increased flood and storm intensities, which cause major disruption for farm operations.

The most significant emerging pictures are the complex response of whole-farm systems over time, and the role of multiple stressors. If only one climatic driver, or a single production element, is considered in isolation, it raises the risk of misinterpreting threats from climate variability and change. This study has endeavoured to look at the most critical elements together to avoid this problem.

> ***"...adjusting current management within its known range of flexibility (tactical adaptation) could provide a way of turning potential negative climate change impacts into positive outcomes."***

The whole-farm systems approach taken in this evaluation is critical to improving understanding of both climate impacts, and when examining the benefits and risks around adaptation. Whole-farm modelling indicates that retaining current management regimes in a warmer future will produce mild to moderate negative impacts on the farming system as a whole (Table 3). By 2040, most of the modelled locations experienced productivity and profitability losses under both high and low climate scenarios.



Tactical adaptation

Current dairy systems are inherently flexible, and some New Zealand field studies, supported by overseas modelling, indicate that adjusting current management within its known range of flexibility (tactical adaptation) could provide a way of turning potential negative climate change impacts into positive outcomes.

Existing options – widely described in rural training literature – offer New Zealand dairy farmers moderate to high degrees of tactical adaptive capacity (Table 2). They can deal with a variable climate by changing pasture rotation and feed wedge strategies to maximise pasture growth. Those same strategies also offer some capacity to manage long-term changes in pasture growth variability. Broader impacts can to some extent be reduced or avoided by a range of other pasture and cow-specific technologies and practices.

The example of 'producing more silage and hay' from Table 2 was evaluated using the DairyNZ whole-farm model under the past and future climate (Table 3). Across the five representative sites, increasing feed flexibility by establishing producing more reserve feed on farm (by setting aside paddocks from the production round) and feeding to good animal condition when excess fodder was available. The results showed an increase in median operating profit in the future climate, and appeared to mitigate any negative impacts from retaining current management. This adaptation allows managers to capitalise on good years, with increased operating profit at those times.

Table 2. Tactical adaptation options.

Systems	Cows	Pastures
• Lengthen lactations	• Cooling during milking	• Sow endophyte-containing species
• Produce more silage/hay	• Minimise animal movement	• Improve pasture assessment and monitoring
• Alter calving patterns	• Shelter	• Use crops to break pest cycles
• Alter grazing rotation lengths	• Supplementary feeding to animal condition	• Use alternative pasture/crop
• Change stocking rates	• Manage soil damage through rotation	• Pasture renewal

Table 3. Modelling of selected adaptation options under future climate projections.

Impact analysis	Management profile	Southland	Canterbury	Taranaki	Waikato	Northland
	Current management	[red]	[red]	[red]	[red]	[yellow]
Tactical adaptation	Silage conservation & targeted grazing	[grey]	[blue]	[green]	[yellow]	[green]
Strategic adaptations	Irrigation	[green]	[red, hatched]	[red]	[yellow]	[blue]
	Pasture species change	[grey]	[green, hatched]	[green]	[green]	[blue]
	Reduced stocking rate	[blue]	[red]	[red]	[red]	[red]

Key:

- [green] Consistently positive under a range of climate change projections.
- [blue] Majority of indicators positive under most climate change projections.
- [yellow] Majority of indicators neutral or negative in most climate change projections.
- [red] Consistently negative across many indicators under a range of climate change projections.
- [hatched] Indicates the Canterbury system was not irrigated in this adaptation option. Canterbury pastures were irrigated in other adaptation options and under current management.
- [grey] Not assessed.

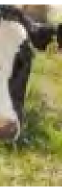


Table 3 is an overall assessment of dairy productivity (pasture growth, milk solids) and profitability (operating profit) indicators taken from the DairyNZ whole-farm model. Five sites representing the main dairy regions were examined given current management, tactical and strategic adaptation options. Table 3 summarises the outcomes across the Primary Sector Adaptation Scenarios (high, low).

Strategic adaptation

The range of current New Zealand dairy farming systems vary in their exposure to the effects of climate change – direct and indirect – and other risks (Table 4). These range from very low-input, pasture-only dairy production systems (industry practice is to call these 'System 1') to high-input systems which supply up to 60 per cent of the cow's diet from purchased supplements ('System 5'). Shifting between current systems is a form of strategic adaptation. Both profitable and non-profitable farms can be found within this spectrum, as profitably is less a function of system choice than farm management.

A number of well-known direct adjustments can change the way current dairy systems respond to shifts in climate that reduce the impacts of climate change. For example, infrastructural changes can be made to the milking platform and farm landscape to reduce heat and cold stress. Permanent change to the pasture species base is also an option, as are irrigation, sustained pasture renewal and the use of new forage crops.

In the whole-farm modelling, irrigation, pasture species change and reduced stocking rates (lower system intensity) were chosen as examples of strategic adaptation. When those options are pooled across all sites (Table 3), the wide spread of results show:

- A small negative change in average operating profit overall, compared with past climate under current management.

Table 4. Strategic adaptation options available to the New Zealand dairy sector.

Systems	*Cows*	*Pastures*
• Minimal input grass based farming ('System 1')	• Install infrastructure in milking shed, shade sprinklers, fans, adequate drinking water	• Change species base of grass farming
• Medium input dairy: strategically use supplementary feeds ('System 2–3')	• Farm design (trees) to provide paddock shade and reduce wind chill	• Irrigation to supplement water deficits and improve water use efficiencies
• High input dairying that extend production through supplementary feed ('System 4–5')	• Refrigeration to cool drinking water	• Ongoing pasture renewal
• Southern wintering systems	• Decrease fibre, increase digestible proteins and fats with supplements	• Introduce new forage crops

- Reducing stocking rates at all sites by 15 per cent placed sustained downward pressure on production and profitability.
- At the other end of the scale, some strategic adaptation options captured more profit in good years, much as tactical adaptation did.
- Although some adaptation options reduce production losses, they are not always cost-effective with only slightly positive – or even negative – shifts in operating profit.
- Some adaptation options, like irrigation, provided positive production and profit outcomes at some sites, but failed at others.

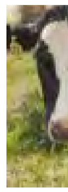
These results reinforce that the strategic adaptation options which demand greater financial risk and/or capital investment, need careful planning. There is no single best approach, and a degree of fine tuning is required at the farm level to bring about success. This highlights a critical role for rural professionals in climate change adaptation: helping dairy operators plan the implementation of strategic change.

Transformational adaptation

New technologies could change the way dairy systems function under climate variability and change – long-term options that could take 5 to 20 years, or more, to realise as adaptive capacity on farm. For instance:

- Pasture technologies could boost top-end ryegrass pasture yields by 20 per cent, from 20 t DM/ha per year at present, to 25 t DM/ha per year.
- Modifying plant morphology – such as increasing the rooting depth of ryegrass – could mitigate moderate to severe water shortages.
- Pasture technologies that support more targeted breeding could bolster physiological responses, and ultimately reduce the effects of environmental stressors on plants.

It is also possible to breed cattle for tolerance to heat and cold stress, as well as improved productive performance. The use of genetic markers helps to target multiple traits in future cattle breeding, pushing the breeding trajectories beyond genetic worth targets.



Key knowledge gaps

A wealth of knowledge and information supports adaptive responses to the direct production risks of climate change. Emerging knowledge of whole-farm system responses reveals a complexity of impacts, but also the flexibility and resilience of modern dairy systems.

Nevertheless, the dairy sector still faces some key knowledge gaps around climate change impacts.

It is important to recognise both the benefits and limitations of holistic farm analysis. It is useful for illustrating some general principles, but does not provide 'management prescriptions.' Continual active engagement with farm managers is an important driver of adaptation.

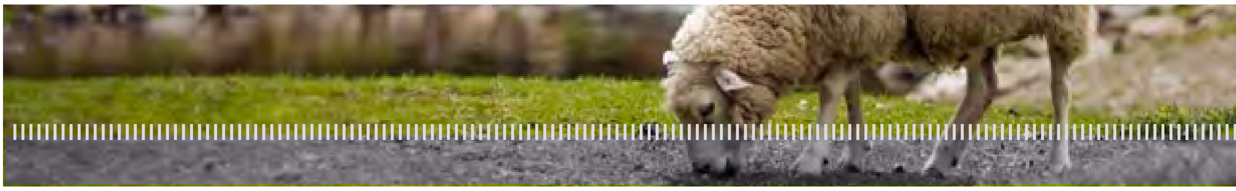
Exploring future targets for nutrient-use efficiency is also an important consideration for the sector, because more nitrogen is needed to capture potential benefits from carbon dioxide fertilisation.

The effects of rising CO_2 concentrations, and changing temperature and rainfall patterns, on pasture and crop plants are not fully understood – especially the implications from any interactions between those variables. It is important to balance modelling estimates with field-based verification in operating dairy systems. Furthermore, research into the effect of these variables on plant molecular processes in many pasture species is either still in its infancy, or not yet begun.

Projected climate changes are more likely to affect dairy cow performance through indirect effects on disease, feed supply and quantity, and extreme weather events. To improve the informational available for tactical adaptation, this broader range of impacts need to be assessed by future whole-farm systems analysis.

An assessment of the dairy farming system under climate change is available in:
Technical Report Chapter 3: Dairy
The Dairy Exporter Great Farming Guide to Climate Change provides regional exposure information and practical adaptation case studies specifically for the dairy sector.
The Dairy Exporter Great Farming Guide to Extreme Weather provides information on emergency management under extreme events.
Seasonal production and body condition score guides provide up-to-date information about the timing adjustments in dairy systems and feed flexibility:
www.dairynz.co.nz

SHEEP & BEEF



Notes

Primary production under higher carbon dioxide (p15)
Adapting to changes in drought (p32-33)
Water Resources (p57-65)
Dairy (p17-23)

Sheep & Beef

Key messages

- Current variation in pasture growth shows that hill country is sensitive to climatic effects.
- Changes in average annual pasture production by 2040 are likely to be modest and largely positive. However, changes in seasonality – mainly increased spring growth and reduced autumn and summer growth – are very likely, and will drive changes in current management.
- Continuing with current management will have different consequences for profitability, depending on location, but the examples shown here include reduced, unchanged and increased responses.
- Greater fluctuation in feed supply will require adaptation. Suitable responses will involve flexibility in stocking rates, conservation of feed, changed timing of reproduction and increased animal growth rates.
- In theory, existing strategic adaptation options will be sufficient to sustain or increase profitability. However, the extent of such changes as stock movements between farms and regions, or increased forage conservation, will provide substantial challenges.

Introduction

Meat is New Zealand's second-largest food export, accounting for nearly 10 per cent to 15 per cent of annual exports, worth NZ$7.2 b in the 2011/12 financial year. Each year, we export roughly equal amounts – 350,000 tonnes – of sheep meat (lamb and mutton) and beef meat.

About 80 per cent of New Zealand's pastoral land, mostly hilly or rolling, is used to raise sheep and beef animals under a range of management regimes and climatic conditions. The large diversity of sheep beef production is a challenge for this review as it is not possible to analyse every form of production or region with the detailed approach needed to assess adaptation. However the diversity is also as an asset for the sector. With profitable sheep beef production occurring in almost all of New Zealand's climatic environments – from 450 to-1400mm annual rainfall – high levels of adaptive capacity are already in place, and provide knowledge and experience to build longer term responses.

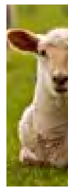
Most sheep and beef farm systems are extensive, with low fertiliser and purchased feed inputs. That means their profitability and sustainability are especially sensitive to climate conditions. Experimental field research has shown that pastures are very also responsive to elevated CO_2 levels, so future pasture production is going to be different. This section presents the best estimate of what these changes will be in specific locations. However, several issues currently under research could alter future hill country sheep and beef operations, including changes in nitrogen fixation and herbage quality in response to higher temperatures and CO_2 levels.

Impacts

The general impacts of climate change on the pastures are similar for the sheep-beef and dairy sectors – it is important for managers to review these general effects which are described in more detail in the dairy section. However, less intensive grazing management means that pastures do respond to climate pressure differently in an extensive sheep-beef system. For this reason it is necessary to go beyond the general evaluations and undertake a more detailed farm systems analysis. This also allows adaptation options to be assessed for the sector.

To provide a sample of the production diversity in the sector – but still carry out the detailed analysis required, three farm types were carefully selected: an extensive finishing-breeding operation in Southland, a hill country farm in Hawke's Bay and a 'hard' hill country farm in the Waikato. Together, these three farm types account for nearly 70 per cent of New Zealand's sheep and beef stock units, but do focus on higher performing units in average to above-average rainfall zones.

A farm modeling system was used to project future pasture growth rates under a range of future climate scenarios. Impacts on the profitability of three hill country farms could then be examined. The farm systems were then adapted by making changes to the management systems, after which profitability was re-assessed.



This detailed analysis confirmed that the general climate change impacts hold on hill country farms. Impacts are both positive – such as dry matter gains – and negative, such as greater variability in feed supply. This more specific sheep-beef system analysis provides some new insights, where changes in the seasonality of pasture growth were evident, in line with rising temperatures, CO_2 fertilisation and changes in rainfall patterns. Site by site, results showed that:

- In Southland, total annual dry matter production increased with climate change, allowing more stock to be carried. There was a marked shift in the seasonality of the pasture growth curves, with the spring peak occurring earlier, as well as a drop in dry matter production in the late summer/autumn 'shoulder' (Figure 4).
- In the Hawke's Bay, total annual dry matter production increased only slightly with climate change. As in Southland, there was a marked shift in the seasonality of pasture growth curves: the most obvious being a decrease in summer dry matter production (Figure 5).
- In the Waikato, annual dry matter production increased by just over 10 per cent, and, as with the other two sites, there was a change in seasonality, with more growth in spring, and lower growth rates in the autumn (Figure 6).

