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Mind the gaps: Synthesis and systematic review of climate change adaptation in New Zealand's primary industries

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Manaaki Whenua
Landcare Research

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Summary

Project and client

In 2007 the Ministry for Primary Industries (MPI) established the Sustainable Land Management and Climate Change (SLMACC) programme to encourage targeted research on mitigation and adaptation to climate change, and enhancing forest sinks. This report reviews, synthesises and assesses the outcomes of MPI's investment in adaptation research through the SLMACC programme over the last decade.

It is intended to be read in conjunction with three concurrent reviews and the survey results report (Figure S1):

- mitigation review (van der Weerden, Jonker, Fleming, Prescott, de Klein & Pacheco 2018)
- forestry review (Dunningham, Grant & Wreford 2018)
- technology transfer review (Payne, Turner & Percy 2018)
- project leader and stakeholder survey results (Payne, Chen, Turner & Percy 2018)

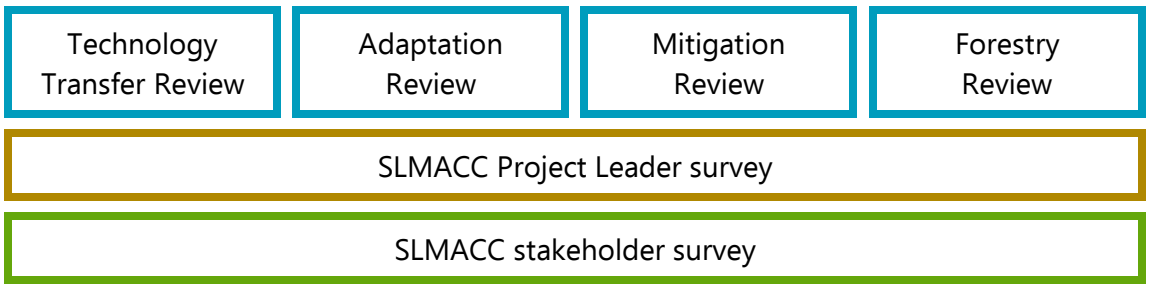

Figure S 1. Concurrent SLMACC reviews and surveys.

Background

The future of New Zealand primary industries will depend on their ability to adapt to climate change. Although considerable advances have been made in understanding the impacts and implications of climate change, determining what exactly is *known*, *not known* and *needs to be known* about adaptation for primary industry policy-makers and decision-makers is crucial.

This report summarises the state of knowledge, focusing on SLMACC adaptation projects, and reviewing and synthesising the published literature. The evaluation:

- provides an up-to-date assessment of the state of adaptation science and its outcomes
- identifies critical knowledge gaps and future research priorities
- identifies barriers and enablers to enhancing the impact of previous and future adaptation research.

The report provides a valuable baseline for tracking knowledge production, and can be used to inform future research agendas to enhance resilience to climate change in New Zealand primary industries. It also represents a critical reflection point, whereby existing knowledge, potential gaps and future opportunities are presented.

Methods

Mixed methods – largely consistent with the other reviews – were used to assess 32 projects against an evaluation rubric to identify outcomes and impacts. In addition to the rubric, the Adaptation Review Group developed the Adaptation Knowledge Cycle: a classification scheme to highlight projects' analytical focus and key contributions, based on a typology of impacts, implications, decisions or actions (I-I-D-A).

Impacts-focused research provides a description of first-order impacts of climate change on the primary production system. This research identifies impacts but stops short of articulating how these impacts might flow through to challenge existing practices and lead to actions on the ground. *Implications*-focused research examines the knock-on or cascading effect of specific climate impacts on the primary production system and implications for management. Research with a *decisions* or *actions* focus provides information to make adaptation decisions, by identifying when, where and what decisions need to be made; or it supports changes in behaviour and implementation of on-the-ground actions for adaptation.

The following methods were used to conduct the review:

- evaluation of 32 SLMACC adaptation projects against the evaluation rubric to determine project outcomes and impacts
- a systematic literature review and annotated bibliography of the published peer-reviewed literature related to adaptation in New Zealand primary industries
- development and application of the Adaptation Knowledge Cycle to assess I-I-D-A for SLMACC project outputs and the published literature to identify salient characteristics and contributions to adaptation knowledge
- a 'Mind the Gaps' workshop with primary industry stakeholders and adaptation researchers, to evaluate SLMACC adaptation project outcomes and identify knowledge gaps and future priorities
- a cost–benefit analysis of adaptation research for pastoral farming
- supplemental data from project leaders' and researchers' surveys.

Results

What do we know?

The review shows that the SLMACC fund has made a significant contribution to our understanding of the impacts of climate change for New Zealand primary industries. Much of the investment (2007 – 2017) has supported targeted research focusing on the impact of climate variability and extremes on a range of land management systems. This research has played a critical role in establishing a common understanding of the risks of climate

change for affected sectors, in particular pastoral farming, and the climate research community.

Adaptation research funded through the SLMACC programme has delivered science outcomes in three key areas.

1 Research projects have delivered new knowledge in critical areas and have enhanced our understanding of the following areas in particular: drought, pasture-based farming, biosecurity and climate change, arable cropping, horticulture and viticulture, pan-sector adaptation science, and climate variability and extremes.

2 Research investment has supported and developed crucial research capability and capacity for New Zealand researchers and promoted international collaboration.

3 Investment in adaptation research over the past 10 years has demonstrated excellent value for money. A cost–benefit analysis conducted on the research projects on the pastoral sector (dairy and sheep and beef) indicates a very high benefit-to-cost ratio (2.38).

Impact and adaptation projects have also played a significant and vital role in developing adaptation research capability and capacity through funding early-career researchers. The projects have fostered interdisciplinary collaborations for climate change research and have seeded international networks. Since its inception the fund has been a vital – and often the sole – source of funding for adaptation research in New Zealand. Despite lower investment in adaptation as an overall component of the SLMACC programme, it has had a demonstrated effect in terms of leveraging additional science investment and developing a community of adaptation research in New Zealand.

Adaptation projects have produced information that is useful, useable and used. The fund has supported a diverse range of projects across multiple primary industries. This diversity is a key strength, and should be maintained because it advances climate change knowledge on multiple fronts. It has delivered new knowledge for critical areas relating to climate change impacts and primary industries, including drought, variability and extremes, and for key sectors, including pastoral farming. Much of what we know about the impacts of climate change for the primary industries has been as a direct (through targeted research funding) or indirect (enhancing research capability and capacity) result of the fund. Projects have answered critical questions in a timely fashion, including policy options to meet our obligations under international treaties.

The results from the rubric evaluation demonstrate the impact and outcomes associated with the programme.

Evaluative criterion	Average rubric score
Build science capacity and capability enhancement	**High degree**
Influence on science	**Moderate degree**
Engagement and networks	**Moderate degree**
Learning, awareness and knowledge exchange among end users	**Moderate degree**
Usability of research for end users	**Moderate degree**
Influence on stakeholders and impact for NZ	**Moderate degree**

Rating criteria

1 **Low degree** (Never or seldom, with clear weakness)	**2** **Moderate degree** (Mostly, or sometimes with few exceptions)	**3** **High degree** (Always to almost always)	**IE** **Insufficient evidence**	**E** **Emergent**	**N/A** **Not applicable** (e.g. not asked for by SLMACC)

Figure S 2. Evaluation rubric results for adaptation projects.

What do we not know? Gaps

The review has also revealed empirical and methodological knowledge gaps. These were identified through the analysis of each project, the results of a workshop with industry, end users and researchers, and a systematic review of the published literature.

The results show that adaptation research is still under-represented in both SLMACC funding and in the published New Zealand literature. A systematic review found only 22 journal papers in the international literature focused on adaptation in New Zealand primary industries between 2007 and 2017. This is compared to 224 journal papers relating to mitigation in New Zealand over this same period, 26 of which were direct outputs from SLMACC projects alone (van der Weerden et al. 2018). Overall investment in adaptation research has also been significantly lower than investment in mitigation. Out of the total SLMACC investment of $51 million since 2007, just over $7 million has gone into adaptation research. The largest project funded was worth $1.5 million, but most projects were relatively small. The average value of individual projects was $214,500, and the median value across the range of adaptation projects was $150,000.

The lower levels of investment in adaptation research and comparatively less published literature are compounded in SLMACC projects by a focus on broad, national-scale impacts for selected industries. There is over-representation of pasture-based (especially dairy) farming in much of the SLMACC research, and limited research on fast-growing, climate-sensitive industries such as high-value horticulture and viticulture. Regional analyses of adaptation have been conducted, but they are often based on limited spatial analysis of select regions, including Hawke's Bay and Bay of Plenty, with some case studies from the South Island. There has been very little work from other major regions with significant agricultural industries, including Canterbury, Otago, the West Coast, Waikato, Taranaki and Northland. Studies are also delimited by a sector focus in most cases, and there are few examples of regionally based analyses that consider the interaction between adaptation decisions across multiple sectors or issues (e.g. water management).

Advances in adaptation science increasingly emphasise the need to consider planning for multiple futures. Tools and processes – such as applied adaptation pathways – have distinct knowlede requirements in order to inform decision-making and planning processes. We developed and applied the Adaptation Knowledge Cycle to highlight the characteristics and attributes of adaptation-relevant science: Impacts, Implications, Decisions and Actions, linking it to the process of developing an applied adaptation pathway (Figure S3).

Classifying research outputs in this way shows a significant emphasis to date in SLMACC research and the published literature on probabalistic and biophysical modelling of climate change impacts. Most SLMACC adaptation projects to date have focused on understanding the impacts and implications of climate change (65%, and 15% respectively). There is less information about the management implications of climate change, and very little information on decision-making or how best to enable adaptation action including policy design to incentivise adaptation (Figure S3).