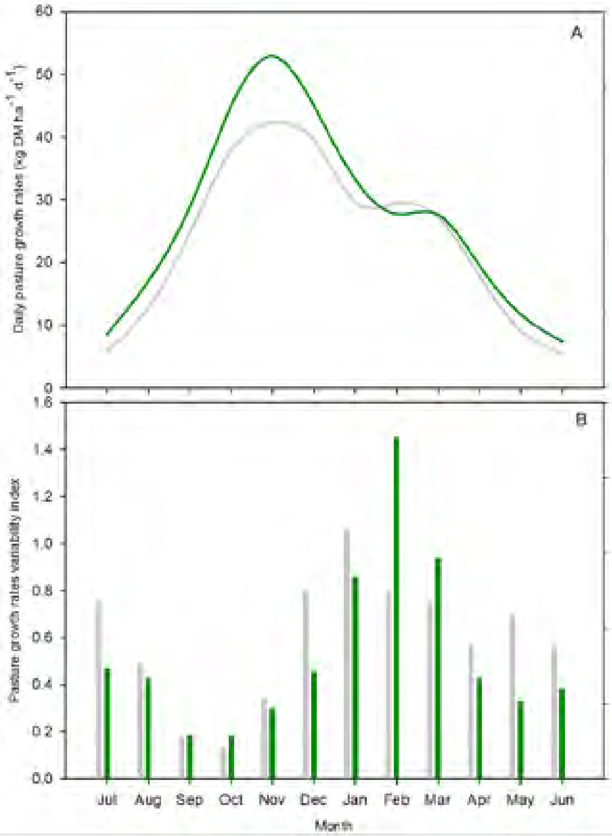
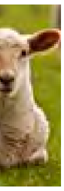


Figure 4. Projections of monthly pasture growth rates under the high climate change scenario for the 1990 (grey) and 2040 (green) time periods in Southland. (A) Average monthly pasture growth rates. (B) Variability in the 20-year monthly growth rates (B; calculated based on the 90th, 50th and 10th percentiles).



"Impacts are both positive – such as dry matter gains – and negative, such as greater variability in feed supply."

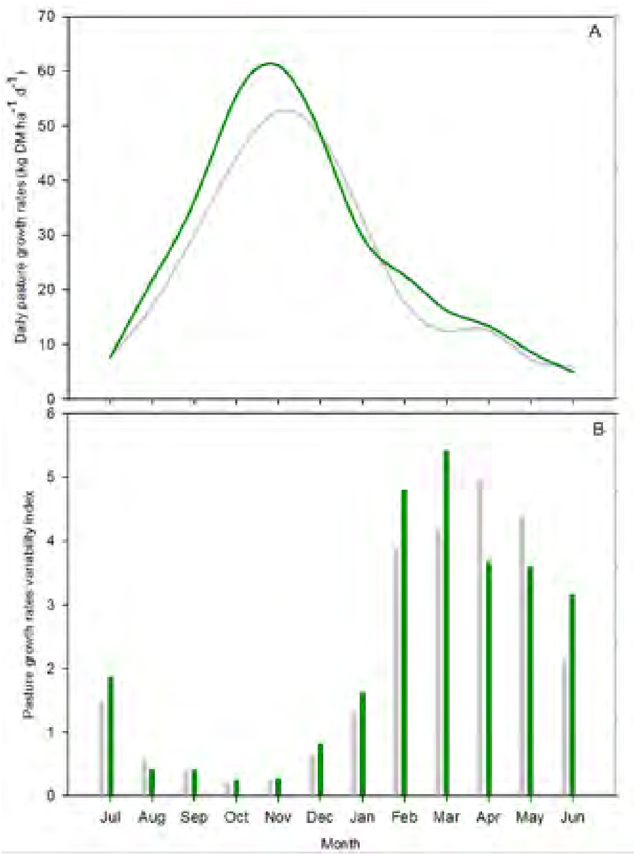


Figure 6. Projections of monthly pasture growth rates under the high climate change scenario for the 1990 (grey) and 2040 (green) time periods in Waikato. (A) Average monthly pasture growth rates. (B) Variability in the 20-year monthly growth rates (B; calculated based on the 90th, 50th and 10th percentiles).

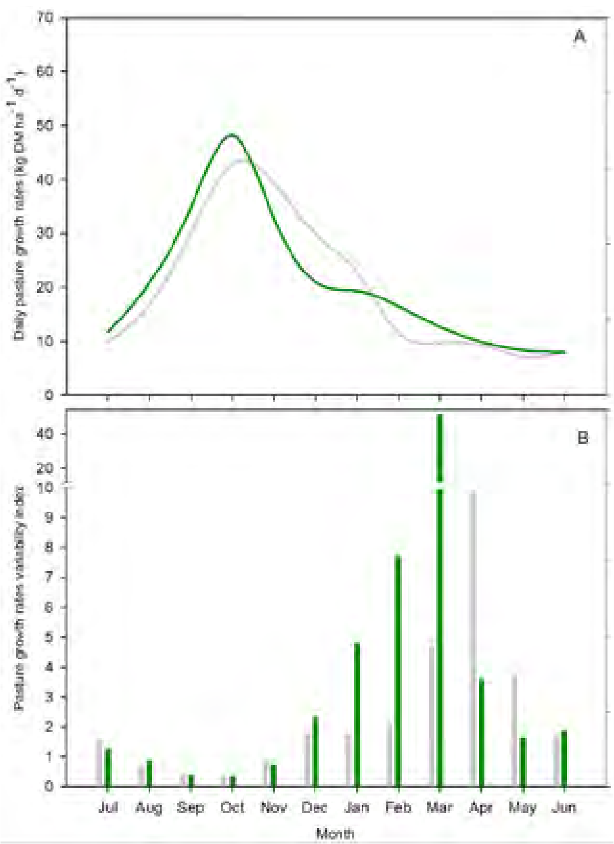


Figure 5. Projections of monthly pasture growth rates under the high climate change scenario for the 1990 (grey) and 2040 (green) time periods in Hawke's Bay. (A) Average monthly pasture growth rates. (B) Variability in the 20-year monthly growth rates (B; calculated based on the 90th, 50th and 10th percentiles).

Adaptation options

Extensive sheep beef systems do not have the option of controlling their inputs to the same extent as intensive production (dairy, horticulture or meat finishing). Options like the choice of plant material, irrigation, or adjusting fertiliser or pesticides are limited in hill country. As a consequence, extensive farmers accept and manage direct climate impacts, and a survey of general adaptation options is in Table 5. The information note on drought identifies some additional adaptation options that target this risk. At a general level:

> ***"There is sufficient existing understanding to not only reduce any negative impacts, but take advantage of potential opportunities."***

- The sheep beef sector has a wide range of management responses (tactical adaptation) that deal with the significant regional and microclimatic variability found in New Zealand. These are likely to be ideal under low level climate changes, if they are within the bounds of existing region-to-region variability.
- If climate change is too great for this level of adaptation many of the necessary strategic adaptation options already exist. This involves transferring knowledge and experience between regions that currently differ substantially in climate variability. General responses involve making large adjustments to stocking rates, and/or the amount and timing of forage conservation. There are also more transformational options such as changing locations or more comprehensive system and land use changes.

Biologically-based industries will inevitably be affected by a changing climate and increasing CO_2 concentrations. There is sufficient existing understanding to not only reduce any negative impacts, but take advantage of potential opportunities. These require careful consideration as part of farm planning and in some cases regional planning. A suite of options are summarised in Table 5, while the information note deals with approaches to managing drought.

On-farm implementation and evaluation of these general adaptation options requires a far more detailed and site-specific approach. A subset of these general options was tested in detailed modelling for the three farm types. Although the farm decision-making environment is complex, simple management rules can be used to evaluate the main factors. The options analysed were buying or selling supplementary feed, and bringing in contract grazing animals. The modelling results illustrated that:

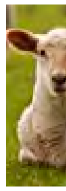
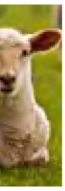


Table 5. Impacts and adaptation to climate change on hill country sheep and beef enterprises.

Impact	***Tactical***	***Strategic***	***Transformational***
Changed seasonality in pasture growth; in particular increased spring growth and loss of autumn 'shoulder' in Southland and Hawke's Bay	Earlier lambing Faster lamb growth rates (through higher plane of nutrition) Increased flexibility in stock number Increased feed conservation (hay)	Faster lamb growth rates and increased reproductive efficiency (through selection and breeding) Out of season lambing Irrigation	
Increased variability in annual feed supply particularly in Hawke's Bay	Increased flexibility in stock number Purchase of supplementary feed and feed conservation	Exchange of stock and feed between regions Faster lamb growth rates and increased reproductive efficiency (through selection and breeding) Increased unit size Grow drought tolerant species	Change location Change whole farming system or land use type

- Gross margins for a non-adapted 1990 Southland farm system under 2040 conditions increased. However, adapting the system – primarily by increasing lamb growth rates to take advantage of earlier, more vigorous spring growth – realised further gains in gross margin. Lambing percentages increased, driving an overall increase in whole farm reproductive efficiency (Figure 7).
- By making tactical changes to stock policy in the Hawke's Bay system – primarily by increasing lamb growth rates and finishing them faster – the adapted 2040 farm system held on to 1990's median gross margin (Figure 8).
- For Waikato, applying the 1990 management system to the pasture growth curves projected for 2040 made little impact on the median gross margin of the enterprise. However, tactical adaptation not only increased the median gross margin substantially, but the inter-annual variability in gross margin decreased as a consequence (Figure 9). A major issue in Waikato was how to deal with excess feed. The simple management rules assumed that excess feed would be converted into hay, and used for contract grazing of dairy heifers. However, especially on the hard hill country modelled here, it is unlikely that haymaking or heifer grazing can be carried out to the extent modelled in this exercise.



The comparisons need further refinement before any options could be implemented, but they highlight that sufficient strategic-level flexibility exists in current beef-sheep production systems to manage a range of climate changes.

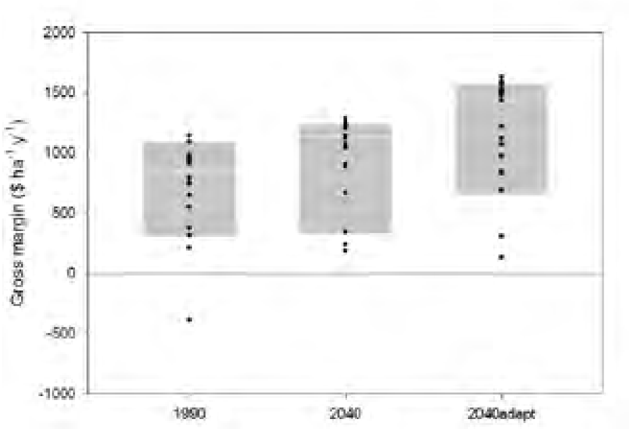


Figure 7. Boxplots of the gross margins for Southland using the high climate change projections for: the current farming system in the time period 1980–1999 (labelled "1990"); the current farming system with projected pasture growth for 2030 – 2049 ("2040"); and an adapted farming system with projected pasture growth for 2030 – 2049 ("2040adapt"). The bottom boundary of the box indicates the 10th percentile, the line within the box marks the 50th percentile (median), and the upper boundary of the box indicates the 90th percentile. The individual annual gross margins are also shown.

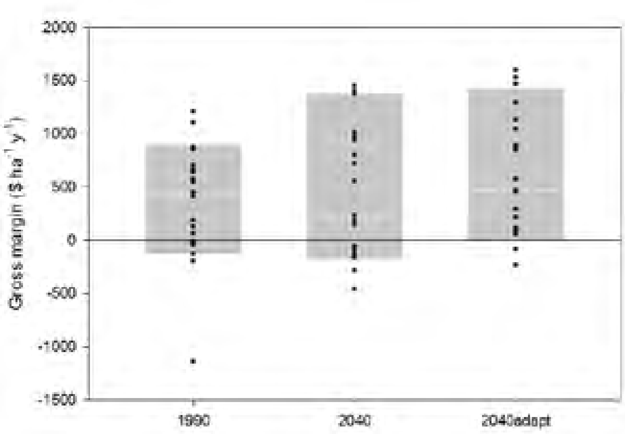


Figure 8. Boxplots of the gross margins for Hawke's Bay using the high climate change projections for a) the current farming system in the time period 1980 – 1999 (labelled '1990'); b) the current farming system, with projected pasture growth for 2030 – 2049 ('2040') and c) an adapted farming system, with projected pasture growth for 2030 – 2049 ('2040adapt'). The bottom boundary of the box indicates the 10th percentile, the line within the box marks the 50th percentile (median), and the upper boundary of the box indicates the 90th percentile. The individual annual gross margins are also shown.

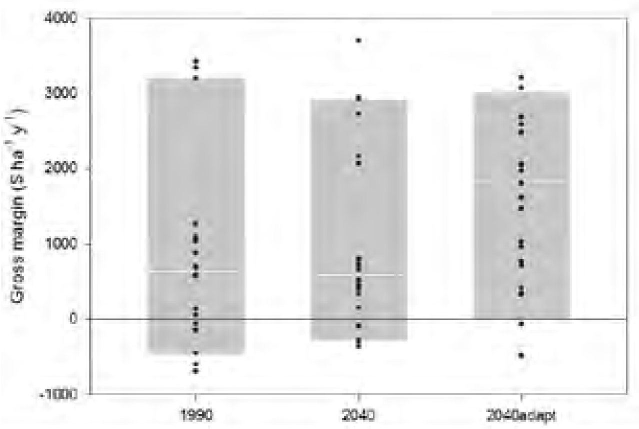


Figure 9. Boxplots of the gross margins for Waikato using the high climate change projections for a) the current farming system in the time period 1980 – 1999 (labelled '1990'); b) the current farming system, with projected pasture growth for 2030 – 2049 ('2040') and c) an adapted farming system, with projected pasture growth for 2030 – 2049 ('2040adapt'). The bottom boundary of the box indicates the 10th percentile, the line within the box marks the 50th percentile (median), and the upper boundary of the box indicates the 90th percentile. The individual annual gross margins are also shown.

Knowledge gaps

There are a number of key knowledge gaps which, if addressed, would contribute to the sectors adaptation options:

- Given diversity in the sector further analysis is needed to understand the impacts and adaptation on average to lower performing units.
- More information is needed on the consequences of increased frequency of poor years, particularly when they occur consecutively.
- It is possible that greater variability in future pasture production will demand more feed and stock movements between regions. However, it was not possible to test whether droughts might be more likely to occur simultaneously in neighbouring regions in future. If they are, tactical adaptation options, like buying and selling supplements, would be more difficult to implement.
- Feed conservation was an important method of dealing with pasture surpluses and transferring energy to other times of the year. The practicality of increasing pasture conservation, and the consequences for pasture quality of not conserving, have not been considered here.
- Hill country farms differ in aspect, slope and altitude, and these factors can have marked influences on pasture productivity. Understanding how these microclimates are affected by change, and the degree to which they provide new opportunities or further management options is important.
- The analysis did not include the potential influence of climate change on weeds, N fixation (the major source of N in hill country farms), animal diseases, feed intake and heat stress.

Overall, climate change brings a generally positive outcome for pasture growth in New Zealand. However, the likely changes in seasonality present substantial challenges to farm management in dealing with both excess feed and feed shortages. There are some promising adaptation options that can maintain or increase farm profitability under mid to moderate climate changes.

Technical Report Chapter 4: Sheep & Beef
Beef and Lamb New Zealand has a range of resources and guides relating to pasture management, improving lamb and beef genetics and other adaptations:
www.beeflambnz.com
The Ministry for Primary Industries has a number of practical climate change case studies were farmers have implemented adaptation options:
www.mpi.govt.nz

Dairy (p17-23)
Sheep & Beef (p25-31)
Broad acre cropping (p35-39)
Horticulture (p41-47)
Forestry (p49-55)
Water Resources (p57-65)

Adapting to changes in drought

Drought affects all primary production, but the arable and pastoral sectors (dairy, sheep and beef) are especially vulnerable to the relatively short, seasonal droughts typical of New Zealand. Future drought projections signal changes for some leading agricultural regions:

- These range from a doubling, to well over a doubling, of the number of major droughts in the most exposed regions by mid-century.
- Change is centred on the east coast, particularly Canterbury, but much of the North Island may also be affected.
- The most likely changes in major drought frequencies from the present to the future (2040) are in shown in Figure 10.

Enhancing resilience to drought now is a win-win strategy. Not only will it help farmers better prepare for these future drought projections, but also for the next few years, regardless of climate change trends.

- The main objective is to avoid as many direct impacts on production and income as possible, while better positioning a business for early and rapid recovery from drought.
- This can be realised through more flexibility, building more buffers into farm systems, setting fall back positions, having a plan before a drought hits and continually learning from drought.

> ***"...a doubling, to well over a doubling, of the number of major droughts in the most exposed regions by mid-century."***

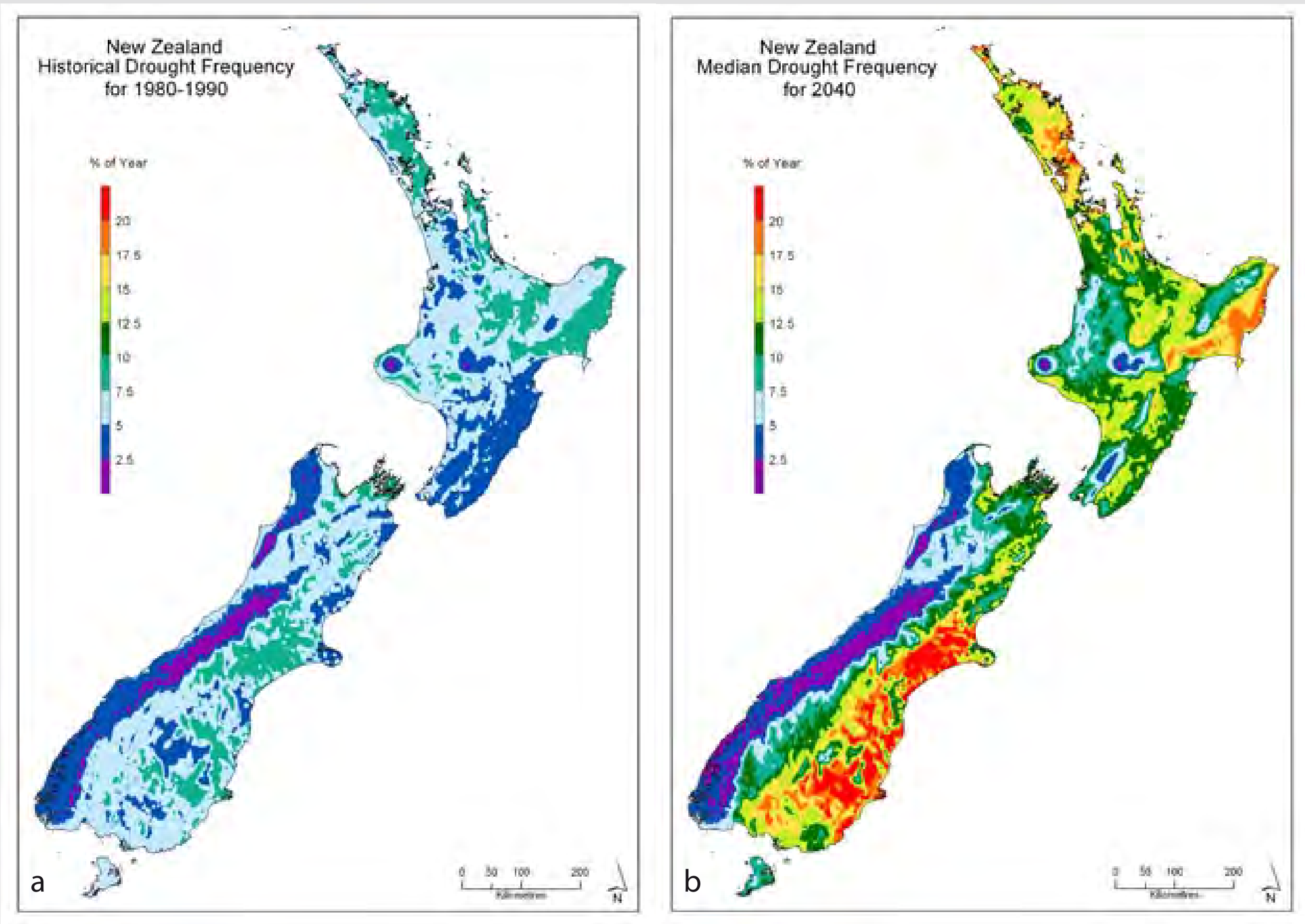


Figure 10. Most likely changes to drought under climate change. (a) Historical frequencies (1980–1990). (b) Future median drought frequency across all available models and 'mid-range' (A1B) emissions scenario. Droughts are defined as soil water deficits that last for a month or more below the 10th percentile at any time of year. The base period is 1980–1990.

Tactical adaptation solutions

- Feed production and storage for supplementary and ration feeding
- Purchasing low-cost feed during surpluses, and storing it
- Accurate pasture assessment and feed budgeting
- Responding early, through staged de-stocking and strategic culling
- Drought planning, including 'what-if?' analysis, based on a range of seasonal outcomes
- Monitoring performance so as to learn lessons
- Maintaining an emergency cash surplus
- Managing debt
- Rotating crops
- Using irrigation allocation
- Managing personal stress levels
- Achieving high production in good years.

Strategic adaptation solutions

- Conservation agriculture to improve soil water retention
- Pasture/crop species change and increased diversity, to respond to rain when it falls
- Improved irrigation efficiency
- Production diversity (multiple production systems)
- Income diversity (off-farm income sources)
- 'Out of phase' farming, to sell stock when there is a shortage, and buy when there is a surplus
- Building supportive communities.

Transformational adaptation solutions

- New crops and cultivars
- New irrigation schemes
- Better provision for stock transfer between regions
- Genetic innovation.

"Enhancing resilience to drought now is a win-win strategy."

For a practical guide to dealing with drought, access the Beef and Lamb dry conditions toolkit:
www.beeflambnz.com
For more information on droughts see the Government's On-Farm Adverse Events Policy and the drought case studies on the Ministry for Primary Industries website, or contact the local Rural Support Trust:
www.mpi.govt.nz
www.rural-support.org.nz

BROAD ACRE CROPPING

Notes

Horticulture (p41-47)
Adapting to changes in drought (p32-33)
Water Resources (p57-65)
Dairy/Sheep & Beef (feed and forage crops, p17-31)

Broad acre cropping

Key messages

- Assuming adequate water and soil nutrient supply, potential yields of temperate cereal crops could increase by as much as 20 per cent under future temperature and CO_2 concentrations.
- There are clear benefits in translating this potential into actualised profitable crop yields. This will require careful technological and managerial change, through adjustment in production timing and shifts in rotation, along with species selection and breeding to match the new environment.
- In some cases, yields of other crops, such as maize, peas and potatoes could slightly decrease, because high temperatures shorten the crop cycle and reduce the time available for sunlight interception and photosynthesis. These negative impacts can be minimised by adapting crop management.
- Summer crops may become increasingly difficult to grow in regions with diminishing water supplies. Improving irrigation practices and water use efficiency, as well as building drought resilient systems, are key strategic adaptation solutions. New crops, and new or improved irrigation infrastructure, are additional strategic adaptation options.
- An ongoing dilemma is how to meet local and global crop demand while avoiding further environmental impact.
- Climate change impacts on overseas markets and crop producers will affect broad acre farming in New Zealand through international trade.

Introduction

Globally, broad acre crops such as wheat, maize and rice provide nearly half the calories consumed by humans. In New Zealand, broad acre cropping covers a range of land uses, and arable crops such as wheat, barley, maize and oats cover around 165,000 ha. Vegetables, such as potatoes, onions, peas, carrots and seed crops, cover some 55,000 ha, while forage crops like maize – along with cereal silage and brassicas for grazing – occupy more than 350,000 ha. These crops are frequently grown in intensive, flexible rotations.

The exact makeup of broad acre crop rotations varies between regions. Crops are chosen according to current market value, within the particular constraints imposed by local soil and climate.

Impacts

Climate change is likely to affect both the yield and quality of broad acre crops in New Zealand. Increases in atmospheric CO_2 stimulate canopy photosynthesis – especially in temperate C3 crop species – and reduce water requirements for leaf transpiration. Warmer temperatures may also stimulate crop yields, making for faster emergence, canopy development and growth rates during winter, spring and autumn, when most crops are inhibited by cold temperatures.

"...changing sowing dates, using varieties with different maturity, or shifting to alternative crop species."

However, such accelerated crop development also shortens crop cycles, reducing the time available for sunlight interception and photosynthesis.

Changes in rainfall – amount, seasonality and year-to year-variability – affect the risk of drought and floods. These can have severe impact on crop yields and, sometimes, quality. Climate change also alters the incidence and activity of plant pathogens, insects and weeds, which could reduce yields and compromise crop quality.

Simulation modelling can explore the complex interactions between climate change effects and their consequences for crop yields.

Setting aside the unknown impacts of pests and extreme events, projections for 2030–2050 indicate that potential yields of temperate cereals, such as wheat and barley, could increase by up to 20 per cent. This is due to the boost in photosynthesis from extra CO_2 fertilisation and higher temperatures, which would offset any negative impacts from shorter growth lengths caused by faster crop development.

Similar potential yield increases are projected for forage crops, like winter cereals and brassicas, which are harvested in a vegetative state and have longer periods to grow, thanks to the shortening of cycles of adjacent annual crops.

For other crops and locations, climate change effects were more variable, and some were slightly negative. Without adaptation, yields of forage crops, such as silage maize, along with more temperature-sensitive crops like potatoes and peas, are reduced under some climate change scenarios.

In these cases, shortened growth cycles – due to accelerated development driven by higher temperatures – overpowered the CO_2 fertilisation effect on photosynthesis, which is less pronounced in C4 crops such as maize.

The combination of warming with varieties that have low CO_2 fertilisation response– particularly in scenarios where the isn't a strong drying effect – demand adaptive measures that shift the growth period to cooler times of the year. This can be achieved either by changing sowing dates, using varieties with different maturity, or shifting to alternative crop species (see Table 6).

Table 6. Adaptation options for broad acre cropping.

Tactical	*Strategic*	*Transformational*
• Change in crop calendars • Change in crop varieties • Use of conservation agriculture • Improvement in soil water and irrigation management • Improvement in soil nutrient management • Improvement in pest management	• Change in crop species • Develop new 'climate-resilient' genotypes • Use of precision agriculture • Monitoring and forecasting programmes • Irrigation development and expansion	• Develop new cropping systems • Development and adoption of innovative technologies • Change to alternative land uses

Adaptive capacity

When climate change favours crop growth, the adaptive options – outlined in Table 6 – must ensure that any potential gains are fully realised through the provision of adequate water, nutrients and differential crop management. Most tactical adaptation options – and some strategic ones, such as the development and expansion of irrigation – suit this purpose (see Table 6).In a warmer future, catchment hydrologies could well alter, as may water allocation policies. This could see irrigation allowances constrained. To explore these impacts and the effectiveness of adaptive options, the APSIM model was used to evaluate yield responses under just such a scenario.

A crop rotation of wheat, barley, kale and greenfeed crops in Canterbury during 2030–2050, under the high climate scenario, assumed decreasing irrigation allowances and two irrigator types with contrasting efficiencies (roto-rainer and centre-pivot).

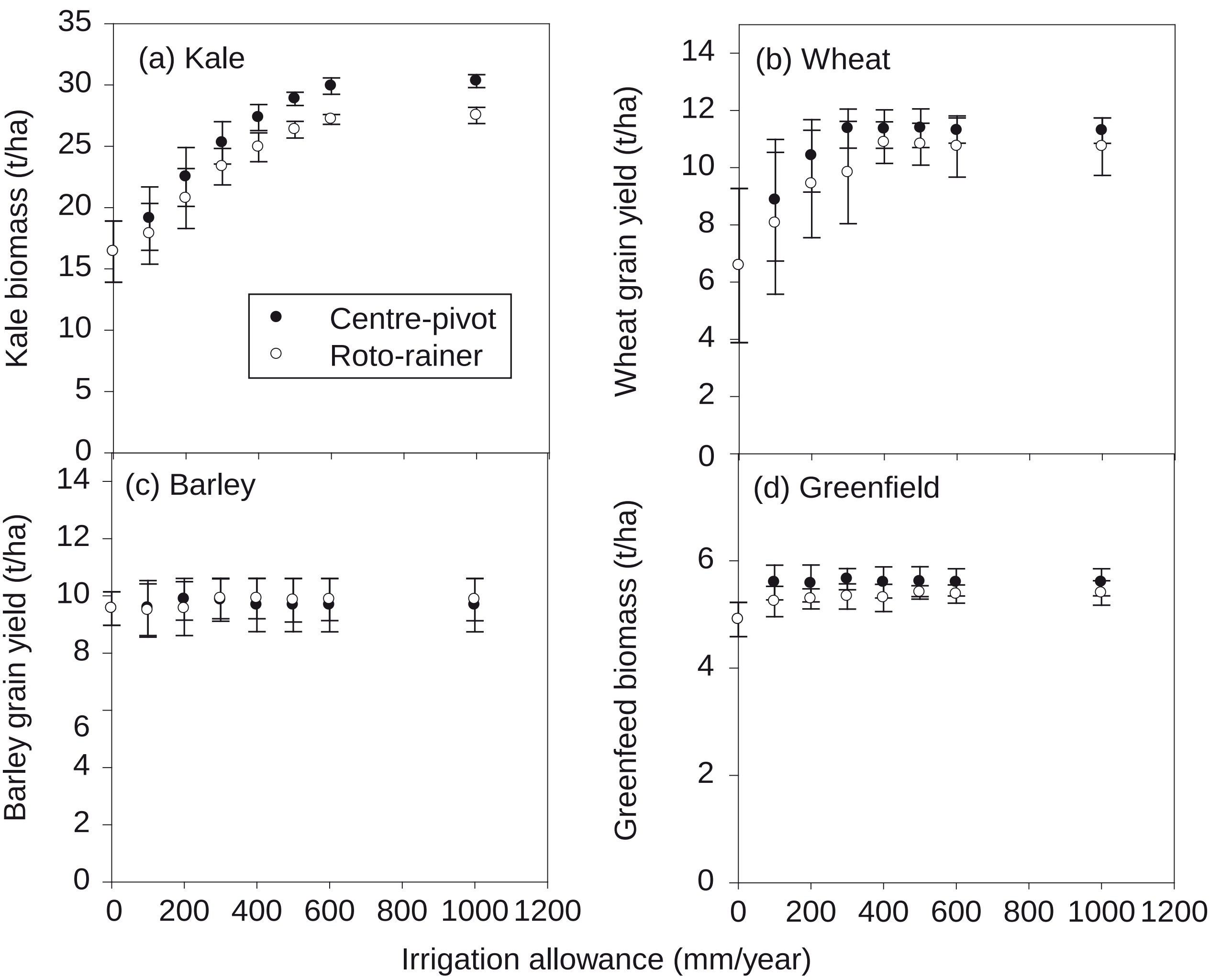


Figure 11. Simulated yields of four crops grown in a rotation in Canterbury assuming contrasting maximum annual irrigation allowances from 0 to 1000 mm, two irrigation systems (centre-pivot and roto-rainer) for the high emissions scenario from 2030–2049. Error bars delimit the 25th and 75th percentile of 20 year simulations.