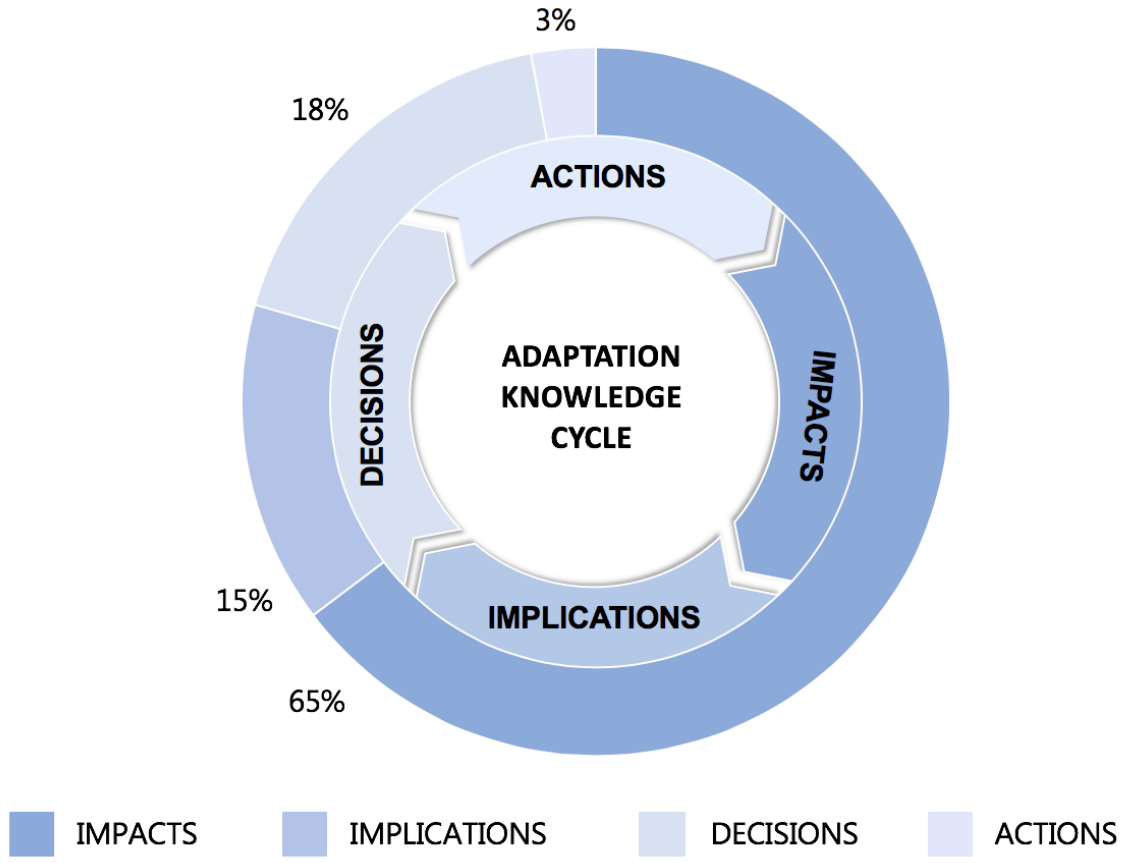

Figure S 3. Adaptation Knowledge Cycle and SLMACC research focus.

To address the adaptation deficit – the difference between what we know about the impacts and action to address it – new insight into primary industries' thinking, planning and acting for climate change is urgently needed. Without the appropriate science delivered in a decision-relevant context, it will become increasingly difficult – if not impossible – to adequately prepare.

What do we need to know?

To inform future adaptation planning, additional work is required to better understand the implications, decision-making processes and obstacles to action. More detailed understanding of location-, season-, time- and sector-specific responses to climate change is also necessary.

Insight into the behavioural factors that lead to adaptation intention, decision and action – including how to effectively frame climate change messaging and better understand the motivations behind adaptation – can assist with the design and implementation of incentives, targeted communications strategies, and policy measures.

Empirical and methodological gaps need to be addressed. In addition to the sectoral and spatial gaps identified above, there is a need for diverse methodological approaches to gain insight into the full range of impacts and implications, as well as the factors that influence decision-making. This is likely to require larger interdisciplinary teams and well-funded projects with sufficient time (i.e. longer than the typical 12-18 months projects currently run for) that are also able to develop communications and outreach materials to enhance impact.

Conclusions

In summary, the adaptation projects funded by SLMACC:

- have delivered new knowledge and enhanced our understanding of the impacts and implications of climate for New Zealand primary industries, and have supported research to gain insight into farm- and sector-level decision-making and adaptation action
- have provided critical pathways for adaptation research in the absence of other funding – SLMACC has fostered the development of early-career research capability and capacity, and has fostered an adaptation community of practice
- demonstrate high potential value for money, by pointing to the value that could be generated – or losses avoided - through targeted investment in adaptation research to support primary industries' response to climate change
- have catalysed additional investment adaptation research through Crown Research Institute core funding and in turn, adaptation projects have effectively utilised tools and processes, leveraging the science investment
- have effectively documented the evolution of climate change adaptation research in the primary industries, highlighting areas of research focus (pastoral, arable and dairy) and areas where further research is needed (biosecurity, horticulture and viticulture)
- have captures context-dependent and location specific impacts
- have highlighted the need to advance research in social systems and the importance of interdisciplinary collaboration across natural, engineering, social and decision sciences
- can broaden their scope, and build on empirical work characterising the impacts and potential implications of climate for New Zealand primary industries, by

better understanding adaptation decision-making processes and strengthening the link between information and action.

Recommendations

Adaptation to climate change is emerging as a priority science need in the primary sector and across New Zealand society more generally. The insights gained throughout this review have informed the following recommendations that we believe would provide a foundation for further adaptation research to support climate-resilient primary industries.

We recommend:

- **Closing knowledge gaps through cross-cutting and targeted research.** Understand research excellence to mean both depth of insight as well as breadth of application and usability and increase investments in integrated, cross-sectoral and targeted adaptation projects to address empirical and methodological gaps;
- **Improved coordination between adaptation science, policy and practice.** Strengthen the connection between the theory and practice of adaptation and promote the development of networks adaptation researchers, decision-makers, practitioners, and policy-makers;
- **Enhancing adaptation communication and knowledge exchange.** To make SLMACC communication more meaningful beyond science and government, strive to make findings useful and useable for industry and demonstrate adaptation successes to enhance relevance and credibility of adaptation science for stakeholders and end users;
- **Innovative methods for adaptation monitoring and evaluation.** Designing and implementing innovative methodological approaches such as the Adaptation Knowledge Cycle, can help understand and track progress towards adaptation outcomes. This can improve the ability to design effective policy interventions and demonstrate the impact of adaptation science, supporting the transition towards climate-resilient primary industries;
- **Refocussing the adaptation research agenda.** Harness the current momentum in the primary sector and across New Zealand society more generally to give higher focus to climate change adaptation and promote the systematic examination of policy-specific and sector-specific characteristics of adaptation governance; and
- **Bridging funding gaps to address the adaptation deficit.** There is a need to give higher focus to climate change adaptation and acknowledge that mitigation and adaptation require equal attention and to their interconnections. To advance and progress the momentum of adaptation research in New Zealand, continue with at least the same funding level, or ideally increased funding to guarantee climate-resilient futures for the primary industries.

1 Introduction

New Zealand's productive sector is currently operating in an environment of increasing risk and uncertainty. Primary enterprises will contend with more frequent climate crises (e.g. drought and flood), ecosystem services degradation (e.g. eroding soils, water pollution), biosecurity incursions, changing social and market demands (e.g. the demand for sustainable products) and subsequently new industry and public policy. Some of these risks act as persistent pressure on enterprises, while others act as short, sharp shocks. Collectively they can have a significant impact on the sector and New Zealand's economy.

Many of these non-climate-related risks will be compounded by the impacts of climate change, which is expected to lead to warmer temperatures, decreased precipitation, increased likelihood of extremes such as high intensity rainfall and wind events, and the emergence of the impacts of sea level rise in low lying areas that compound with river flooding.

The increased frequency of such events is extremely relevant to New Zealand. They will challenge management systems in the primary sector with implications across the New Zealand economy and society. The primary sector contributes 7% of GDP and accounts for 79% of export earnings (StatsNZ 2018). Approximately half the land base is in productive pasture and arable cropping, including 1.8 million hectares of productive forest plantation. Nationally, it is a significant economic driver, employing 350,000 people, and is fundamentally important to many local and regional economies. Climate events such as El Niño–Southern Oscillation (ENSO) have demonstrated their impacts on the economy, and there is increasing evidence of human influence on recent climate extremes affecting New Zealand (Harrington et al. 2014).

Primary sector economic activities such as pastoral farming, horticulture, viticulture and cropping are acutely vulnerable to climate change (Cradock-Henry 2016). The shift towards more intensive production and high-input systems has exposed the sector and there is further potential to create new risks and increase uncertainty for producers. Overall, as much as 79% of New Zealand's economic activity is considered vulnerable to future climate change (Fitzharris 2007).

Successful adaptation to climate change in rural environments and enterprises is vital to securing New Zealand's economic resilience. At the most general level, climate adaptation is what people do to avoid and recover from unusual or extreme climate events (Table 1). Adaptation in the primary industries encompasses diverse strategies that can used by individual farmers and land managers, sectors, industries and regions to adequately respond to climate change. It involves adjusting practices, processes, and capital in response to the actuality or threat of climate change, as well as responses in the decision environment, such as changes in social and institutional structures or altered technical options that can affect the potential or capacity for these actions to be realized Adaptation is "positive response to the prospect of climate change" (Clark & Nottage 2012).

To support adaptation actions, decision-makers must understand the nature of the sector's vulnerability, in terms of who is vulnerable, the nature of the vulnerability, the

nature of the stresses, and the capacity to adapt to ongoing changing risk where uncertainties prevail (Moss et al. 2013).