The analysis showed that summer crops – represented by forage kale – were the most sensitive to restricted water allocation, producing only half their attainable yield when grown under dry-land conditions (Figure 11).

In contrast, crops such as wheat, barley and greenfeed, grown during cooler periods when water demand is lower, would suffer less from irrigation constraints. Use of more efficient irrigators, such as centre-pivots instead of roto-rainers, consistently improved yields of all crops, particularly in light soils with low water storage capacity.

Growing crops in soils with higher water holding capacity also ensured greater resilience to the effects of limited water allocation. Careful selection of crop location based on accurate understanding of soil properties is an example of adaptation to limited water supply.

Stronger climatic changes might require more expensive 'strategic' adaptation options. For example, developing and expanding irrigation infrastructure might increase the resilience of arable systems to high uncertainties in rainfall. Such uncertainties are what most dramatically impact crop yields in free-draining soils.

Similarly, plant breeding and selection programmes could target new crop varieties better suited to drier, warmer conditions – perhaps with deeper root systems and/or different maturity.

Extreme climate change might demand long-term investment in transformational adaptive options. That could mean, for instance, establishing new broad acre cropping industries in New Zealand, such as rice or soybean. Or, investing in research and development of crop species with radically improved physiological characteristics. It may be possible in the future to breed crops which have more efficient photosynthesis and drought resilience. In some circumstances, it may be most expedient to adopt alternative land uses, like dry-land livestock or agro-forestry.

Knowledge gaps

More studies are needed to improve the accuracy of climate change impacts and adaptation assessments for broad acre cropping systems. Remaining knowledge gaps include:

- Data on experimental results from comparison of adaptive options.
- Uncertainties in rainfall projections (amounts and seasonality) that largely impact crop yield.
- Climate projections and crop responses to extreme events such as heat waves, severe droughts and floods, which are not well represented in current models:
   - › The magnitude of CO_2 fertilisation under farm conditions.
   - › The unknown impact of climate change on yields through biotic factors such as insects, diseases and weeds.

Historically, advances in agricultural technologies have had profound effects on global and regional crop production. It is still uncertain whether future technological advances will have similar effects in a warming climate, either by reducing yield gaps – the difference between actual and potential yields – and/or by increasing potential yields.

The fortunes of New Zealand broad acre crops will not be determined by local impacts alone. The impact of climate change on other key producing countries, the balance in global supply and demand for food, changes in commodity prices, trade policies and the viability of alternative land uses will all play their part. All these factors will influence New Zealand's broad acre sector, and our choices, as we adapt to a warmer world.

"...any potential gains are fully realised through the provision of adequate water, nutrients and differential crop management."

Technical Report Chapter 5: Broad acre cropping

Industry organisations such as Horticulture New Zealand and the Foundation of Arable Research have information on adaptation options and climate impact assessments:

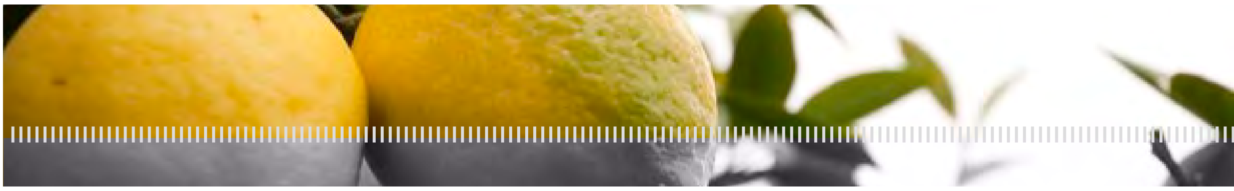
www.hortnz.co.nz

www.far.org.nz

Climate change fact sheets and case studies are available from the Ministry for Primary Industries:

www.mpi.govt.nz

HORTICULTURE



Notes

Broad acre cropping (p35-39)
Adapting to changes in drought (p32-33)
Water Resources (p57-65)

Horticulture

Key messages

- The main impacts on apple, kiwifruit, and grape growers will be increases in vegetative biomass, pest/disease risks and changes in plant development.
- The sector has considerable adaptive capacity, in that growers can relocate and expand relatively rapidly, as exemplified by the recent spread of vineyards.
- Growers have a range of tactical adaptation options. A favoured approach is to shift harvest timetables, in combination with altered pruning regimes, to ensure yields and quality meet market demands.
- Strategic adaptation options, such as planting new, more climate change-tolerant varieties, can be considered.
- Climate change will exacerbate water demand, and irrigation management will probably need refinement, depending on soil type. New irrigation schemes are a key transformational change for the sector.

Introduction

Horticulture is a NZ$6 b industry. Export revenues from wine, kiwifruit and apples total some NZ$3.4 b in 2011/12 – realised from just 55,000 ha of land. Marlborough is the country's grape-growing hub, while the bulk of kiwifruit are grown in the Bay of Plenty. Hawke's Bay is the major apple-producing district. Commercial vegetable production also makes a large contribution to New Zealand's economy, through both domestic revenues and export earnings (NZ$560 m in the 2011/2012 season). Vegetable production is spread widely across the country, but production is centred in Canterbury, Hawke's Bay, Auckland, Manawatu-Wanganui, Gisborne, and Waikato. Impacts and adaptation options for some crops like potatoes and brassicas are described in the section on broad acre cropping.

Impacts

The impacts of yield from temperature rises, CO_2 increases, and rainfall changes were modelled based on the Primary Sector Adaptation Scenarios. 2050 was a target year for perennial horticultural crops, and five local soil types were considered for each of the three regions – Marlborough, Bay of Plenty and Hawke's Bay. Five local soil types were considered for each region. Responses to climate change include shifts in biomass production, changes in crop phenology from winter chilling through bud break to harvest date, plus the impact on fruit quality. The need for irrigation, and changes in groundwater recharge underneath crops, was investigated; as well as the impacts of extreme high temperatures and frosts.

"Responses to climate change include shifts in biomass production, changes in crop phenology from winter chilling through bud break to harvest date, plus the impact on fruit quality."

Impacts on biomass and yield

Growers of perennial horticultural crops currently prune to control vegetative vigour, and to ensure appropriate fruit yields and quality. To attain the sort of fruit sizes demanded by markets, they control flower numbers.

Generally with current interventions, tactical adaptation should see vegetable, as well as fruit and berry yields across the three main export crops, hold steady. In the case of apples, they might increase slightly.

Apples

By 2050, Royal Gala above-ground dry matter production in the Hawke's Bay is expected to increase by 17.5 per cent, under the high emissions scenario. To limit vigour, winter pruning will need to be stepped up accordingly. Hawke's Bay fresh-weight apple yields are tipped to rise from 85 tonnes (T) per hectare (ha) to 90 T/ha under the low scenario, and to 97 T/ha under the high scenario.

Kiwifruit

Winter chilling is already an issue for floral initiation in kiwifruit, and some growers spray with hydrogen cyanamide (HC) to ensure optimal king flower set on winter buds. Without HC, the fresh-weight yield of 'Hayward' green kiwifruit is presently estimated at 29 T/ha in the Bay of Plenty. However, under the low emissions scenario, that yield is expected to drop to 27 T/ha; and it drops to 26 T/ha under the high scenario.

Health concerns could yet see HC phased out. However, in the event of its continued use – or use an equally effective alternative – current yield, around 33 T/ha, is predicted to remain static under the low scenario, and to fall to 32 T/ha under the high scenario. Tactical intervention, therefore, would remain effective.

Grapes

Marlborough grape growers currently employ various interventions – such as pruning, leaf trimming and bunch thinning – to curb 'Sauvignon Blanc' yield to about 10T/ha of fresh-weight. This is an industry strategy to prevent oversupply. The simulations predict a current yield of 12.6 T/ha. Under the low scenario, this is predicted to decline slightly to 12.3 T/ha, and to 11.8 T/ha under the high scenario.

Vegetables

The direct impact of increased temperatures on vegetable production will be a balance of two effects. Warmer temperatures will extend the potential growing season, thereby allowing earlier planting and later harvest. On the other hand, the period of growth for any given planting will generally be reduced, because higher temperatures will lead to more rapid plant development. Warmer temperatures may also escalate pest and disease incidence. However, in some eastern regions, a predicted drop in rainfall and humidity could actually reduce disease pressure.

Increased atmospheric carbon dioxide concentrations are likely to increase yields of some vegetable crops. Increased yields of onions, beetroot and carrots have been reported, but other crops, such as French beans, showed no response to increased CO_2 levels. Any increases in yields from carbon fertilisation will, to some extent, be counteracted by the reduced period of growth prompted by higher temperatures. Elevated atmospheric CO_2 has also been shown to decrease the nitrogen-to-carbon ratio in plant tissues, which may reduce the nutritional value of some vegetables.

Changes in rainfall patterns due to climate change will affect vegetable production. Higher temperatures will drive up plant water use, so the vegetable industry will become more reliant on irrigation in some regions. It is possible that increased seasonal rainfall and storm intensity in some regions will exacerbate crop damage due to waterlogging, flooding, or soil erosion.

Impacts on phenology and quality

Changing temperature patterns will significantly influence crop development of perennial trees and vines, altering timing and stage length.

Apples

There is already an overabundance of flowers on apple trees, which is dealt with by either chemical or manual thinning. The impact of climate on fruit quality traits is limited to the period between flowering and harvest. The flowering date of 'Royal Gala' apples in the Hawke's Bay is expected to shift from October 7th to October 3rd under the low emissions scenario, and to October 2nd for the high.

The season length – currently 134 days – will shrink. Under the low scenario, it will contract to 127 days: under the high, to 124. Fruit diameter of Royal Gala is expected to rise slightly, from 79.7mm to 80.4mm under the low scenario, to 81.9mm for the high scenario.

Kiwifruit

In the Bay of Plenty, in the absence of HC, the date of 'Hayward' kiwifruit bud break is expected to be some 12 days later than it is today, under the high scenario. Flowering date is unchanged, but harvest (typically when the fruit reach Brix 6.5°) is projected to happen seven days later than it does now. Fruit mass and dry matter content should remain largely unchanged.

Grapes

Grapes are harvested at Brix 21.5°. In Marlborough, bud break in Sauvignon Blanc grapes is projected to happen four days earlier than it does now, while flowering could happen 10 days earlier. Veraison will occur 15 days earlier, and harvest will begin 21 days earlier than today.

Vegetables

For some crops at some locations – especially green-leaf crops such as lettuce – an additional rotation may become possible within the growing season. However, the shortened timeframe between planting and harvest can have a negative impact on vegetable quality. For example, higher temperatures can lead to premature seed head development in some crops, or delay curd initiation and increase leaf number in cauliflower.

Other impacts

Horticulture also experiences effects from extreme high temperatures and frost, and climate change may modify the frequency of these events in the future.

Grape high temperature hours (HTH), defined as when air temperature exceeds 32°C, can be estimated readily with models. Marlborough averages just one HTH a year, although the record maximum is seven. The median number of HTHs by 2050 is expected to be three (with a maximum of 21) under the low scenario, and six (maximum of 28) under the high scenario. Such high temperatures could degrade fruit quality, and adaptation will be needed in Marlborough and other grape growing regions.

Calculations of frost likelihood, when air temperatures drop below 0°C, took into account the changing patterns of bud break and harvest. This was considered across 11 regions for apples, kiwifruit and grapes. Generally, any effect from fewer spring frosts will (to some extent) be offset by earlier bud break. There should be fewer damaging autumn frosts in most areas.

Adaptation

Many of the anticipated impacts of climate change on these fruit crops will be positive. Yields should rise, or at least be sustained. Fruit size and fruit dry matter should similarly increase. Frost risk will lessen – or at least not worsen. There will, however, be some potentially negative impacts which will demand adaptation. Horticulture has a range of adaptation options that can be used to respond to these impacts (Table 7).

Tactical adaptation

Winter pruning, by laying down the correct wood types and number of buds, sets up the next year's crop, while summer pruning controls vegetative growth and competition between plant resources. In future, while frequency of pruning will remain unchanged, summer pruning may need to be more intensive.

Higher temperatures will require more overhead netting, driving up capital investment. However, there may be additional benefits, such as less wind rub, more protection

Table 7. Horticulture adaptation strategies.

	Apples	***Grapes***	***Kiwifruit***	***Vegetables***
Tactical	• Winter pruning • Summer pruning • Sunburn protection • Overhead netting for protection • Enhanced irrigation management	• Winter pruning • Summer pruning • Over-vine netting for protection • Enhanced irrigation management	• Winter pruning • Summer pruning • Girdling • Chemical enhancement of flowering • Overhead netting for protection • Enhanced irrigation management	• Planting new cultivars • Shift locations of crop sites • Adjust sowing and harvesting schedule
Strategic	• New cultivars • New irrigation schemes			
Transformational	• Contraction in existing areas • Expansion into new regions			

from storms and hail, and less sunburn. This will reinforce an emerging trend in perennial tree and vine crops, both here and overseas.

Climate change will exacerbate water demand, and irrigation management will probably need refinement, depending on soil type. However, improvements may well bring down costs, thanks to lower water charges. With the right management, they could even enhance fruit quality.

Currently, kiwifruit quality is enhanced by girdling, despite some concerns that the practice might offer more entry points for diseases such as the kiwi fruit vibe disease PSA. Better understanding of optimal girdling times, and perhaps new technologies, could make for cost savings in future.

Some growers presently use hydrogen cyanamide to boost kiwifruit flowering: if this chemical should be banned, it might create a major problem for the 'Hayward' variety. So far, alternatives have not proved particularly effective, and it may be that more strategic or transformational change will be needed to maintain flower numbers and yields.

Current apple flowering is excessive, but climate change might reduce the need for chemical and manual thinning to control it.

Development of new vegetable cultivars is already very much part of New Zealand's vegetable industry – and this is expected to be an important aspect of adaptation to climate change. While New Zealand's major fruit crops are perennial, most vegetable crops are annual. Therefore, changes to new vegetable cultivars – or different crops – can be rapidly implemented in a single season.

Commercial vegetable production is generally part of a multi-annual rotation cycle that involves other crops and pastures – frequently on leased land. This flexibility means that locational shifts in response to climate pressure are a well proven tactical adaptation. As regional climates change, innovative growers might be expected to trial different crops, which may be better adapted to warmer conditions.

Strategic adaptation

New cultivars are regularly introduced across all horticultural sectors, but the strategic focus in a changing climate will be to select appropriate varieties for each region. This should be possible, given that there is sufficient genotypic variation in current germplasm holdings.

Cultivar change might force marketing costs onto regions already well-known for iconic varieties, such as Marlborough's Sauvignon Blanc. Such sweeping strategic shifts, however, are not anticipated before 2050.

The Government's Irrigation Acceleration Fund will drive new schemes that should benefit horticulture. Though capital costs are high, the benefits are correspondingly large. But while many proposed schemes take future climate change into account, its impacts on future irrigation resources are not well understood.

Transformational adaptation

Innovative growers and industries, recognising the possibilities for growing new crops and cultivars, will expand or shift into new regions. New infrastructure will be expensive. However, that hasn't limited, for example, the expansion of viticulture into Marlborough over the last 40 years.

If those new regions already produce other horticultural crops, some infrastructure might already be in place. Regional shifts will also bring social costs, such as lost employment, but are likely to happen over an extended period, which may help minimise such impacts.

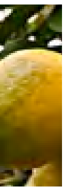
"New cultivars are regularly introduced across all horticultural sectors, but the strategic focus in a changing climate will be to select appropriate varieties for each region."

Conclusions

Horticultural production is highly managed, and many current interventions and/or adaptation options already encourage the production of high-quality, fit-for-purpose fruit and berries. Tactical adaptation – such as irrigation, the use of chemical thinning, trimming, pruning and flower inducing sprays – are standard practice. Before 2050, these can be easily modified and employed to drive tactical adaptation to climate change.

There are already many strategic adaptation options in use, such as the introduction of new cultivars and infrastructural investments in overhead netting for hail protection and shading.

The horticultural industry – especially viticulture – is nimble. It has shown it can respond to economic opportunities with transformational change, exemplified by the spread of vineyards in New Zealand in general, and Marlborough in particular. Climate change may dictate transformational change, such as shifting existing crops to new regions, but – competition for land and water notwithstanding – the industry will respond.



Technical Report Chapter 6: Horticulture

The horticulture sector is supported by a training information portal which describes strategies to manage current climate variability and increasingly adaptation options:

www.hortito.org.nz

Horticulture New Zealand and associated industry groups also provide information:

www.hortnz.co.nz

www.nzwine.com

www.zespri.com

Fact sheets and case studies are available from the Ministry for Primary Industries:

www.mpi.govt.nz

Notes

FORESTRY

Notes

Primary production under higher carbon dioxide (p15)
Adapting to changes in drought (p32-33)

Forestry

Key messages

- Forestry has a different impact profile and planning horizon to the other land-based sectors, given its relatively slow biological response rate and long harvest cycle.
- The most certain direct impact of climate change is increased yield of radiata pine in many plantations.
- Under climate change, forestry also faces less predictable – but expected – increases in risk from indirect impacts, from pests and diseases, fire risks and extreme storms, which may reduce productivity and compromise wood quality
- Forest companies already manage those same risks over a long planning horizon through adaptive risk management, but climate change is expected to exacerbate existing problems.
- Foresters have a range of tactical management options – such as silviculture and site and species selection – or interventions, like spraying and ongoing monitoring. Once production forests are established, options and opportunities for adaptation to site-specific impacts are reduced.
- As the forest sector learns more about indirect impacts, strategic and transformational adaptation becomes increasingly focussed on adjusting management to cope with them.

Introduction

Forestry provides about three per cent of New Zealand's GDP. With annual export earnings of NZ$4.3 b (2011/2012), it is New Zealand's third largest merchandise export earner. The sector employs 31,800 people, or 1.4 per cent of the national workforce.

New Zealand production forests are largely monocultures: radiata pine comprises 90 per cent of all plantings, while Douglas fir makes up just 6 per cent.

Forestry financial returns are realised after many decades – around 28 years for radiata, and between 40 and 60 years for Douglas fir. This means that management and land-use decisions made many years ago determine adaptation options today.

New Zealand research has shown that climate change is expected to improve radiata pine yields, and change the risk profile of indirect impacts from biotic and abiotic influences on tree productivity and survival.

This chapter reviews that research, within the context of wider international work on direct and indirect productivity impacts on radiata and other species. Recently-modelled productivity results for 2040 and the 2090s are reviewed, along with those developed using the Primary Sector Adaptation Scenarios. Relevant adaptation options from both Australian and other international research and reports are identified.

"Direct climate impacts are largely positive for tree growth. However, storms, wind and fire can seriously affect mortality and timber production..."

Impacts

With higher concentrations of atmospheric CO_2, radiata pine productivity is expected to increase in most plantations by an average of 19 per cent by 2040, and an average of 37 per cent by 2090. South Island plantations will receive additional benefit as warmer temperatures boost photosynthesis. Precipitation might decrease in some areas, but this can, up to a point, actually improve productivity, as trees use water more efficiently. However, where water or nutrients are in short supply, productivity will fall.

Direct climate impacts are largely positive for tree growth. However, storms, wind and fire can seriously affect mortality and timber production, as can climate-induced changes to the wider forest ecosystem, both direct and indirect.

Wind is a significant physical risk to forests. The degree of risk relates to a stand's vulnerability to toppling or breakage, and exposure is expressed as the critical wind speed at which damage occurs. Moderate increases in wind speed will not unduly affect many stands with a high critical wind speed, but vulnerable stands will be critically susceptible to even small changes in the wind climate.

Fire risk is evaluated as a combination of immediate weather, ignition sources and fuel loads. Forests that receive less rainfall, and face higher temperatures more frequently, will be placed at greater fire risk. Furthermore, climate change can alter the frequency, intensity and activity of fires, extending both the fire season and potential acreage burnt.

Increasing temperatures, higher wind speeds, and lower rainfall and/or humidity will see fire risk increase, particularly in coastal Otago and Marlborough, southeastern Southland and along the western North Island coast. An extreme climate change scenario also projects a heightened fire risk in the lower North Island and Bay of Plenty. However, more precipitation along the western coasts of both islands by 2090 could ease some of that risk.

A milder climate change scenario projects reduced fire risk in parts of Canterbury, Northland and Southland.

Browsing insects and pathogens can reduce productivity and degrade trees. Shifts in temperature and rainfall can prompt sometimes sudden expansions in pest populations, and their habitable geographic range. Climate can influence the growth and development of natural predators of pests, with consequent flow-on impacts. The pathogens and competitors that currently constrain pest numbers could

"New Zealand plantation forestry has so far prospered in the face of risk, through knowledge production and risk management strategies, both adaptive and reactive. But climate change will raise the stakes."

be similarly affected. Finally, climate change could stimulate physiological changes in tree defences.

Modelling can predict changes in suitable habitat for insects, pathogens and weeds under different climate scenarios: for instance, the geographic range of the pine processionary moth is projected to extend to 93 per cent of the plantation estate by the end of the century. Similarly, Dothistroma, a foliar pathogen which causes needle-blight, will cover the entire country by the end of the century under mid range climate scenarios.

While the incidence of the pathogen causing Swiss needle-cast (*Phaeocryptopus gaeumannii*), is not expected to change in a warmer and drier climate, its impacts are expected to intensify in a warmer, wetter environment. The incidence of *Armillaria* is expected to increase with rising temperatures, but a wetter climate might ameliorate that impact. Losses from fungal infections by *Sphaeropsis sapinea* (syn. *Diplodia pinea*) are predicted to increase in a warmer, drier climate, but not in a warmer, wetter one. Pitch canker (caused by *Fusarium circinatum*) is not yet present in New Zealand, but climate change will offer it a suitable range across most of the North Island, and in northern and coastal areas of the South Island.

Weeds are expected to respond to increases in temperature and CO_2 in much the same way as trees, subject to any constraints from rainfall, soil moisture and nutrient availability. They will also undergo changes in phenology and growing season. Overall, this will probably result in warm-adapted weed species colonising new locations. Current 'sleeper' species could become problematic as climatic zones shift, and weeds in general will exhibit increased productivity. Interactions with insects, pollinators, pathogens and disease might alter.

Wider weed distribution, and more aggressive growth, will increase competition with trees for nutrient and water resources, and probably lower stand productivity.

The climatic niche model, Climex, predicts that the distribution of *Buddleja davidii* to increase – albeit with much regional variation – particularly in the Southern Alps. Likely invasion areas are the south and east of the South Island, where disturbance typically associated with forest management will favour *Buddleja* establishment.

Wood properties critical to timber product performance are partly determined by temperature and water availability, which determines the rate and seasonality of growth. Generally, wood density decreases as growth rate climbs, though the relationship can be weak. Density also decreases under higher temperatures and water availability. However, conversely, it is also is affected by water stress, which alters the proportion of growth between earlywood and latewood cells. Thin-walled earlywood has a negative relationship with density, whereas thick-walled latewood has a positive relationship.

Adaptation

A long crop rotation length makes forestry a very different proposition from agriculture or horticulture. Today's young plantations will not be harvested until around 2040, and are growing in a changing climate. At less-than-optimal sites, climate change has the potential to cut productivity, while ramping up business and management risks. At more fortunate sites, on the other hand, with ample water and nutrients, temperature and CO_2 increases make for a more productive environment for both radiata pine and new species.

Managers need to review the vulnerability, impacts and risks their plantations face – especially around new forests. Adaptation strategies must then be carefully considered, because climate impacts manifest differently at successive stages of forest management.

To maintain profitability, and increase revenue and biological growth, forestry may have to overcome potentially significant impacts over the next century. Climate changes over the next 30 years are not expected to be catastrophic. However, likely changes in climate, such as increased variability and potentially more extreme events could exacerbate the detrimental impacts of biotic and abiotic stressors and/or disturbance. Prudent adaptation strategies can minimise the damage from those impacts.

New Zealand plantation forestry has so far prospered in the face of risk, through knowledge production and risk management strategies, both adaptive and reactive. But climate change will raise the stakes. Existing strategies need to be enhanced and re-prioritised, rather than new ones developed from scratch, to accommodate changes in risk profile.

Tables 8a and 8b present a summary of the anticipated impacts and potential adaptation options according to the type of adaptation. Transformational changes are considered separately as they have added importance for the forestry sector given its longer planning horizons.

Tactical adaptation

Forest managers have less flexibility than their colleagues in other land-based sectors: their adaptation options are constrained by the sunk economic value of the existing crop, and the long time frame before an economic return is realised.

Short-term climate change risk has limited catastrophic[1] impact. Changes in the severity, occurrence and geographic spread of different impacts can largely be addressed by existing risk management methods.

Managing the effects of extreme events, such as the establishment of new pests, or more severe storm damage, is part of a company's adaptive risk management processes, but solutions are not always obvious, easy, or cheap. Typical adaptive strategies to minimise risk include modifying silvicultural regimes – and the timing of forest operations such as thinning or harvesting – forest age class structure, developing fire-smart landscapes and re-engineering long-term infrastructure.

[1]Many risks identified could have catastrophic impacts, such as fire or a new pest. Catastrophic risk could occur where risk interactions are additive or multiplicative on each other, and from significantly increased range expansion, magnified severity, uptake, and increased control costs.

Table 8a. Climate change-related impacts on the forestry sector and associated tactical and strategic adaptation options.

Impact	***Tactical***	***Strategic***
Productivity changes positive to negative	• Growth and climate monitoring	• Identification of new sites • Changed silviculture options
Expanded range of pests, disease, and weeds	• Identification • Monitoring spread • Site preparation (herbicides and cultivation) • Weed control • Thinning • Stand density	• New monitoring and prediction • Improve controls • Bio-control • Risk assessment of incursion • Post -harvest regulation • Herbicide efficacy • Economic impact assessment
Erosion	• Risk identification • Harvest timing/management • Roads maintenance • Action plans	• Longer rotation • Road design • Off-site impact assessment • Decommission roads
Tree loss from wind, rain, extreme events	• Thinning regimes	• Mapping of risk • Silviculture planning • Diversify tree age
Drought	• Transportation • Seedling hardening • Planting options • Weed control • Soil moisture retention • Site preparation	• Nursery practices • New establishment techniques • Timing of planting
Fire	• Operation timing • Manage debris • Restrictions on access • More fire infrastructures • Wider public road offsets	• Manage spacing • Fire breaks • Roadside fire options • Fuel load targets

Table 8b. Climate change-related impacts on the forestry sector and associated transformational adaptation options.