Table 1. Common definitions of adaptation

Source	**Definition**
Intergovernmental Panel on Climate Change (IPCC)	Adaptation is the process of adjustment to actual or expected climate and its effects. In human systems, adaptation seeks to moderate or avoid harm or exploit beneficial opportunities. In some natural systems, human intervention may facilitate adjustment to expected climate and its effects (IPCC 2014).
United Nations Framework Convention on Climate Change (UNFCCC)	Adaptation refers to adjustments in ecological, social, or economic systems in response to actual or expected climatic stimuli and their effects or impacts. It refers to changes in processes, practices, and structures to moderate potential damages or to benefit from opportunities associated with climate change (UNFCCC website).
United Nations Development Program (UNDP)	Adaptation is a process by which strategies to moderate, cope with and take advantage of the consequences of climatic events are enhanced, developed, or implemented (UNDP 2005).
United Kingdom Climate Impacts Program (UKCIP)	Adaptation is the process or outcome of a process that leads to a reduction in harm or risk of harm, or realisation of benefits, associated with climate variability and climate change (UKCIP 2003).

The Sustainable Land Management and Climate Change (SLMACC) research programme was established in 2007. Administered by the Ministry for Primary Industries (MPI), the fund aims to address the impacts of - and adaptation to - climate change, mitigation of agricultural greenhouse gases and improvements of forest sinks, under the paradigm of sustainable land management (Rys 2013). The SLMACC fund aims to contribute to the achievement of New Zealand's broader climate change targets, through funding research to understand the impacts of climate change, thereby improving risk management and increasing the resilience of the primary sector to climate change (Ministry of Agriculture and Forestry 2011). This will be achieved by equipping land managers and their advisors with both information, and technologies, to mitigate and adapt to climate change.

With funding from the SLMACC programme, a number of research projects have explored various aspects of vulnerability, resilience and adaptation in the primary sector. In addition, a wealth of research has been conducted by university researchers, private consultants, and industry and sectoral agencies. This work has provided multiple insights into climate change vulnerability, and the challenges and opportunities for adaptation. Findings from this research can inform adaptation policy development, and identify key vulnerabilities, the determinants of vulnerability, differences in vulnerability between different sectors, and entry points for adaptation policy.

Successful primary industries will be the ones that are able to anticipate and mitigate identifiable risks and that have the built-in buffers and adaptive capacity to respond to unexpected risk. The capability and capacity of primary industries, therefore, has never been more important to assess, influence and monitor.

1.1 Scope of this report

This project addresses research under the SLMACC programme "Theme 1: Impacts of climate change and adaptation" which includes:

- Vulnerability to climate change
- Direct and indirect impacts of climate change
- Adaptation to climate change

The impact of the SLMACC programme is a critical component of the government's commitment to enabling a climate-resilient New Zealand. Reviewing the impact of science investment to date can help inform future research strategy and funding priorities, and support the case for further investment. Ensuring the viability and sustainability of primary sector is vital to New Zealand's economic well-being. There is already evidence showing the effects on climate change and adaptation will be required even if greenhouse gas emissions can be reduced due to the lag time in effect of emissions to date (MfE 2018).

The following report reviews the state of adaptation science for New Zealand's primary industries to determine what exactly is *known*, *not known* and needs *to be known* about climate change adaptation for primary industries. Based on a robust evaluation of SLMACC adaptation projects, expert consultation, end-user and industry engagement, cost–benefit analysis and systematic review of the published literature, it summarises and assesses the state of knowledge.

The evaluation provides an up-to-date assessment of the state of adaptation science and its outcomes, identifies enablers and barriers to adaptive capacity, and considers the value for money of previous research. Knowledge gaps are identified, providing a baseline for tracking knowledge production, and for informing future research agendas to enhance resilience to climate change.

The report is organised as follows: Section 2 outlines the methods used in the review; Section 3 describes the characteristics of reviewed SLMACC-funded adaptation projects; Section 4 reports on the outcomes and impact of each project, followed by a discussion of the Adaptation Knowledge Cycle in Section 5. In Section 6 critical knowledge gaps in adaptation research are explored, and the barriers and enablers to more effective implementation are identified in Section 7. Finally, recommendations for implementation and future research directions are discussed in Section 8.

2 Methods

To synthesise the state of knowledge, a mixed method approach was used to provide a robust and multi-pronged perspective on the success and impact of the SLMACC fund with respect to adaptation. Consistent with the other reviews (technology transfer, mitigation, and forestry), we participated in the project scoping and planning workshops, and in the development of the programme logic model and evaluation rubric.

The following methods were used in combination to conduct the review:

- development of an evaluation rubric
- evaluation of 32 SLMACC adaptation projects against the evaluation rubric to determine project outcomes and impacts
- a systematic literature review and annotated bibliography of the published peer-reviewed literature related to adaptation in New Zealand primary industries
- development and application of the Adaptation Knowledge Cycle to assess projects against the following criteria: impacts, implications, decisions, and actions; SLMACC projects and the published literature were assessed against the typology, and the salient characteristics of each were derived
- conversations with key informants involved in climate change research in New Zealand to identify critical components of the adaptation research landscape over the last decade
- a Mind the Gaps workshop with primary industry stakeholders and adaptation researchers to evaluate SLMACC adaptation project outcomes, identify knowledge gaps and determine future priorities
- a cost–benefit analysis of adaptation research for pastoral farming
- analysis of supplemental data from project leaders and researchers surveys.

The relevance and use of each of these tools and methods is briefly described here, followed by a more detailed discussion of the method for the adaptation review.

2.1 Rubric, stakeholder and researcher surveys

To provide a common element across the SLMACC reviews, an evaluative criteria rubric was co-designed at a workshop in March 2017. This process was led by the Technology Transfer Review Group and involved attendees from the other review teams and MPI. Collectively the group articulated and agreed on the critical success factors (or key aims) for the SLMACC fund using an agricultural innovation systems perspective (Botha et al. 2017). This approach enabled a system-wide focus on how SLMACC projects have contributed to climate change mitigation and adaptation in New Zealand (Campbell et al. 2015) over the past decade.

This wider systems view is increasingly considered an informative way to approach complex problems (such as climate change) that involve multiple interacting drivers, conflicting goals, trade-offs, feedbacks, non-linear responses, and potentially unintended consequences (Schut et al. 2014a,b; Spielman et al. 2009). From the critical success factors,

a programme logic framework was developed ('logic model'), which then informed a rubric to evaluate the key aspects of performance of the SLMACC fund.

The evaluative criteria rubric was constructed by the Technology Transfer Review Group and MPI. It specifically assesses capability and capacity building, stakeholder engagement, knowledge exchange, uptake and use of the research, and impacts. The rubric was circulated and refined among the four review groups before final approval by MPI.

Information to populate the rubric for the 32 adaptation projects was obtained through two main mechanisms:

- an interrogation of the main project outputs (typically a report)
- a survey sent to project leads and key stakeholders, and follow-up phone conversations where necessary.

The surveys were designed to elicit information that could not be obtained through an examination of the project outputs (refer to Payne et al. 2018b for more information). The complete evaluation rubric for reviewed projects is included in Appendix A.

2.2 Project summaries

Descriptive summaries were generated for each of the SLMACC projects considered in the review (Appendix B). These summaries contain project-related details on the key organisation and named partners, project duration, total funding, main target audience, and lead author. The one-page summaries also contain a project summary, project components, and project outcomes.

2.3 Systematic literature review

A systematic review of the published white literature on climate change adaptation in the primary sector in New Zealand was carried out to complement the SLMACC adaptation reports (Appendix C). 'Systematic review' refers to a methodological approach that synthesises and summarises the state of knowledge on a given topic or research question, structured to rigorously summarise existing understanding (Ford et al. 2011). A strict methodology is used to collect, appraise and compile knowledge from all pertinent studies on a specific research question to ensure objective, transparent, traceable and upgradable outputs (Petticrew & Roberts 2006). This approach provides a clear method to extract and analyse data, and to organise and identify both duplicated research and gaps in knowledge (Fedorowicz et al. 2011).

Systematic reviews have been widely used in the field of health care, and are, more recently, beginning to prove their value in addressing questions in the social sciences (Green & Higgins 2011). This type of knowledge synthesis can improve understanding of inconsistencies in diverse evidence and identify evidence gaps to help define future research agendas.

2.4 Key informant short discussion

To provide a context for how climate change research has evolved in New Zealand,

an interactive timeline poster was designed by the Adaptation Review Group and presented for comment at the Deep South National Science Challenge annual conference poster session (4– 6 September 2017). The purpose was to elicit critical temporal factors and contextual elements related to policy changes and research directives from key informants, especially those who had been involved with, and instrumental in, climate change research and policy in New Zealand since the 1990s. Several prominent researchers and policy-makers were deliberately sought out for their input into the timeline (refer to Appendix D).

2.5 Mind the Gaps Workshop

A half-day workshop with climate change researchers, primary industry stakeholders and end users was held in Wellington on 17 May 2018 (Appendix E). The aim of the workshop was to discuss the impact of SLMACC adaptation research, and to identify critical knowledge gaps and emerging priorities. Stakeholders from across the primary sector had the opportunity to engage with adaptation and climate change specialists about how best to prepare for climate change, and ensure greater alignment between information needs and science delivery for climate-resilient futures.

2.6 Analytical approach

The research team has classified and categorised the data in several ways. This provides a robust analysis describing the development of primary sector-focused climate change adaptation literature in New Zealand, thematically organising research outputs, and identifying knowledge gaps. For each adaptation research output (i.e. SLMACC project reports and published, peer-reviewed literature) the following data characteristics were identified and recorded.

Thematic analysis: The reports were read and categorised according to thematic areas such as drought, biosecurity (including pest diseases), and variability and extremes, and key messages were summarised.

Sector: For each item the sectoral focus was identified. Where projects or papers addressed multiple sectors or activities in an area, they have been classified as cross-sector; otherwise they have been categorised as pastoral, dairy, arable, or horticulture and viticulture.

Georeferenced: The impacts of climate change will be felt in different parts of the country. Eastern regions of New Zealand, for example, are likely to become hotter and drier, while western regions may become wetter. To gain insight into the prevalence of geography in SLMACC research, the scale (national/regional) and location of each research output was recorded. Results can be used to identify where most research is situated and suggest spatial gaps where attention might be needed.