Impact	***Transformational***
Productivity	• Relocation and land use planning • New genotypes • Species and regime evaluation • Improved prediction • Species change
Pests, disease, and weeds	• New control measures • Breeding programmes • Plant technologies • Integrated weed management • New silviculture
Erosion	• Less intensive harvesting • Slope stabilisation • Analysis of erosion risk
Extreme events	• Quantifying productivity impacts
Drought	• Reducing transpiration • New knowledge of seedling responses • Greater seeding resilience cover crops
Fire	• Landscape-level fire planning • Altered distribution of plantations and plantation age classes • Review location of new forests
Planning	• Estate planning incorporating climate change • Tools for predicting growth and yield • Develop new approaches for management planning • Develop alternative products such as biochar, biofuel, and carbon forests

Any solution focused on the effect of immediate climate variability and extreme events is beneficial, as it forms a basis for lessening long-term vulnerability. Increased monitoring of forests, and the surrounding environment, is critical to ensure any changes are identified before they become problematic. Adaptive strategies for forests in currently low-risk locations would need to re-evaluate risk profiles under different climate change scenarios.

Strategic and transformational adaptation

Strategic and transformational adaptation options partly provide the knowledge demanded by properly developed and implemented longer-term adaptation strategies. They also support any requisite changes in operational business. Typically, these levels of adaptation would address sites where change may be extreme, or happen quickly, making sites unsuitable or sub-optimal for forestry. This is a significant risk if sites are susceptible, for instance to pests or adverse events, or if it alters economic expectations from forests.

Generally, forest productivity suffers when either biotic or abiotic factors impede biological growth, or directly damage or kill trees. Most strategic and transformational adaptation options consider advanced concepts in forestry practice: that means, however, there is limited knowledge around their feasibility implementation.

Strategic adaptation and risk assessment also recognises that productivity impacts are determined by the interrelationship of many different risks. Therefore, it needs to focus on the interrelationships between risks, where different risks might occur at the same time, at the same site. This makes it easier to gauge cumulative impacts.

The key themes in determining adaptation options and knowledge requirements are:

- **Building natural resilience**, which can be achieved through developing tree breeds with heightened resilience and/or resistance to negative impacts, or which can take better advantage of improved growing conditions.
- **Enhancement of management practices,** either through new technologies or by adoption of existing innovations, at risky sites. This includes establishment practices, fire mitigation, silviculture, harvesting and pest and weed management.
- **Better quantification of climate and climate change impacts** on productivity from biotic and abiotic sources at a range of scales. From detailed site-specific impacts to national impacts, and projected into the future for the current and further rotations.
- **Forest ecosystems and interactions** must be better understood. Not enough is known about the population dynamics, growth rates, and life cycles of critical forest ecosystem components.
- **Forest planning** tools for the future may not be able to use growth data from the past, because climate change may alter growth rate and wood quality characteristics over time. In addition, they may have to model CO_2, temperature, nutrition, water, competition, disturbance and pests, as well as volume growth.
- **New forests** may be planted for uses other than timber. As sites become suitable, or unsuitable, for long-term rotations, other applications – such as carbon forests or short-rotation forests for bio-energy and bio-fuels – may become viable. Meanwhile, modelling suggests that radiata pine and Douglas fir could be planted in new locations.
- **Monitoring** will need to be stepped up. The impacts and timing of climate change are imprecise, with varying levels of uncertainty. Therefore, more impact monitoring is needed; not just to improve our understanding, but to build confidence in future projections of climate change impacts. So far, no monitoring programmes specifically scrutinise climate change response, so future programmes must incorporate those particular variables affected by climate change, and assess any changes in ecosystem function. Key climate change response indicators could include ecosystem demographics, fecundity, and phenology, weather and pest incidence.

Climate change exposes forestry to some extreme risk, and established forests have fewer options for adapting to unexpected events, due to current levels of investment. Climate change adaptation options for future forests are mostly transformational, with typical options promoting better, more resistant tree species matched to site-specific risks and environment.

Knowledge gaps

The major knowledge gaps arise from the strategic and transformational adaptation options listed above, especially in areas of new science, such as new, climate change-resistant clonal material; and in as-yet unknown interactions between climate, tree growth and the gamut of other factors.

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Industry organisations provide information about adaptation options for the New Zealand forest sector:

New Zealand Forest Owners Association:
www.nzfoa.org.nz

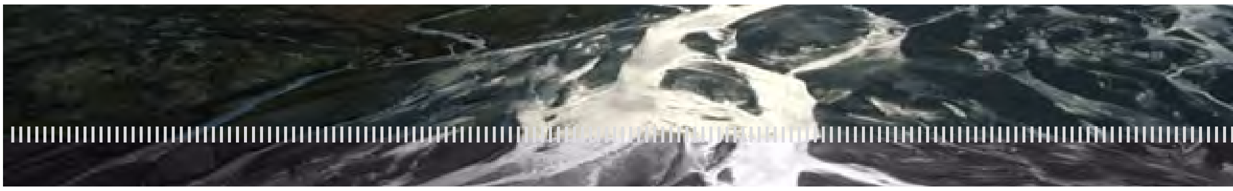
New Zealand Farm Forestry Association:
www.nzffa.org.nz

New Zealand Institute of Forestry:
www.nzif.org.nz

Fact sheets and research reports are available from the Ministry for Primary Industries:
www.mpi.govt.nz

Notes

WATER RESOURCES



Notes

Regional climate change in New Zealand (p11-13)
All sectors

Water Resources

Key messages

- Water resource planning and decision making consider long planning horizons, so decisions made now need to take account of the climate of the future. For example, water consents can be issued for up to 35 years – well within the time frame of climate change.
- Climate change is set to modify the average – and most importantly, the variability of – water availability in catchments. River flows across the country are more likely to decrease, or remain unchanged, with the exception of those sourced from the Southern Alps, which may show increases, particularly in winter and spring. More extreme floods are expected, particularly in the north, along with more drought, particularly in the east. Average temperatures will be higher, as will evaporation rates. It is less clear how change will affect lakes, aquifers and water quality.
- New Zealand catchments show significant variation, so these general impacts need to be considered alongside local hydrological properties. Water demand will increase, for both production and in-stream uses, which may be stressed by higher water temperatures.
- Increased erosion and sedimentation rates, along with more flooding, will have significant effects on infrastructure such as bridges and flood protection works. This brings additional maintenance and operation costs.
- Water and asset management planning can help address the effects of climate change. These processes can increase flexibility, and develop cost-effective responses to a changing climate, including future access to water.
- Transformational change in water resource management is not straightforward. Institutional barriers need to be addressed including planning processes. Collaborative processes that include land managers and communities are one way to begin addressing these barriers.
- Land-based sectors have many options for adapting to climate change. These include: getting involved in water resource decision-making, changing farm schedules and irrigation systems to make more efficient use of water; changing crop varieties or genotypes; conservation farming; water harvesting and storage; and more precise monitoring of plant water requirements.

"New Zealand catchments show significant variation, so these general impacts need to be considered alongside local hydrological properties."

Introduction

Freshwater is the general term given to water held in snow and ice, in our rivers, lakes and wetlands, in our soils, and in groundwater aquifers.

Water is critical to land-based sectors and therefore the economy. Compared with many other countries, New Zealand has abundant water, but this is not uniform; the west coast is generally wetter, while the east coast is drier. Some years are wetter or drier than others, due to fluctuations from existing climatic variability.

Annual and decadal variability in climate can be traced through to stream flows and water storage volumes in many New Zealand systems. This variability leads to droughts and floods, which cause significant damage to the land-based sector and water resource infrastructure. Climate change is a longer-term influence on water resources which interacts with this natural variability. Knowing how much water is available, and how its abundance and quality changes over days, weeks and years, or still further into the future, is essential information for land and water managers.

As the climate changes, so too will the availability of water resources. Some resulting impacts may be beneficial, some harmful. Different water resources will be affected in different ways. How and when these changes will come about is not fully understood. This raises another challenge: we will have to manage water amid increasing uncertainty.

Most of New Zealand will be less affected by the arid conditions that climate change will bring to many other major primary producing countries, including parts of continental Europe, North and South America and Australia. This is because we are a small, mountainous country surrounded by water, which buffers the impacts of change, compared to that suffered by large continental land masses. Through warming of the surrounding oceans and lower atmosphere, the country is exposed to an expected overall intensification of the hydrological cycle, which affects water resources (See 'Regional climate change in New Zealand' Information note).

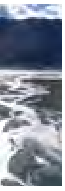
Impacts

Climate change is expected to alter how water resources are distributed in space and time. There is reasonable certainty around some projected changes, but less around others.

The most likely changes are:

- Average temperatures will increase, although not uniformly across the country. This will generally boost plant growth rates and plant water demand.

- Less precipitation will fall as snow, and less snow and ice will be stored in catchment headwaters. This will in turn affect river flows from alpine catchments; mean flows will be higher in winter and early spring, and mean and low flows will be lower in summer and autumn, as base flow recedes more rapidly.
- Rainfall averages are likely to rise in the south and west of both islands, and fall in the east and north, particularly during summer and autumn (Figure 12).
- In addition to average changes, more extreme floods and droughts are more likely. Coastal Canterbury and Gisborne are especially likely to experience more severe droughts. More extreme storms are expected to strike the north and northeast of the North Island, as sub-tropical cyclones track further south more frequently. This will threaten infrastructure such as roads, bridges and stopbanks designed for lower historical flow records.
- Water temperatures in our lakes and rivers will rise, putting freshwater creatures under more physiological pressure.
- Evaporative demand will increase, and as a consequence, soil moisture levels will fall more rapidly without irrigation or other management techniques.
- Sea levels will rise, placing more stress on coastal communities and low-lying land. Areas that rely on extensive drainage networks, such as such as the Manawatu and Hauraki Plains, will be particularly vulnerable.



Other less-certain or data-deficient changes include:

- On-farm irrigation and regional water resources infrastructure being susceptible to climate change. The level of exposure is relative to condition, age and maintenance of these assets. There may be additional operation and maintenance costs.
- Recharge to aquifer systems may become less reliable, which means sustainable water yields from groundwater could fall.
- Saline intrusion into shallow river mouths and coastal aquifers may increase as flows decline and sea level rises.
- Impacts on lakes, which vary against a background of more evaporation, will lower volumes and levels, particularly in large shallow lakes.
- More intense storms will cause more erosion and channel sedimentation, putting infrastructure, such as bridges and culverts, under more pressure.
- Declining water quality as more sediment and nutrients are mobilised and flow into water bodies.

The severity of these impacts will depend on local hydrological settings, the location and design of infrastructure and settlement patterns.

These conclusions are informed by knowledge of physical and biological processes in our water bodies, and by various studies outlined in the technical report. They provide a snapshot of what may happen, but they do not cover the country comprehensively. Different study methods can give different results. For instance, effects on river flows have been studied in about 14 catchments: some examples and

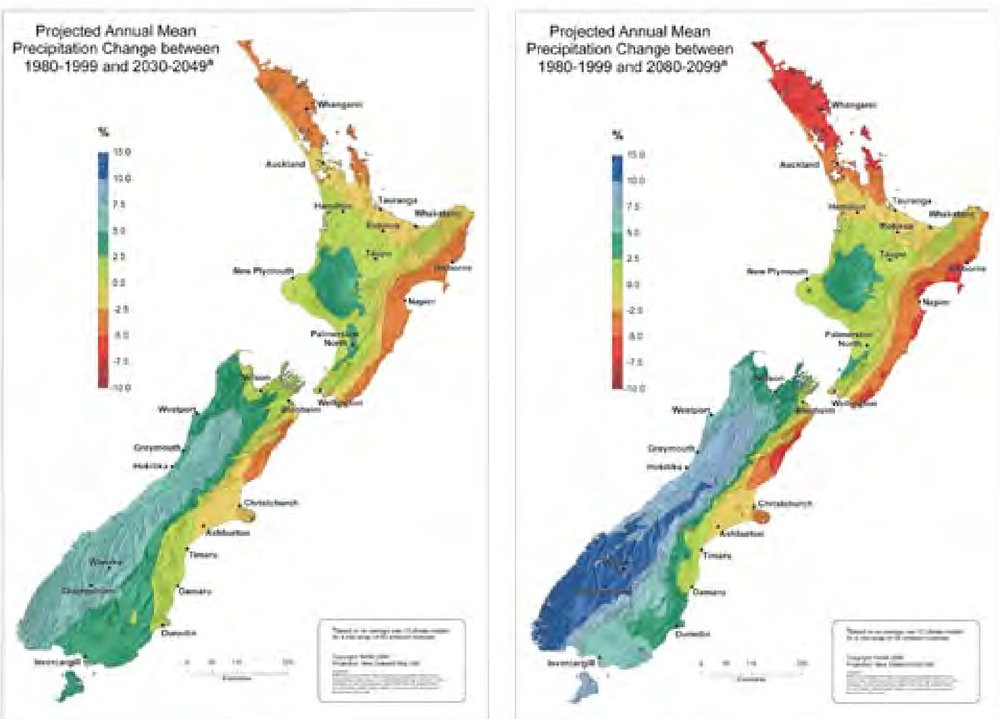


Figure 12. Projected mean annual precipitation change (per cent) for 1980–1999 and 2030–2049 (left); and 2080–2099 (right). A1B scenario is averaged from 12 downscaled AOGCMs.

their main findings are listed in Table 9. This shows that the predicted effects of climate change vary, even in similar catchments, and that water managers will need to factor in local conditions which increase or decrease vulnerability to best anticipate likely changes. It is important to focus on 'key regions' initially, as this type of detailed study may not be required across the country.

Studies of changes in evaporative demand are shown in Table 10.

"…we will have to manage water amid increasing uncertainty."

Table 9. Example studies of the general direction of climate change impacts on river flow and flood discharge.

Study location	***Key finding***
Awanui River, Northland*	*Reduced* average and winter/spring flows *Stable* autumn flows
Waihou River, Northland	*Increased* summer flood risk[#]
Thames-Coromandel and Hauraki Plains, Waikato	*Increased* peak discharge
Uawa River, East Cape	*Increased* summer flood risk[#]
Tukituki River, Hawkes Bay	*Reduced* summer/autumn/winter flow
Motueka River, Tasman	*Reduced* summer flows *Stable* winter flows
Waimea River, Tasman	*Decreased* average flow *Increased* low flow days
Buller River and Westport, West Coast	*Reduced* to increased peak discharge[+] *Increased* town inundation risk
Waimakariri River, Canterbury	*Increased* average winter/spring flow *Stable* or decreased summer autumn flow[+]
Ashley River, Canterbury*	*Reduced* or remained constant average monthly summer and spring flows *Increased* monthly winter and autumn flows
Rangitata River, Canterbury*	*Increased* average, winter and spring flows *Reduced* summer flows
Clutha River, Otago	*Increased* average and winter flows *Stable* summer flows
Oreti River, Southland	*Increased* average, summer and autumn flow[+] *Decreased* winter flows

[+] Wide range in estimates, due to the range in projected rainfall.