Temporal: It is also valuable to categorise SLMACC reports and published white literature according to year of publication. This is useful in and of itself to provide additional context for reports and journal papers based on publication date. It is also helpful in interrogating if there is a link between research approaches or concerns articulated in reports and journal papers and the year of publication. In addition, there have been key policies, research outputs and other events that have influenced the content of the SLMACC requests for proposals.

Adaptation Knowledge Cycle

To further assess the specific outcomes related to adaptation research, the Adaptation Review Group developed an analytical framework of what we consider to be the key characteristics and attributes of adaptation-relevant science: the Adaptation Knowledge Cycle (Figure 1). The framework is based in part on previous work by members of the review team in the Climate Change Impacts and Implications project (Lawrence et al. 2016). The framework has been further adapted to the context of the primary industries based on our collective experience and expertise.

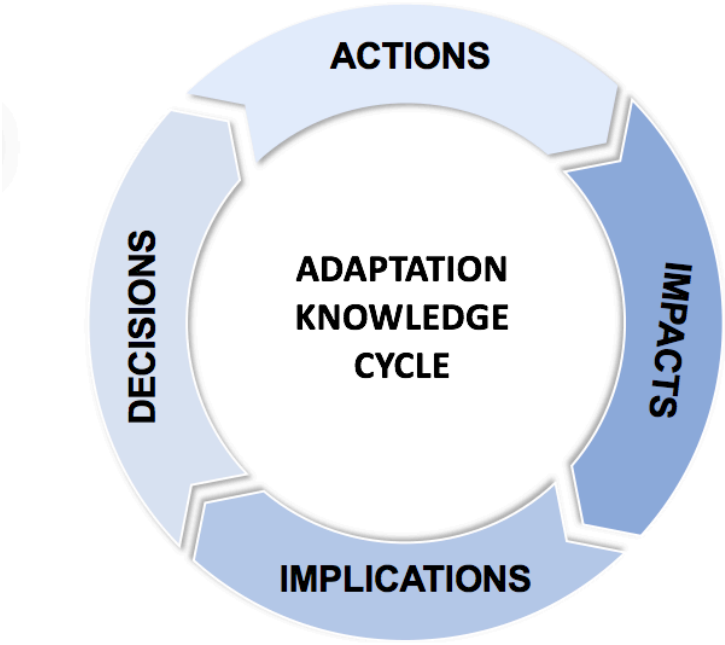

Figure 1. Adaptation Knowledge Cycle.

Our adaptation-specific typology was applied to further classify projects and papers according to their analytical focus: impacts, implications, decisions or actions (I-I-D-A). **Impacts**-focused research provides a description of first-order impacts of climate change on the primary production system. This research identifies impacts but stops short of articulating how these impacts might flow through to challenge existing practices and lead to actions on the ground. **Implications**-focused research examines the knock-on or cascading effect of specific climate impacts on the primary production system and implications for management. Research with a **decisions** or **actions** focus provides information to make adaptation decisions by identifying when, where and what decisions

need to be made; or it supports changes in behaviour and implementation of on-the-ground actions for adaptation.

It is important to note that the position of a project along the cycle may be related to the maturity of the research field. For example, research follows a logical temporal sequence, whereby the understanding of impacts occurs before research on implication or actions.

To apply the typology, we summarised each project, reviewed commentary and feedback from the researchers' responses to the survey(s), and discussed the project as a team. Not all projects fitted neatly within the boundaries of the framework. However, to facilitate interpretation, each project has been assigned to a single category in the knowledge cycle.

2.7 Review process

The tools and methods described here were used in combination to conduct this review. First, the project outputs were thoroughly examined, for each individual project. This included reading all relevant documents, highlighting sections that related to the evaluative criteria rubric, and making notes on key evidence and issues. Once all outputs had been processed, the reviewer made preliminary assessments in the rubric about the relevant project. For each line in the rubric, one to two sentences were written regarding the evidence found or justification used for each assessment. Where further information was needed to make a judgement, relevant individuals (project leaders or stakeholders) or resources were identified and sought out.

Second, project leaders were identified and contacted for a phone interview to help both corroborate the existing assessments in the rubric and provide evidence regarding gaps. Additional evidence typically required from project leaders related to capacity and capability building, the uptake and use of the resources or events within the science community, and research impacts. Project leaders were also asked, where possible, to identify additional stakeholders or end users to interview on outcomes and impacts achieved in the project. Where a specific resource was cited as being relevant (e.g. an evaluation report), this evidence was requested, and where provided, examined.

Once all projects had been reviewed and assessed using the rubric, the primary reviewer proposed a preliminary list of themes that were common across the projects, relating to lessons learned, areas for improvement, and science gaps in technology transfer. All relevant outputs were then re-examined considering these themes. Projects were examined for:

a presence or absence of each theme

b key quotes pertaining to each theme

c evidence of response to each theme.

Each theme was then reported on, using these data as evidence and examples.

Finally, the project leader and stakeholder survey data were examined in relation to the findings of this review. Data were analysed in MS Excel, with supplementary analyses and graphs created using MS Excel, Binder and Plotly.

2.8 Limitations and disclaimer

In the absence of any formal monitoring and evaluation of the (2007 – 2017) SLMACC projects prior to this review, there is considerable variability in the degree to which we have been able to assess project outcomes and impacts. When reading our assessment, it is important to keep the following in mind.

Many projects were conducted 10 years ago, and principal investigators had moved overseas, changed research fields, and/or not followed projects' impacts. In other cases, research leads were reluctant to participate in the evaluation given the criteria their work was being assessed against. Some projects, for example, were designed and delivered with the express aim of providing evidence to inform policy directions for government, and reports were not widely disseminated, limiting their impact with industry, for example.

For other projects we reviewed, the uptake of knowledge may have had less to do with its usefulness and more to do with the predominant political and social environment with respect to attitudes to climate change (Reisinger et al. 2011) or methodological approaches that did not rely on significant levels of stakeholder engagement.

In the early work on adaptation there was a greater emphasis on impacts-oriented or outcome-vulnerability studies. These studies often relied on model-based assessments and did not usually include stakeholders or end users in the analysis. We have tried to address this in part by incorporating a temporal aspect to the review.

Project managers were asked to self-report on the impacts of their project, but it was not always possible to triangulate this with data provided from other sources. Where data have been limited, we have drawn on the results of the stakeholder and researcher surveys. Where multiple sources of data (project outputs, survey data and interview data) could be triangulated, high-level judgements about achievement of outcomes and impacts have been made.

For most projects, a lack of sufficient evidence resulted in the use of the assessment category 'insufficient evidence' for outcome and impact criteria. For those projects where assessments could be made, it was difficult to attribute these findings definitively and purely to the relevant project. It is also important to note that this review was not exhaustive: it was impossible to interview all project team members, or to gain the perspective of the many stakeholders who participated in the projects.

We therefore ask that readers take the above limitations into account and interpret the findings of this review cautiously – as indicative as opposed to definitive findings about adaptation research supported through the SLMACC programme.

When reading our assessment, it is important to keep the following in mind.

- **The report reflects the current state of adaptation knowledge in the primary industries**. The assessment is based primarily on the review and synthesis of SLMACC adaptation projects (2007 – 2017) and the published literature. By understanding the impact and outcomes of adaptation research we hope to establish a baseline from which to measure changes in levels of understanding, preparedness and adaptive capacity.

- **The focus on adaptation is shifting rapidly.** In the 6 months prior to this report, two major reports on adapting to climate change in New Zealand have been released (Stocktake and Recommendations from the Climate Change Adaptation Technical Working Group 2017 and 2018), and there is growing interest in adaptation, both from researchers and from policy- and decision-makers. We have tried to reflect this dynamism in our review, but have been limited by practical considerations of time, resources and the scope of this report.
- **The assessment is based on the qualitative expert judgement of the research team**, and information provided by SLMACC research providers, end users and stakeholders. Because there has been no previous evaluation of SLMACC projects, nor a requirement or expectation of researchers to collect data on the impact of their work, in some instances we have had to make subjective decisions based on our familiarity with the research, or after consultation with end users.
- **Success factors used to develop the rubric were derived from current thinking on agricultural innovation systems.** These criteria may be different from those that were relevant at the time of projects' funding. The requirement of research projects to produce tangible outcomes for stakeholders is a relatively recent occurrence and was absent from earlier research requirements.

The following discussion synthesises evidence from multiple sources to provide a comprehensive review of SLMACC adaptation research.

3 Review materials

This section briefly summarises the project characteristics and observable trends in adaptation research funded by the programme. One-page summaries of each project can be found in Appendix B. Each narrative includes:

- **key project details:** the key organisations involved, the funding amount provided, named partners, and the main audience for the project
- **project summary:** the key aims and objectives, methods and content of the technology transfer activity
- **project components:** a description of how the project performed when evaluated against the evaluative criteria rubric constructed for this review – criteria included building science capacity and capability enhancement, influence on science, engagement and network building, and learning, awareness and knowledge gained among end users; plus, the usability of research for end users, influence on stakeholders, and impacts for New Zealand (direct and indirect) were also considered
- **outcomes:** a presentation and evaluation of any evidence that indicated outcomes and/or impacts achieved because of the project.

Since 2007 SLMACC has funded 32 projects under Research Theme 1: Impacts of climate change and adaptation worth $7M (Table 2).

Table 2. SLMACC adaptation review projects

RESEARCH LEAD	FUNDING YEAR	MPI AMOUNT	TITLE (FINAL REPORT)	CONTRIBUTION TO ADAPTATION
Basher	2012	$150,000	Impacts of climate change on erosion and erosion control methods: a critical review	Identifies areas of New Zealand most susceptible to erosion given climate change projections.
Beresford	2012	$150,000	Climate change impacts on plant diseases affecting New Zealand horticulture	Models how temperature increases in different regions of New Zealand will affect horticultural diseases (e.g. apple black spot, kiwifruit vine disease). It concludes that only the most extreme climate change predictions for 2090 will cause a noticeable increase in disease risk.
Bright	2012	$722,000	Projected effects of climate change on water supply reliability in Mid-Canterbury	Catchment-scale modelling to predict the effects of climate change on weather elements, surface water flows, and groundwater flows.
Burton	2008	$65,063	Learning from past adaptation to extreme climatic events: a case study of drought	Examines the 'tacit' knowledge (instrumental, embedded knowledge) of farmers in NZ. It looks at past extreme weather events to see what the best coping strategies for future droughts.

RESEARCH LEAD	FUNDING YEAR	MPI AMOUNT	TITLE (FINAL REPORT)	CONTRIBUTION TO ADAPTATION
Clark	2008	$63,390	Drought, agricultural production & climate change: a way forward to a better understanding	Recommends a programme of research that encompasses applied risk analysis with enabling science initiatives. The aim is to maintain high levels of innovation in adapting to climate change.
Clark	2011	$150,000	Scenarios of regional drought under climate change	Uses models (with data from the IPCC) to predict drought frequency and intensity under three major global greenhouse gas emissions scenarios (B1, A1B, and A2). Highlights the need for adaptation in regions, such as the Canterbury Plains, where there is a high likelihood that droughts will increase in frequency and intensity.
Clark	2012	$1,493,333	Impacts of climate change on land-based sectors and adaptation options	Summarises existing data on climate change and then offers adaptation options for a range of land-based industries (dairy, sheep and beef, cropping, horticulture, forestry).
Cradock-Henry	2013	$150,000	Operationalising resilience in dairy agroecosystems	Develops a novel framework for assessing resilience in dairy-agro-ecosystems.
Cradock-Henry	2015	$150,000	Impacts, indicators and thresholds in sheep-and-beef land management systems	Uses a stability landscape model to characterise resilience in sheep-and-beef land management systems, and then develops an indicators-based evaluation framework.
Crush	2014	$500,000	Defining climate adaptive forage traits and genetic resources	Records responses of eight different perennial ryegrass cultivars to elevated CO_2 levels. Results help with plant breeding strategies for different climate change scenarios.
Dodd	2009	$125,321	Tomorrow's pastures: subtropical grass growth under climate change	Models how pasture will be affected by increases in CO_2, and then uses that information to verify an ecosystem model to simulate future conditions for a hypothetical farm.
Dunningham	2015	$210,000	Innovative and targeted mechanisms for supporting adaptation in the primary sector	Reviews tools and mechanisms used in New Zealand climate change adaptation communication and research, and then identifies the motivating levers of decisive action at different scales across the primary sector activities. The intention was to identify communication mechanisms to support climate change adaptation in the primary sector.
Fitzsimons*	2012	$150,000	Farm-level adaptive capacity to climate change: the role of financial strategies and financial institutions in Australia	Identifies the opportunities and challenges to financial adaptation in Australia's primary industries.

RESEARCH LEAD	FUNDING YEAR	MPI AMOUNT	TITLE (FINAL REPORT)	CONTRIBUTION TO ADAPTATION
Fowler	2008	$51,945	Vulnerability of New Zealand pastoral farming to the impacts of future climate change on the soil water regime	Offers a 'bottom-up' alternative (through analysis of regional-scale impacts on hydrological cycle and soil water regime) to 'top-down' climate change models.
Guo	2008	$19,730	Climate change risks to pastoral production systems	Examines three grass species in conditions of elevated CO_2. Concludes that enhanced stress on the plants due to elevated CO_2 only occurs at the end of the growth cycle.
Howlett	2013	$150,000	Impact of climate change on crop pollinator in New Zealand	Provides evidence of how bee and insect pollination will change given current climate change predictions of a 4-degree temperature rise in 100 years.
Kean	2015	$150,000	Effects of climate change on current and potential biosecurity pests and diseases in New Zealand	A summary of the potential impacts of climate change on exogenous pests, weeds, and diseases entering New Zealand.
Kenny	2008	$60,200	Adapting to climate change in the kiwifruit industry	Examines the effect of climate change on kiwifruit growers, and adaptation responses that could be made.
King*	2012	$150,000	Farm-level adaptive capacity to climate change: the role of financial strategies and institutions	Identifies alternative business models, financial strategies, products and services to increase farmers' adaptive capacity for climate change.
Lieffering	2008	$51,030	Improved field facilities to study climate change impacts and adaptations in pasture	Experiments undertaken to assess how to best simulate night-time soil and vegetation warming.
McCusker	2014	$80,000	Climate Smart Intensification options for New Zealand pastoral farmers: a farmer's guide to intensification options in the context of climate change	Collates data on the threats and opportunities of farm intensification in the context of climate change.
McMillan	2010	$150,000	Flood risk under climate change: a framework for assessing the impacts of climate change on river flow and floods, using dynamically-downscaled climate scenarios	A framework of climate scenarios and a hydrological model are combined to look at changes to the frequency and strength of floods during climate change. Results of the modelling are presented through two case study catchments (Uawa River and Waihou River).
Mullan	2011	$150,000	Scenarios of storminess and regional wind extremes under climate change	Uses models to predict changes in the frequency of extreme wind events under climate change. The results indicate that extreme winds will increase in all regions over winter, but will decrease over summer.

RESEARCH LEAD	FUNDING YEAR	MPI AMOUNT	TITLE (FINAL REPORT)	CONTRIBUTION TO ADAPTATION
Newton	2008	$60,314	Enhanced modelling capability to conduct climate change impact assessments	Farm-scale modelling to see how farms can remain profitable under climate change scenarios. Combined with OVERSEER to predict what the environmental impacts of these adaptations would be.
Newton	2011	$141,881	Impact of elevated atmospheric carbon dioxide concentration on pasture, production forestry and weeds	Collated findings from several authors. The first chapter presents experiential evidence of the impacts of elevated CO_2 on pasture; the second examines the effect of elevated CO_2 on forestry; the third examines the effect of elevated CO_2 on weeds.
Newton	2014	$148,010	Detection of historical changes in pasture growth and attribution to climate change	Examines changes in pasture yield between 1960 and 2004 to show historical trends in biological systems relating to changes in climate.
Renwick	2013	$149,565	Four degrees of global warming: effects on the New Zealand primary sector	The document examines many issues under the assumption of a 4 degree rise in temperature by 2100. The issues include growing days and frosts, extreme rainfall and flooding events, pasture growth, forestry, and animal heat stress.
Rosin	2015	$471,168	Evaluating intensification trajectories in the context of climate change	Makes a series of recommendations for future-proofing New Zealand's pastoral farming from the effects of climate change.
Sturman	2015	$500,000	Development of advanced weather and climate modelling tools to help vineyard regions adapt to climate change.	Examines the relationship between relationship between climate variability and viticulture production in New Zealand, then uses that as basis for understanding how grapes will react to different climate change scenarios. Information can might help grape growers avoid risk factors such as frost, and extreme temperatures.
Tozer	2011	$150,000	Improving sustainable lifetime performance of pastures: Learning from extreme climatic events	Examines the effect of changing climate on weeds entering pasture, and tests the hypothesis that increasing species diversity in sown species reduces the risk of growth of invasive weeds.
Trolove	2008	$74,341	Forage crop opportunities as a result of climate change	This research contrasts existing crop models with simulated weather data to look at predicted changes to forage crop production between 2040 and 2090.
Zemansky	2010	$150,000	Framework for assessment of climate impacts on New Zealand's hydrological systems	Identifies trends in hydrological systems in conjunction with climate change predictions.
TOTAL		**$7,078,291**		

* Fitzsimons (2012) and King (2012) focused on adaptation in Australian financial services and primary industries, and so have not been included in the subsequent analysis.

The total investment in impacts and adaptation research is just over $7,000,000. The largest project funded was worth $1,493,333 (Clark & Nottage 2012) and synthesised information on short/medium-term adaptation across all primary industries, including forestry. The average value of individual projects was $214,500, and the median value across the range of adaptation projects was $150,000. The range between the largest and smallest funded projects is $1,473,603.

Projects have been led by a range of institutions, with half of all projects involving more than one research partner and six projects involving three or more institutions, suggesting relatively high levels of collaboration (Table 3). One project involved an international research organisation (Sturman et al. 2015). AgResearch and NIWA stand out as research organisations that advance projects without involving another research organisation.

Table 3. Research organisations involved in SLMACC adaptation research

ORGANISATION	NUMBER OF PROJECTS LEADING/ NAMED PARTNER
NIWA	12
AgResearch	11
Manaaki Whenua – Landcare Research (formerly Landcare Research)	10
Plant & Food Research (inc. Crop and Food Research)	8
DairyNZ	3
GNS Science	3
Agricultural Research Group on Sustainability (ARGOS)	2
AgriBusiness Group	2
AgriBusiness and Economics Research Unit (AERU), AquaLinc, Beef and Lamb Limited, Earthwise Consulting, Foundation for Arable Research (FAR), MetService, Rezare Systems, University of Canterbury, University of Rennes (FRA)	Each 1 count

3.1 Trends in SLMACC adaptation research

In addition to the characteristics of individual projects, there are some observable trends in terms of overall funding for adaptation research through the SLMACC programme. As shown in Figure 2 (overleaf), most of the investment has been in impacts-focused research. Since 2012 the range of projects funded has widened to incorporate more work on implications, decisions, and actions.

Funding for impacts and adaptation research peaked in 2012, dropped significantly in 2013 and recovered slightly in 2014. Figure 2 also shows trends in funding allocation across SLMACC projects over time, and the relative funding distribution between impacts-, implications-, decisions-, and actions-focused research.

Closer analysis shows the largest investment has been in research addressing the impacts of climate change and adaptation in all primary industries. Most research on pastoral and arable farming was done in 2008, 2012 and 2014. The focus on adaptation in dairy farming

increased between 2012 and 2014. The kiwifruit industry, horticulture, seed crops and viticulture are covered by singular projects and have not been continuously analysed in the SLMACC context.