* Only considered a 'mid-range' climate scenario, so full potential impact not quantified.

[#] Produced with new climate projections with improved estimates of rainfall extremes.

Table 10. The effects of climate change on evaporative demand.

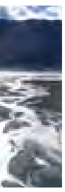
Study location	***Key results***
Nationwide	There are a wide range of future scenarios, ranging from moderate through to very large increases in evaporation. The 'mid-range' outcome is for annual average evaporation to increase everywhere by the 2030s, except for the west coast of the South Island. Evaporation increases are greater again by the 2080s, and drought risk rises substantially for eastern and northern parts of both islands. Droughts become more common in spring and autumn. Future estimates are also influenced by better accounting for wind and radiation.
Ashley River, Canterbury	Evaporation increases by 75 mm/year in headwaters in 2040, and by 150 mm/year on the plains. These rates of increase double for 2090.
Rangitata River, Canterbury	Evaporation increases by up to 60 mm/year in 2040 on the plains, with small decreases in the headwaters.
Waimakariri River, Canterbury	Evaporation increases by 60 mm/year in headwaters in 2040, and 140 mm/year on the plains. These rates of increase double for 2090.

Water demand

There are many demands on our water resources. Providing for the life-supporting capacity of aquatic ecosystems, community water supplies and stock water are all given emphasis over other uses in the Resource Management Act (RMA). Other major uses include hydro-electric power generation, recreation and irrigation.

Just how much water is used in New Zealand is unknown. However, about two-thirds of irrigation and drinking water is taken from our rivers and streams – the remainder comes from groundwater. Regions rely on surface and groundwater to differing degrees.

Different sectors have different requirements around water and soil moisture. Grain crops generally require most of their water during spring and early summer; after that, crops benefit from drying off before harvest. Pasture requires water throughout the irrigation season, as do many horticultural crops. Stock water requirements are a priority during prolonged drought, particularly in eastern and northern regions. It will become increasingly important to protect water bodies from farm irrigation runoff as flows decrease during summer and autumn.



Some rivers, streams and aquifers are already over-allocated, a condition blamed for lower flows in many spring-fed streams. Demand for irrigation water will rise as higher temperatures increase evaporation and decrease soil moisture. However, so too will the needs of aquatic ecosystems, as warmer water temperatures put more stress on biota.

Water resource management will become even more challenging with climate change, as it will need to also accommodate broader issues such as kaitiakitanga and economic development objectives.

Water resource management

Water resource management policy in New Zealand is set both nationally and by region. The Fresh Start for Freshwater programme sets out a number of national initiatives, including the National Policy Statement on Freshwater, the Water Clean-up Fund, the Land and Water Forum and the Irrigation Acceleration Fund.

The Resource Management Act (RMA) provides the overarching framework for water management. Regional councils must give effect to national policy statements in regional policies and plans. The National Policy Statement for Freshwater Management 2011 specifically requires councils to address climate change. The policy was put in place to address water quality decline, water demand, integration across land and water management, and to improve Māori involvement in decision making.

The RMA devolves day-to-day management of water resources to 16 regional authorities (12 regional councils and 4 unitary authorities). Regional authorities set policies and plans to manage the quantity and quality of water in rivers, lakes, wetlands and aquifers in their region. These generally set levels or flows that must be maintained in lakes, aquifers and rivers, often on a seasonal basis, to protect in-stream values. They also usually set out how water will be allocated. Regional authorities issue resource consents for activities such as taking, using, damming or diverting water, or discharging to water. These can be granted for up to 35 years, which is well within the time horizons analysed in this report.

Regional authorities also have management responsibilities for drainage and river control schemes, and for soil conservation. Authorities have an important role in managing future responses to a changing climate affecting the above responsibilities. Farmers, growers and foresters will need to be part of that management to ensure land-based sectors are able to effectively adapt.

Regional authorities are already taking action on climate change. For example:

- Marlborough and Tasman Districts have constructed water storage schemes in water-short areas such as the Waimea Plains. These have been funded by benefitting ratepayers. A similar scheme in the headwaters of the Tukituki River is being promoted by the Hawke's Bay Regional Council to irrigate the Ruataniwha Plains. These schemes will help future-proof productive areas against drought.
- In line with Ministry for the Environment guidance, some authorities are advocating for design standards for new infrastructure which take account of climate change. These include updated design standards for infrastructure such as bridges and stopbanks.
- Some regional plans provide additional reserves (called 'blocks') of water that can only be taken in conjunction with seasonal water storage. The Proposed Hurunui and Waiau River Regional Plan provides 'C' blocks in both rivers conditional on seasonal storage, so that reliable water is available when river flows are low.
- Encouraging the temporary or permanent transfer of water permits.

There are also some other emerging adaptation options that regional authorities could consider. An example is promoting seasonal groundwater recharge from rivers by discharging water to land.

Incorporating climate change scenarios into statutory regional water plans is not straightforward. Analysis is based on historical flow records, so allowing for future change always involves uncertainty, and potentially greater costs to ratepayers. Current water resource planning under the RMA can be adversarial, involving expensive litigation in the Environment Court.

Identifying institutional barriers and new ways of involving stakeholders in water resource planning are key transformational adaptation options. Collaborative approaches promoted by the national Land and Water Forum, and the Canterbury Water Management Strategy are two current examples.

Adaptation by the land-based sectors

The extent of adaptation depends on both the degree and rate of climate change. The key will be to ensure that decisions are forward-looking, rather than based solely on past data and information – planning for the future, not the past.

As described in Box 1, adaptation options can be considered tactical, strategic or transformational. These categories are a continuum, and some options could be considered under two or more levels. Drawing on the sector-based reviews, water resource adaptation options for primary production are listed in Table 11, and some of these are briefly described in the following text.

> ***"The key will be to ensure that decisions are forward-looking, rather than based solely on past data and information – planning for the future, not the past."***

Table 11. Some options to adapt to changing water resources in New Zealand – drawn from sector-based reviews.

Tactical	***Strategic***	***Transformational***
• Identify key thresholds for production system and likely changes in the future • Changing cropping and grazing calendars • Changing crop varieties • Conservation agriculture • Improving soil nutrient management • Greater irrigation • Ensuring irrigation is efficient • Taking steps to reduce erosion • Actions to reduce contamination of surface and groundwater • More efficient management of water resources • Avoiding salinisation of groundwater • On farm water storage • Changing stock numbers • Land managers reviewing their current water and discharge consents • Land managers reviewing infrastructure condition and maintenance schedules, such as stock water, drainage, stopbanks, storage	• Changing crop species • Developing new crop genotypes • Precision agriculture • Monitoring and forecasting programme • Expanding and improving access to irrigation • Offset groundwater abstraction with artificial groundwater recharge • Incorporate climate change risks into resource and hazard management • Incorporate climate change risks into new and existing infrastructure • Catchment water storage • Getting involved in local government water management planning and policy processes • Join scheme committees, and be part of making future asset management decisions, including funding • Trading of rights to take water • Collaborative processes • Developing 'plans of action' to future-proof existing water resources infrastructure	• Develop new cropping systems • Improving crop uptake and conversion efficiency potentials • Different land uses • Re-evaluate the societal values behind water allocation • Inter-regional water transfers • New adaptive planning techniques, to learn from coming extreme events, and guide the selection of adaptation options • Research and development • New irrigation schemes that are sensitive to future climate conditions • Identifying and addressing institutional barriers

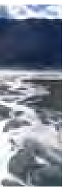
Tactical adaptation

- **Reviewing this report** for impacts on your sector, and understanding what they may mean for water use and adverse events in the future.
- **Changing cropping and grazing calendars** to help align crop growing periods with shifting seasonality of water availability and evaporative demand. This adaptation may be most valuable where snow-fed rivers are used for irrigation, as in parts of Canterbury.
- **Changing crop varieties** could help adjust to seasonal shifts in the availability of water and higher evaporative demand.
- **Using conservation agriculture techniques**, such as leaving the previous season's crop residue on a field, can help retain soil moisture, and reduce water logging and erosion.
- **Improving soil nutrient management** can promote more efficient use of nutrients, and reduce the effects of farm runoff on water bodies.
- **Increasing irrigation efficiency** can increase crop or pasture yield for a given volume of water. Reducing leakage from water races, and irrigating at times of low evaporative demand can have similar benefits.
- **Increasing irrigation** is an obvious adaptation available to farmers. A potential impediment is that water may not be available when it is needed, due to reduced water supplies or increased competition with other water users. Greater seasonal water storage, both within irrigation schemes and on-farm, may be necessary.

- **Participation in regional planning processes** is essential, to ensure that production, environmental and social values are reflected and balanced in water resource plans. An important adaptation is simply maintaining or lifting involvement in regional planning.

Strategic adaptation

- **Changing crop species** would enable farmers to grow more water-conservative or drought-tolerant crops. These could yield greater economic output for a given volume of water, or be better suited to a more variable climate.
- **Developing new crop types** that use water more efficiently.
- **Using precision agriculture techniques** to make irrigation more effective, and water use more efficient, by pinpointing when and where water is needed.
- **Monitoring and forecasting programmes** which more actively monitor soil hydrological conditions – as well as forecast near-future water supply and evaporative demand – can help use existing water resources more efficiently. Examples include better scheduling of irrigation during a week, or better selecting cropping decisions during a growing season.
- **Expanding and improving access to irrigation** through development of new irrigation schemes, inter-basin transfers, and better conjunctive use of surface and ground waters. Developing new irrigation schemes is also a viable adaptation option.
- **Investigating managed groundwater recharge schemes** which store water in infiltration basins during times of low water need and high supply. This increases the net recharge rate, and helps balance net groundwater depletion in a region.



Transformational adaptation

- **Improving crop uptake** and conversion efficiency potentials, involving the development of new crop genotypes.
- **Land use changes** should water supplies become too precarious for existing uses.

Technical Report Chapter 8: Water Resources

Hydrological monitoring information and data is available at:
www.niwa.co.nz

Guidance for local government is available at:
www.mfe.co.nz

A detailed evaluation of climate change impacts on rural water infrastructure is available from the Ministry for Primary Industries:
www.mpi.govt.nz

Information on irrigation is available from Irrigation New Zealand:
irrigationnz.co.nz

Identifying the right adaptation options

This is not a simple task. There is no single optimal approach, but the best will likely be a portfolio of staged responses that address different threats and different levels of risk, and do so at different times. It is likely that multiple stakeholders adapting in concert will yield benefits greater than would be possible separately.

The following questions may help guide decision-making. This applies as much to land owners and industry groups as to local and central government:

- How does climate change affect water resources in an area and for a sector? Think about current water resources and any thresholds for instance, soil moisture levels.
- Of these potential impacts, which affect a specific operation now, and into the future? Think about the production system, inputs into the system, getting produce to market, as well as any benefits and advantages from changes in management now.
- How do these impacts compare to those outside the water resources sphere? Can these impacts be managed as part of other business-as-usual activities: for instance, regular maintenance on stock water systems, or decision-making processes, such as a regional water plan?
- What adaptation options are relevant to water resource impacts? Look at current good practice, and discuss with industry representatives. Are there good examples overseas that can adopted for use in New Zealand?
- Are there 'win-win' adaptation options which have benefits now: increasing irrigation efficiency, for instance; or training staff in best practice?
- Are adverse impacts likely to occur within the planning horizons of existing or new activities, such as water storage, stock water systems, flood or drainage management? Are rainfall or flow estimates factoring in the changing climate, or are they based on past data?
- What are the potential costs and benefits of acting, compared to not acting? are there any critical thresholds that affect when action occurs?

Notes

CROSS-SECTOR ADAPTATION & NEXT STEPS

Notes

Cross-sector adaptation

Key messages

- While valuable, the sector-based approach does not cover the full suite of impacts or adaptation solutions available to land managers.
- A changing climate will also affect biological systems and environmental services that are important to the resilience of production systems.
- Secondary impacts should be expected: for instance infrastructure, changing demands for skills and labour, economic and social impacts in the wider community. These areas are not as well researched or developed as other work presented in this report.
- There are many examples of actions that can spread the direct and indirect impacts of climate change, for example basing a land-based sector business around multiple forms of production.
- A major challenge is adapting under multiple stressors and cumulative impacts as they are difficult to identify and anticipate. These limitations, along with scenarios of more severe climate change, mean that engaging with transformational change is important to meet challenges and capture benefits.

Previous chapters have assessed impacts and adaptation sector-by-sector, but other impacts can be identified that affect all sectors simultaneously. There are also adaptation options that can be applied across many sectors or require a multi-sector response. By their nature, these adaptation options tend to be strategic or transformational.

Environmental impacts: under climate change in New Zealand these include increased erosion, caused by more intense rain, increased nutrient discharge from efforts to capture carbon dioxide fertilisation, and biodiversity impacts. In some cases, such as erosion, these impacts have 'on site' effects and can limit or restrict production, leading to a shifts in the resilience of businesses. There are also 'off-site' effects influencing broader community and environmental values. Environmental impacts are often considered negative, but there may also be positive effects, as well as opportunities to improve environmental performance through adaptation responses.

Pests and diseases: rising temperatures will strongly affect the abundance and distribution of pests, as well as the viability of controls. General assessments suggest that warming will create more favourable climates for some pests at southerly ranges. However, for other pests, increased temperatures will decrease their range. Initially this will occur as a series of 'hot spots' given the very specific host and population factors that govern pest distributions. A sector-specific consideration of pest impacts can be found in the Forestry section.

The implications of rising temperatures on animal bacterial/viral diseases and pathogens have not been given a lot of attention in New Zealand. In principle, both positive and negative impacts are possible, depending on the specific biology and transmission risk factors.

"A changing climate will also affect biological systems and environmental services..."

There are also direct impacts on biocontrol systems, an important management option for pest and disease control in New Zealand. Increased temperatures, CO_2 concentrations and changes in water availability are likely to affect the individual species in a biocontrol system differentially, changing rates of development and reproduction, and susceptibility to parasitism and diseases. Climate change can have beneficial, neutral or harmful effects on the stability of a biocontrol system by influencing the abundance of pests and control species, their hosts and habitats as well as the relationships between them.

Infrastructure: underpins the primary sector, but is exposed to risks from climate change. A range of infrastructural impacts have already been identified for water resources, but there are also broader operational considerations given transport networks, energy supply and processing facilities.