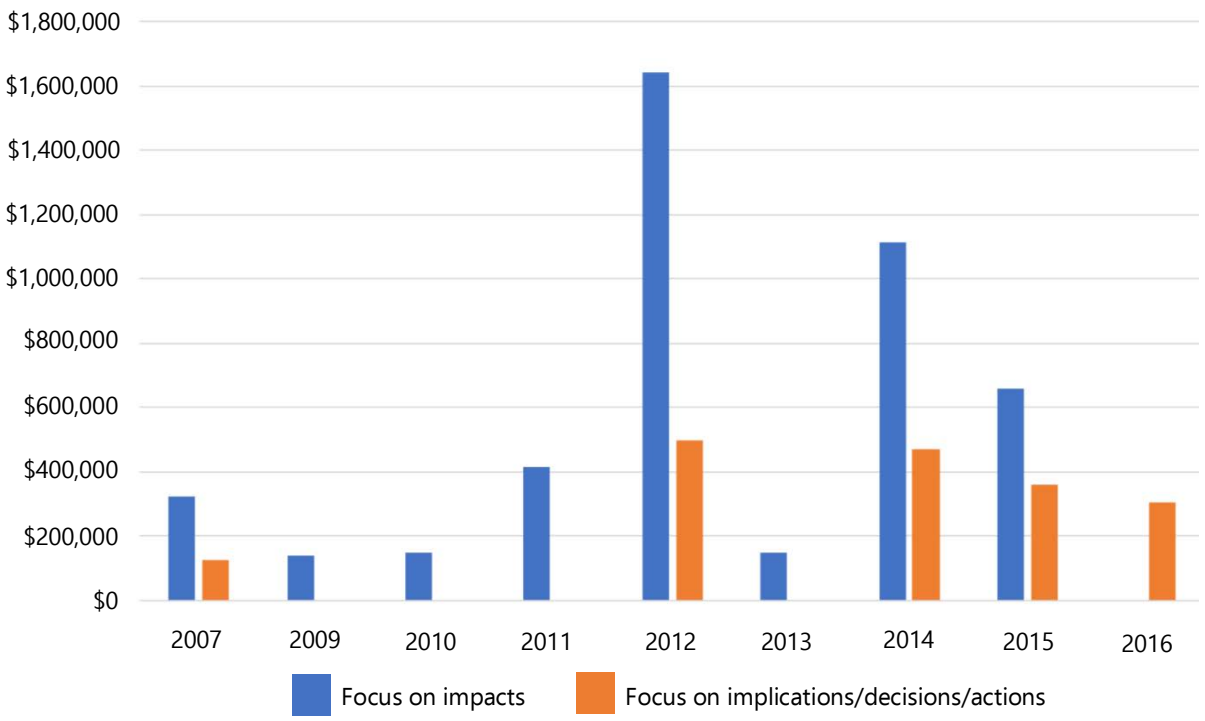

Figure 2. Funding and adaptation knowledge.

Projects focused on the general impacts of climate change nationally and feature prominently in the funding period (2007–2017). Most research projects provide a medium- to long-term adaptation perspective. Most research projects cover climate change effects and adaptation responses in all New Zealand: it appears that regionally focused studies receive less funding on average. Projects on viticulture in Marlborough/Waipara are an exception to that observation.

In summary:

- The research from 2007 to 2017 shows a clear focus on understanding the impacts of climate change.
- Impacts and implications research have received considerably more funding than decisions- and actions-focused research projects.
- A majority of studies are focused on the breadth of climate change impacts, often at a national scale. In-depth sector-specific analyses are under-represented in SLMACC funding.
- Pastoral, arable and dairy industries are explored, but mostly in terms of impact.
- Viticulture and horticulture appear to be under-represented in terms of science investment through SLMACC.

These preliminary observations are discussed and elaborated on in further detail in the remaining sections of the report.

4 Rubric evaluation outcomes

To assess the outcomes and impact of SLMACC adaptation projects, each one was evaluated against the rubric, and the Adaptation Knowledge Cycle developed specifically for the adaptation review. The following section reports on the extent to which the desired outcomes have been achieved by the adaptation projects; and the degree to which SLMACC research has supported and enabled adaptation outcomes for the primary industries based on the rubric evaluation criteria. Further analysis based on the Adaptation Knowledge Cycle follows in section 5.

4.1 Impacts of climate change and adaptation outcomes and impacts

Thirty-two projects were evaluated using the rubric. The average scores (between 1 and 3 out of a possible 3) across each of the six main categories of criteria are shown in Table 4, along with an overall score and rating. The complete rubric is available in Appendix A. Projects whose average scores are between 1.0 and 1.6 have been classified as LOW (never or seldom, with clear weakness), from 1.7 to 2.3 as MODERATE (never or seldom with clear weakness); and from 2.4 to 3.0 as HIGH (almost to almost always). Where there is insufficient evidence for a score, the IE label applies. Generally, there was insufficient evidence on some measures for many projects, which leads to a tentative assessment of trends that might not reflect the breadth of research undertaken.

Table 4. Average scores in the evaluative criteria rubric across adaptation projects

	RATING (AVERAGE SCORE)
1 BUILD SCIENCE CAPACITY AND CAPABILITY ENHANCEMENT	
Builds capacity for NZ to research in topic area (e.g. climate change and sustainable land use) at all levels	HIGH (2.7)
Improves capability and skills among emerging or early career researchers.	HIGH (2.7)
	OVERALL: HIGH (2.7)
2 INFLUENCE ON SCIENCE	
Promotes collaboration among research providers, and/or between different disciplines	HIGH (2.5)
Generates high-quality research related to topic area, which is credible and legitimate (e.g. citations, impact factor) with relevant stakeholders (e.g. Intergovernmental Panel on Climate Change)	HIGH (2.6)
Utilises robust, best practice research methods (poor: may use random or unexplained methods; excellent: may use novel methods or techniques, sound results)	MODERATE (1.8)
Results in uptake and use of research within science community (excellent would result in strong uptake and use of research within science community)	MODERATE (1.9)
	OVERALL: MODERATE (2.2)
3 ENGAGEMENT AND NETWORKS	
Builds collaborative networks of key stakeholders and/or end users (poor: may include homogeneous networks that disperse following project, and excellent networks are heterogeneous (e.g. different epistemologies, type of expertise, values) and enduring	HIGH (2.4)

Uses participatory research processes appropriate to level of engagement needed to achieve outcomes (based on MPI Extension Framework); e.g. where end users have the opportunity to shape research approach, sources of knowledge and outcomes	**MODERATE (2.1)**
Uses structure or processes to guide stakeholder engagement (poor: may have no clear processes for stakeholder engagement; excellent: may use processes like a community of practice)	**MODERATE (1.9)**
Practices action learning (if applicable)	**LOW (1.6)**
	OVERALL: MODERATE (2.0)
4 LEARNING, AWARENESS AND KNOWLEDGE EXCHANGE AMONG END USERS	
Generates new knowledge in topic area (e.g. climate change and sustainable land use)	**HIGH (2.5)**
Promotes knowledge exchange (particularly dissemination of research findings)	**MODERATE (2.2)**
Builds increased awareness and knowledge in topic area	**MODERATE (2.3)**
Promotes practice or behaviour change among intended end- or next-user groups	**HIGH (2.4)**
	OVERALL: MODERATE (2.4)
5 USABILITY OF RESEARCH FOR END USERS	
Generates specific, usable, fit for purpose knowledge and research for policy and trade/negotiation, research, science and stakeholder communities	**MODERATE (2.1)**
Aligns research with the needs of next- or end users of the research, and is responsive to next- or end user needs and knowledge gaps (poor: may lack alignment; excellent: may involve iterative research to meet user needs)	**MODERATE (2.3)**
Acknowledges context and effects of the research knowledge or recommendations on the broader climate system or topic area	**MODERATE (2.2)**
Creates accessible, available outputs	**MODERATE (1.9)**
	OVERALL: MODERATE (2.1)
6 INFLUENCE ON STAKEHOLDERS AND IMPACT FOR NZ	
[How the research is designed and delivered] maximises how wide-reaching the research influence is (inter/national, across relevant sectors and functions; e.g., policy, industry and community attitudes and behaviours)	**LOW (1.6)**
Results in uptake and use of research by stakeholder groups (policy, government, industry or community)	**MODERATE (1.8)**
Influences stakeholders positively in their awareness/ consideration of decision-making, and/or action around topic area (e.g. climate change and sustainable land use) (e.g. policy, government, industry or community)	**MODERATE (2.0)**
Achieves significant direct impacts or benefits for NZ (poor: may be no impact; good: incremental; excellent: may be wide ranging or more immediate impact)	**LOW (1.4)**
Achieves significant direct spill-over impacts or benefits for NZ (poor: may be no impact; good: incremental; excellent: would be wide ranging or immediate impact)	**N/A**
	OVERALL: MODERATE (1.7)

Science capability and capacity

Adapting primary industries to the impacts of climate change is among the most serious and complex challenges facing society, affecting elements of both natural and social systems. As such, adaptation requires new modes of knowledge production and interdisciplinary collaboration across the social, natural, engineering and decision sciences. The results of the review show **SLMACC investment has played an important role in building critical adaptation research capability and capacity.**

The highest scores for adaptation projects were for science capability and capacity enhancement. In both the rubric and through discussions with stakeholders, scientists and end users at the adaptation workshop, SLMACC was regarded as a vital and significant source of adaptation research funding. As one survey respondent noted:

> *MPI's investment in SLMACC means that NZ is in a better position in terms of having the knowledge and understanding that informs NZ global contribution and domestic targets. It is a very unusual in that the evidence base development has preceded the policy response - a model for other policy areas?*

While there have been other climate change programs (e.g. Community vulnerability, resilience and adaptation to climate change (2008-2012), Climate Change Impacts and Implications (2012-2016), SLMACC investment in adaptation research has been a critical – source since its inception. Notwithstanding more recent investment through the National Science Challenges, SLMACC has been the only consistent, accessible and targeted fund for adaptation research for the primary industries in New Zealand. While there have been large projects on climate change they have either not examined primary industries, or it has been only a small component of the programme. A common perception appears to be that *"SLMACC does all the adaptation research for primary industries."*

However, the total investment in adaptation-focused research within SLMACC is relatively small. Nonetheless, the fund has played an important role in leveraging additional science investment and building a community of adaptation researchers and practitioners.

As noted by one of the workshop participants, *"SLMACC funding is often co-funded by [our CRI]. It's a valuable catalyst for us to leverage strategic science investment (SSIF) and core funding."*

Resources also move in the other direction in a synergistic relationship. For example, regional climate models that are developed with SSIF funding are often utilised by researchers in SLMACC projects.

The other notable outcome of SLMACC investment in adaptation, has been the development of an adaptation research community, through its support for early-career (ECR) and mid-career researchers. There are few opportunities for post-doctoral research in New Zealand – in nearly all fields (Hendy 2012) and so SLMACC is significant in terms of building capability and capacity. Two SLMACC adaptation projects have been led by ECRs, and they have been associate investigators or key researchers in at least three others, in addition to two projects that have supported PhD student research. As one researcher stated:

SLMACC has been instrumental in developing my career. My first proposal was for a SLMACC project, which I was successful in obtaining right out of my PhD. Through that experience, I gained practical skills in leading and managing projects, I grew my research networks, and continue to be involved in a large portfolio of adaptation research in NZ and internationally. Many of the colleagues I work with in the adaptation space are also SLMACC alumni and the research collaborations are only getting stronger, and having even greater impact.

There are both perceived and measurable impacts of SLMACC adaptation projects' developing a community of adaptation research in New Zealand. This may be due in part to the accessibility of the fund, the annual funding cycles and support for interdisciplinary teams. Furthermore, despite its small size, SLMACC can gain leverage through links to other researchers and capitalise on funding from other, larger science programmes to foster interdisciplinary teams.

Influence on science

The high **influence on science and capacity building** scores in the rubric assessment reflects the predominant focus on *impacts* of climate change as part of the SLMACC funding rounds since 2007. The focus on understanding complex climate dynamics and their respective **context-dependent impacts** drives many projects to (a) make regional- and national-level specific assessments to ensure relevance for the primary sector, (b) compare methods and tools to assess changes (e.g. downscaling of global climate data to reflect New Zealand-specific climate contexts), and (c) bring insights from this assessment together with practical recommendations for specific sectors.

Most projects produce high-quality research. Generally, projects that scored higher in the criteria related to the earlier research stages (research design, methods and process) tended to also score higher in the latter research stages (have a wide-reaching influence, influence stakeholders positively and promote behaviour change).

The use of novel methods and techniques also seems to coincide with a high degree of capacity building to conduct research in the topic area. According to the rubric results, SLMACC is moderately successful in generating **high-quality research** related to a topic area, which is credible and legitimate (e.g. citations, impact factor) with relevant stakeholders; however, **uptake of results** and use of research within the science community appears relatively low. This is particularly noticeable in comparison with mitigation research in New Zealand (van der Weerden et al. 2018).

Engagement and networks

The average scores across all 32 projects suggest that these projects are moderately successful at generating diverse **collaborative networks** and **conducting participatory research** processes between research providers and disciplines, or between key stakeholders and end users; they also tended to score low on action learning. Part of this may be due to changing expectations with respect to adaptation research. Until relatively recently, most studies of climate change impacts and adaptation did not typically involve stakeholder or end user input (van Aalst et al. 2008).

Our analysis shows that, projects have increasingly included action **learning, participatory methods, and targeted knowledge communication** that respond to end-user needs (see e.g. Cradock-Henry & Mortimer 2012; McCusker et al. 2014; Dunningham et al. 2015). SLMACC was instrumental in supporting early adopters of this approach (Burton & Peoples 2008; Kenny & Porteous 2008). Projects that received lower scores in these categories focused on all New Zealand (Zemansky et al. 2010; Basher et al. 2012; Fitzsimons 2012; King 2012; Renwick et al. 2013), indicating that it might simply be more feasible to conduct participatory, collaborative work in region-specific research settings.

Low average scores in the categories **collaborative networks**, **research influence**, **uptake and use of research**, **and direct benefits** may also be driven by a lack of sufficient evidence for coding. For example, based on the survey results our analysis of research uptake shows relatively high levels of awareness and uptake of SLMACC research by central government. Levels of uptake and awareness of SLMACC however appear to decline among primary industry stakeholders and end users, including local government (Payne et al. 2018b).

Learning, awareness and knowledge exchange

The average scores across all 32 projects suggest that these projects appear to be moderately effective at generating new knowledge in the topic area, and at promoting knowledge exchange. SLMACC projects appear to be moderately successful at raising awareness and knowledge in the topic area as well as promoting practice and behaviour change among intended end users. Projects that utilised best practice approaches also tended to display stronger evidence of promoting knowledge exchange and building increased awareness and knowledge in the topic area. Future projects can build on the SLMACC work done on land-use development over the past 10 years, and advance New Zealand's effort to fit the land use to the land – and the changes it experiences – by including elements that allow for action learning (Dunningham et al. 2015).

Usability of research

The average scores across all 32 projects suggest that these projects have created low to moderately accessible, available outputs. The low uptake of collaborative networks and best practice approaches such as participatory methods, structured stakeholder engagement and action learning might coincide with the low to moderate effects on fit-for-purpose outputs that is reflected, which are reflected in a low to medium degree of alignment with the needs of end users.

This issue is explored further in Section 5 on 'research gaps'.

Influence and impact

The average scores across all 32 projects suggest that these projects score comparatively low on direct impacts or benefits for New Zealand, and for uptake and use of research by stakeholder groups (policy, government, industry and/or community). These results are somewhat surprising as the projects tend to score moderately high on **alignment of research with the needs of next- or end users** of the research, as well as

responsiveness to next- or end-user needs and knowledge gaps (poor: may lack alignment; excellent: may involve iterative research to meet user needs).

Applied research engagement was rated as moderate. One of the key challenges for research in general is to ensure research findings and outputs are useful, useable and used. This is not a recent challenge. Some contexts require the transfer of knowledge (for example, climate services), while others require integrating adaptation research frameworks within the working domains of policy-makers to produce relevant information for their use.

To set-up an empirical and experimental basis for adaptation action, learning cycles – based on past experience, constant monitoring, measuring and improving the capacity to act, and scenario planning – have all been proposed (IPCC 2012).

This requires providing a complete set of information to decision-makers – impacts, implications, decisions and actions - rather than just the growing list of impacts. Farmers might need, for example, information on the climatic conditions under which specific adaptation options would function, but also the types of benefits that could be expected from different adaptation strategies, and the institutional structures required to continue these efforts.

This entails a coordinated approach to the collecting, dissemination and communication of climate adaptation information, closer alignment with the needs of stakeholders, and ensuring opportunities for learning (e.g. in communities of practice).

This is discussed further as part of our gaps analysis.

4.2 Research demonstrates potential value for money

There is significant value in supporting adaptation research. The primary sector contributes $38 billion to the country's export earnings (MPI 2018). Without adaptation, climate sensitive primary industries will be significantly disrupted, as shown by recent droughts. Understanding what the likely future impacts might be, where and when they may occur and what action might be taken to reduce them, can make an important difference to the economy, with implications for rural communities and supporting industries.

As shown in the previous section, the evaluation of SLMACC adaptation projects using the rubric highlights key programme impacts and outcomes, in particular **enhancing research capability and capacity**. As noted in both the survey results and workshop findings, SLMACC has been a valuable source of funding for adaptation research in New Zealand. The targeted nature of the programme has provided a critical investment pathway for primary industries research and climate change; the programme is well known and well regarded, due in part to its long-standing profile, and the near continuous funding. For much of the last decade, SLMACC has been a significant source of adaptation funding, as well as catalysing other science investment – particularly in the Crown Research Institutes, and of the few investments in climate change adaptation research nationally. The SLMACC research to date has enabled the different industries within the primary sector to begin thinking, planning and acting for climate change. Without the knowledge generated

through the resulting research, the primary sector would likely have lower levels of awareness and knowledge about the future impacts of climate change, or of potential adaptation options.

As a complement to the rubric, and subsequent analysis using the Adaptation Knowledge Cycle, the following is an attempt to quantify the potential value for money represented by SLMACC science investment, using the pastoral sector as a case study.

Assessing value for money is a complex exercise and even more so with respect to climate change. First, the impacts of climate change may not occur for several years – even decades – after a project has finished. Therefore, the benefits of the research do not occur until much later. Second, without robust monitoring and evaluation, attributing changes in practice or a particular outcome to a single piece of research – even without this delay in realisation – is almost impossible.

As such, **we are not able to provide an objective measure of the economic benefit of the SLMACC adaptation research on the primary sector**. Instead, we use the proxy indicator of the potential benefits of adaptation. This proxy has its own limitations, particularly because it assumes the research will be adopted and the changes will be effective in adapting to the impacts of climate change.

The following section presents the results of an indicative Cost Benefit Analysis (CBA) illustrating the potential value of adaptation, focusing on the pastoral (sheep, beef, dairy) sectors. The pastoral sector accounts for the largest proportion of the total SLMACC adaptation investment (approximately $2.5 million), and contributes significantly to the national economy. Milk solids, sheep and beef were valued at almost $18 billion in 2017, and the sector is vulnerable to climate extremes such as drought, which exacerbate feed shortages, reduce production, and have implications for animal health (Cradock-Henry & Mortimer 2013; Cradock-Henry & McCusker 2015). The CBA relies on several assumptions regarding uptake of adaptation and therefore **the linkage to the contribution of the SLMACC research is tenuous, and as such should be viewed as providing an estimate of the potential value rather than definitive numbers**. The methodology is presented in summary below, followed by results and discussion. A more detailed methodology is provided in Appendix E.