Flooding and storm surges will affect ports, processing facilities and transport nodes, particularly in low-lying coastal regions. Higher temperatures might buckle railway lines and melt road tarmac. Slips and erosion could hamper transport and processing infrastructure. There is a medium to high likelihood of these impacts in the next 20 to 30 years.

Different sectors are vulnerable to different impacts: dairy, for instance, relies heavily on road and rail freight; while the arable sector is concentrated in areas susceptible to more water stress, which can damage pumping and pipe infrastructure. Dairy, meat and horticulture are also vulnerable to power outages, which require contingency planning.

Socio-economic implications for the wider community: the production impacts and adaptation options identified for each sector will flow through to the wider community and the New Zealand economy as a whole. Current nationwide assessments indicate that without any adaptation direct impacts from changed climate variability on primary production create 'shocks'. However, there are also large opportunities to be had in good years and 'on-average' under mild climate change scenarios. Flow-on effects to local and regional communities have, in general, not received attention to date. In principle there are secondary flow-on effects from decisions to implement adaptation options such as job creation and new markets.

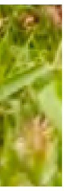
Adaptation

Environmental performance: a range of tactical and strategic adaptation options exist to manage these risks: whole-farm planning, landscape/vegetation design, more efficient nutrient use, system modifications, and establishing conservation zones.

Business diversity: is a response to increasing climate variability by building production and income diversity into an operation. In a risk management context, this exploits differences in the exposure and seasonal timing of impact provided by alternative forms of production.

A 'mixed operation' approach might be tactical: for example, wintering dairy cows to earn additional income on a sheep/beef enterprise. It can also be a strategic adaptation, by developing mixed farming systems – e.g., a fully integrated arable cropping-dairy sector business; or agroforestry. Trade-offs may need to be made but co-benefits may also accrue, for instance shelter from trees.

Land use change: has been identified in all the sectors as one transformational option. It is driven by many interacting factors, not least climate, which largely determines the practical viability of different land uses. Soils and topography also have a bearing. Together, these elements comprise the concept of land capability.



Most regions have a broad land use capability, and the mixed integrated land use model is a normal feature of the main agricultural zones, outside high alpine and hill country. Superimposed upon that capability, market forces and regulatory processes further define, and refine, land use.

Infrastructure: Ensuring that infrastructure is fit for purpose into the future is an important part of ensuring resilience and productivity over the long term. A central tactical adaptation is reviewing current service levels to make sure future needs will be met and updating asset and maintenance registries. This type of information underpins strategic options, from upgrades, improved maintenance and asset replacement. It is also a starting point for considering transformational options like shifting locations of key facilities or retiring infrastructure before its scheduled lifetime to avoid impacts. In cases of long asset lifetimes (20–30 or more years) infrastructural decisions made today need to factor in the climate of the future.

"Innovation in management is in itself a form of adaptation. Responses to multiple stressors and heightened uncertainty elicit new forms of transformational management."

Pest and disease management: there are several strategies available for adapting pest management under climate change (Table 12). These are a good example of 'win-win' opportunities as they align with existing industry efforts under current climate.

Management: will probably need adjustment to accommodate adaptation options to climate change. Such responses are not always new or novel, many land managers already adopt risk management techniques Innovation in management is in itself a form of adaptation. Responses to multiple stressors and heightened uncertainty elicit new forms of transformational management. From a growing mix, three useful approaches are:

- **Adaptive management** – otherwise known as 'learning by doing', or 'continuous improvement' – follows a cycle of monitoring, review, planning, and implementation. It is particularly useful in the face of uncertainty. Drawing lessons from every drought is a prime example, as is business benchmarking. This stakeholder report itself is part of an adaptive management process, representing the 'review' stage of the cycle.
- **Decision making that explicitly deals with uncertainty**, and is a strong theme in climate adaptation. Decision making seeks to find 'win-win' strategies that work across the range of future conditions is a useful first step.
- **Risk management** is a process to assess how a business or production system can achieve specific outcomes given information about the likelihood of an external event, like climate change. Events such as droughts are examined to see how they impact a business, as well as how likely they are to occur. Management responses are developed to reduce any negative effects or capture any opportunities that arise from these events.

Table 12. Adaptation options identified for bio-control and pest risk management.

Tactical	*Strategic*	*Transformational*
Building refuge habitats	Risk management for Integrated Pest Management Systems with new bio control agents	Development of new industries, crops and distribution networks
Pre-emptive action against sleeper pests	Increased genetic diversity	
Pesticides/bio pesticides	New information systems involving monitoring and modelling	
Selecting resistant cultivars	Improved grower awareness, monitoring and reporting	
Use of endophytes	Breeding for resistance	
	Pasture renewal and break crops	

Land managers will need to look critically at the information decisions are based on and how they are made. Strategies based on flexibility, so as to meet challenges and capture opportunities, are likely to become more important over the long term. Other considerations include the degree of buffer and protection against an adverse event, production diversity to trade off downside risks in one form of production against those in another, and reviewing new climate information as it is developed.

Institutional change, as applied to the ownership and governance model of an individual farm, or to the structure of a large industry organisation, can empower adaptation. Identifying institutional barriers, and addressing them, is a relatively new discipline. Structures that achieve better integration, promote a culture of continual learning and promote and reward innovation are key success factors.

The next steps

A changing climate is both an opportunity and a challenge for land sectors. There are a suite of 'win-win' tactical and strategic adaptation options available to manage shifts in production variability in the immediate future. Changes can be made now or in the short term that have economic benefits, as well as increase resilience in the longer term. Potentially, these options not only reduce the negative impacts from a changing climate but also capture the opportunities from increased plant growth.

A key decision will be when to act, as on one hand continually delaying adaptation builds exposure to climate change over time. On the other hand, investing now in expensive adaptation options comes at a cost. In the face of this challenge there is a natural tendency to maintain existing approaches to management.

There is no 'one size fits all' approach to adaptation. The impacts depend on the production system, management choices, local climate conditions, as well as the rate and extent of the changing climate. This report has identified a range of impacts and adaptation options along a continuum of tactical, strategic, and transformational action. Some options may be tactical in one production system but strategic in another. However, all options have one thing in common – they will build more resilience to a changing climate on the ground.

Land managers and professionals will determine the success of the adaptation options used. Decisions from the fine tuning necessary to adapt under local conditions, through to providing knowledge and financial analysis to support strategic land management decisions, will need to be climate-proofed. Implementing the tactical and strategic adaptation solutions identified in this report is within normal risk management practices, and there are considerable opportunities in acting now.

Technical Report Chapter 9: Multi-sector

Detailed reviews of sector infrastructure and biocontrol impacts and adaptations as well as carbon markets are available from the Ministry for Primary Industries:

www.mpi.govt.nz

Information about the integration of trees on farms is available from the New Zealand Farm Forestry Association:

www.nzffa.org.nz

Contact your regional council for information about Environmental Management in your area:

www.lgnz.co.nz

In the longer term, more impacts may emerge from severe or uncertain levels of climate change. These could present a different set of challenges and opportunities, including multiple stressors and cumulative impacts over many seasons, as well as changes to extreme events and impacts on infrastructure. Other risks, such as market or consumer preferences are also difficult to anticipate but will also affect business decisions – such as how best to respond to a changing climate.

The greater the change in climate, or the impacts of that change, the more likely that transformational options will be used. In New Zealand transformational changes have been developed and implemented in the past. Examples include aerial topdressing, artificial insemination, overcoming trace element deficiencies (e.g., cobalt, selenium), as well as genetic improvements in pasture and timber density. The main lesson from these experiences is that implementing transformational adaptation need not be expensive or prohibitive.

Action can be taken now to expand our range of options to prepare for the future, no matter what climate scenario eventuates. This involves keeping a 'watching brief' on the latest information; staging action to manage costs; getting involved and shaping longer-term planning at a regional level; initiating or taking practical actions like monitoring or improving asset inventories in order to reduce important uncertainties; and innovating to expand the range of solutions that are available. Sustained leadership to harness the creative and innovative drive of the land-based sectors is a critical ingredient to success.

Adaptation is a way of future proofing land-based sectors and the New Zealand economy to a changing climate. This report identifies practical adaptation activities that are or can be part of day-to-day business, as well as those that build on the innovative drive of the land-based sectors. It is up to land managers to take up the challenge and translate this into on the ground action.

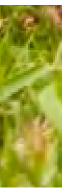
"Adaptation is a way of future proofing land-based sectors and the New Zealand economy to a changing climate."

References

All written content, concepts, model output, figures, tables, equations, and intellectual property used in this report are taken or adapted from and are formally attributed in:

Clark, A.J.; Nottage, R.A.C.; Wilcocks, L.; Lee, J.M.; Burke, C.; Kalaugher, E.; Roche, J.; Beukes, P.; Lieffering, M.; Newton, P.C.D.; Li, F.Y.; Vibart, R.; Teixeira, E.I.; Brown, H.E.; Fletcher, A.L.; Hernandez-Ramirez, G.; Soltani, A.; Viljanen-Rollinson, S.; Horrocks, A.; Johnstone, P.; Clothier, B.; Hall, A.; Green, S.; Dunningham, A.; Kirschbaum, M.U.F.; Meason, D.; Payn, T.; Collins, D.B.G.; Woods, R.A.; Rouse, H.; Duncan, M.; Snelder, T.; Cowie, B. (2012). *Impacts of Climate Change on Land-based Sectors and Adaptation Options*. Clark, A.J.; Nottage, R.A.C. (eds) Technical Report to the Sustainable Land Management and Climate Change Adaptation Technical Working Group, Ministry for Primary Industries, 408 p.

Technical report sources for specific figures, tables, and data cited in this stakeholder report:



	Page	***Source***
Regional climate change in New Zealand Figures	12–13	NIWA (2012) Primary Sector Adaptation Scenario: Chapter 2 Technical report
Figure 2	15	Radiata pine productivity: Chapter 7 Technical report
Figure 3	20	Chapter 3 Technical report from Baisden, W.T.; Keller, E.D.; Timar, L.; Smeaton, D.; Clark, A.; Ausseil, A.; Power, W.L.; Zhang, W. (2010). New Zealand's pasture production in 2020 and 2050. GNS Science consultancy report 2010/154, 88 p. Updated figure courtesy of Baisden & Keller (2012).
Figure 4	28	Pasture growth Southland: Chapter 3 Technical report
Figure 5	28	Pasture growth Hawke's Bay: Chapter 3 Technical report
Figure 6	28	Pasture growth Waikato: Chapter 3 Technical report
Figure 7	30	Gross margins for Southland: Chapter 3 Technical report
Figure 8	30	Gross margins for Hawke's Bay: Chapter 3 Technical report
Figure 9	30	Gross margins for Waikato: Chapter 3 Technical report
Figure 10	32	Chapter 2 Technical report. Adapted from Clark, A.; Mullan, A.B.; Porteous, A. (2011). Scenarios of regional drought under climate change. NIWA Client Report WLG2010-32 for Ministry of Agriculture and Forestry, 135 p.
Figure 11	38	Simulated yields of four crops grown in a rotation in Canterbury: Chapter 4 Technical report
All export value data	Various	MPI (2012). Situation Outlook for Primary Industries 2012, New Zealand Government, Ministry for Primary Industries, Wellington, New Zealand, 52 p.

Appendix 1. Terms to describe adaptation

Internationally recognised terms and concepts precisely define adaptation. The main concepts, as they relate to a land-based sector business, are:

Climate impacts are positive or negative effects on a land-based sector business. These are the consequence of exposure to climate events, and of a business's vulnerability to those events.

Exposure is the climatic setting of the business: the temperature range and rainfall variability it experiences. This can be quantified as 'climate frequency', where every business has a return period for extreme events like drought and severe storms, as well as the averages and variability in climate conditions. These factors are shifting in a changing climate.

Vulnerability defines the way a production system responds to climate drivers. For example, a low vulnerability business emerges from a severe drought in good financial shape, and quickly returns to full production, capturing opportunities the new season brings.

A high vulnerability business is challenged financially by a drought, and is still feeling the effects long after it has passed. It is unable to exploit new opportunities. Vulnerability relates to resources, technologies, management decisions and competencies. No business can control climate exposure, but it can control its vulnerability.

Adaptation is about making changes that lower vulnerability to climate change. It is as much about improving current practices, as it is about going beyond those current practices to reduce vulnerability still further.

Adaptive capacity is the measure of a business's ability to reduce its vulnerability. In primary production, this is determined by factors such as profitability (farm income) and debt levels, income diversity, availability of financial capital, training and education, other human resources like community networks, management and production system characteristics, and technologies and infrastructure. Collectively, these elements are referred to by researchers as financial, environmental and social capital.

Resilience describes an enterprise's inherent ability to return to normal, after a stress or pressure from climate, as determined by the degree to which it can absorb – or be disrupted – by climate change. Resilience has many similarities to vulnerability, but instils a holistic systems view in the complex relationships that underpin the sectors. This is important, as the systems view provides a more detailed and specific understanding of *why* a primary production system might be vulnerable, and *what* can be done to change that.

Maladaptation describes a change that increases vulnerability. It can take many forms, such as adapting to a potential threat which does not eventuate, the risk of an adaptation being detrimental to something else (e.g., to natural ecosystems), and unintended negative consequences of positively motivated initiatives. Avoiding maladaptation is about honest appraisal of knowledge, and developing sound adaptive approaches accordingly.

Appendix 2. Models used in the sector analysis

For detailed model descriptions and more information refer to relevant chapter in technical report.

Chapter	*Model*
Climate	Regional Climate Model Precis coupled to UKMO HDGEM3.2
Dairy	DairyNZ Whole Farm Model
Sheep & Beef Broad acre cropping	Agricultural Production Systems Simulator (APSIM) Sheep and Beef coupled to FARMAX pro B
Horticulture	Spoil Plant Atmosphere Simulation Model (SPASMO)
Forestry	CenW

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Notes

Impacts of Climate Change on Land-based Sectors and Adaptation Options brings together essential information on climate change impacts and adaptation for the land management professional.

It presents the key findings of a body of technical reports, which integrate existing sector knowledge with model analysis. This stakeholder report provides further synthesis and evaluation to describe the state of current adaptation knowledge.

Each chapter is devoted to a particular sector, and sets out the options available to land management professionals in that sector. Broader cross-sector adaptation options are also identified. This bank of knowledge will help assist land managers to build implementable actions that reduce vulnerabilities to climate change and build resilience.