Methodology and data

To determine the potential value for money, the costs of the research area compared with the potential benefits associated with adaptation. The benefits are potential in the sense that they will occur in the future if the climate changes, and if adaptation occurs in these sectors. The benefits of adaptation (used here as a proxy for the impact of the SLMACC research) are calculated as the difference in value to the sector under a changing climate with no adaptation, compared with the impacts if adaptation occurs. We assume that adaptation incurs a cost, and assume a one percent reduction in the output value over the period 2020 to 2040. Further details regarding the assumptions made in this estimation are provided in the Appendix.

We estimate the Net Present Value (NPV) over the period 2008 – 2040, using actual sectoral value data from 2008 – 2017. We apply a discount rate of seven percent as

recommended by the NZ Treasury for R&D investment[1]. This is a relatively high rate for adaptation investment, compared with the UK for example, which uses a rate of 3.5% for the first 30 years, declining to 3% from 31 – 75 years and then 2.5% after 76 years[2].

Results: potential value for money is high

A large number of assumptions are implicit in these calculations and therefore the results should only be regarded as indicative of the potential scale of the benefits. The CBA resulted in a NPV of $3.46 million over the period to 2040. This generates a benefit-cost ratio of 2.38 (indicating that for every $1 dollar invested into the research, $2.38 are returned). **This demonstrates very good value for money**, especially considering the benefits of adaptation are very conservative (Table 5).

Table 5. Summary of indicative CBA for adaptation in the pastoral (sheep/beef, dairy) sector

PV Benefits ($NZD million)	5.96
PV Costs ($NZD million)	2.50
NPV ($NZD million)	3.46
B:C ratio	2.38

This analysis has several limitations, predominantly related to the assumptions made. The assumptions regarding the effect of climate change on the future value of the dairy, sheep and beef sectors, and the effect of adaptation, while in line with what little research is available, are rather crude. **The most important assumption for this research however, is that any action on adaptation is a result of the SLMACC research**, which is difficult to substantiate. Assessing the duration of the benefits that could be attributed to the research is also challenging.

Nonetheless, the analysis points to the value that could be generated (or the losses avoided) by investing in targeted research to support primary sector adaptation to climate change. The critical factor will be whether the research is acted on to realise these potential benefits.

[1] https://treasury.govt.nz/information-and-services/state-sector-leadership/guidance/financial-reporting-policies-and-guidance/discount-rates

[2] https://www.gov.uk/government/publications/green-book-supplementary-guidance-discounting

5 Adaptation knowledge: what do we know?

SLMACC has delivered new knowledge and enhanced our understanding of the interaction between and influence of climate change and New Zealand primary industries. To better understand the ways in SLMACC has contributed this new knowledge, we developed and applied the Adaptation Knowledge Cycle. The Adaptation Knowledge Cycle categorises knowledge about adaptation into one of the following four categories**: impacts**, **implications**, **decisions** or **actions**. Applying the framework and the resulting analysis demonstrates that the SLMACC programme has enhanced our understanding of the impacts of climate change and the implications for critical sectors, and has delivered new knowledge to support decision-making and action for adaptation.

To apply the framework, **adaptation projects** have been clustered according to thematic area. The reports are colour-coded using the Adaptation Knowledge Cycle (I-I-D-A) typology, along with key characteristics (Figure 3).

IMPACTS	IMPLICATIONS	DECISIONS	ACTIONS
Evidence for direct and indirect impacts of climate change for primary industries.	Evidence for the implications of climate change on different components of primary industries.	Evidence that research supports decision-making at different scales to enable adaptation.	Evidence that research delivers knowledge and information to support changes in behaviour.

Figure 3. Adaptation Knowledge Cycle (SLMACC).

A similar coding scheme was used to classify the **published literature** (Figure 4). Literature was derived from systematic review and was cross-referenced with SLMACC findings and themes. A complete annotated bibliography of the references used is provided in Appendix C.

IMPACTS	IMPLICATIONS	DECISIONS	ACTIONS
Evidence for direct and indirect impacts of climate change for primary industries.	Evidence for the implications of climate change on different components of primary industries.	Evidence that research supports decision-making at different scales to enable adaptation.	Evidence that research delivers knowledge and information to support changes in behaviour.

Figure 4. Adaptation Knowledge Cycle (Literature)

5.1 Adaptation projects have delivered new knowledge in critical areas

Results of the thematic analysis show that adaptation projects have made significant advances in our understanding of drought, as well as the impacts of climate change for pasture-based farming. Other thematic, sector and topic areas addressed through these projects include biosecurity and climate change; arable cropping; horticulture and viticulture; pan-sector adaptation science; and climate variability and extremes.

There are no SLMACC adaptation projects on indigenous knowledge, climate change and the primary industries, or on farmer behaviour – though both are prevalent in the published New Zealand literature.

The following section discusses knowledge contributions associated with adaptation projects, organised according to topic area. Where relevant, we further contextualise the discussion, with reference to the New Zealand and/or international published literature.

Drought

Climate change is expected to increase the frequency and severity of extremes: eastern regions are expected to become warmer and drier, due to increased temperatures and declining rainfall. The SLMACC programme has enhanced our understanding of drought, climate change and the primary industries through supporting work addressing both impacts and implications, and exploring on-farm adaptive strategies and decision-making.

As a complement to modelled studies on changing drought frequency and extremes (e.g. Harrington et al. 2014), SLMACC has delivered valuable work on the implications of drought for primary industries and adaptation decision-making (Table 6). Clark and Tait (2008), for example, analysed drought risk in combination with economic analysis to consider the implications for risk management, while Burton and Peoples (2008) extended that even further to examine farmers' 'tacit' knowledge (instrumental, embedded knowledge) and the ways in which they had coped with previous droughts.

Table 6. SLMACC research and published literature: drought and adaptation knowledge

IIDA	Lead author	Year	Sector	Location
Impacts	Tozer	2011	Pastoral	National
Implications	Clark	2008	Cross-sector	National
Decisions	Burton	2008	Cross-sector	Regional; North Otago, South Canterbury
	Cradock-Henry	2013	Dairy	Regional; Bay of Plenty
	McCusker	2015	Pastoral	National
Actions	-	-	-	-

IIDA	Lead author	Year	Sector	Scale/Location
Impacts	Sylvester-Bradley	2008	Horticulture	National
	Zhang	2007	Pastoral	National
Implications	Lee	2013	Dairy	National
Decisions	Cradock-Henry	2008	Dairy	Regional; Bay of Plenty
	Gray	2011	Dairy	Regional; Hawke's Bay
	Hopkins	2015	Cross-sector	National
Actions	-	-	-	-

To support on-farm decision-making and enable adaptation preparedness, Cradock-Henry and Mortimer (2013) developed a model of a drought-resilient farm, incorporating

psycho-social, environmental and economic indicators for monitoring and evaluation. Other practical tools are included in a review of the development and practice of climate-smart agriculture to counter the impacts of drought, high temperatures, and heavy rainfall (McCusker et al. 2015).

There is also drought-related research in the published literature (Table 10). This includes model-based studies of the impacts for wheat phenology (Sylvester-Bradley & Riffkin 2008) and spatial assessment of the effects of climate change on North Island pasture production (Zhang et al. 2007). The implications for the dairy industry are considered by Lee and colleagues (2013), who examined drought in relation to feed availability and flow-on effects for productivity and profitability. There is also work from Hawke's Bay (Gray et al. 2011) and the Bay of Plenty (Cradock-Henry 2008) on adaptation, vulnerability and risk management strategies for farming, and a national perspective on climate change risks is provided by Hopkins and colleagues (2015). With respect to climate change and the primary industries, drought is the most-well-studied impact of climate change on the primary sector, with only research on actions missing.

Pastoral farming

Increases in temperature, extreme rainfall events and higher winds are likely to make pastures more susceptible to flooding, nitrogen leaching, drought, soil erosion and pests, with implications for stock management, productivity and profitability. There is a significant body of SLMACC research focusing on these and other impacts for the pastoral sector (Table 7). This work includes understanding the impacts of changing atmospheric conditions and the impacts on ryegrass cultivars and C4 grass species (Dodd 2011; Crush 2014); pasture stress (Guo and Trotter 2008; Lieffering and 2008; Newton et al. 2008, 2011, 2014); pasture productivity (Fowler et al. 2008); and invasive weeds (Tozer et al. 2011). The emphasis is almost entirely on the pasture component of the pastoral system, with no studies on the impacts of climate change on animals for example.

This is supplemented by additional, but more limited, research on implications and related decision-making challenges. Cradock-Henry and McCusker (2015), for example, draw on concepts from resilience science – tipping points, thresholds and adaptability – and examine the pastoral system in its entirety and evaluate its performance under different scenarios.

There appears to be broad consensus in much of this work that pasture-based dairy systems have relatively high levels of adaptive capacity, and there are opportunities to continue to improve production efficiencies, particularly where rainfall change is small. The SLMACC adaptation projects and the published literature also identify potential adaptation strategies, including the strategic use of supplementary feed, reduced stocking rates, irrigation, or sowing alternative plant species with greater drought tolerance. One paper (Kalaugher et al. 2013) was an output from the largest adaptation project (Clark & Nottage 2012). It uses both qualitative social science and quantitative biophysical models to explore how best to manage farms in the face of climate change.

Table 7. SLMACC research and published literature: pastoral farming and adaptation knowledge

IIDA	Lead author	Year	Sector	Scale/location
Impacts	Newton	2011	Pastoral	Regional; Canterbury
	Tozer	2011	Pastoral	National
	Dodd	2011	Pastoral	National
	Lieffering	2008	Pastoral	National
	Fowler	2008	Pastoral	Regional; Canterbury, Hawke's Bay
	Guo	2008	Pastoral	National
	Crush	2014	Pastoral, Arable	National
	Zhang	2007	Pastoral	National
	Keller	2014	Pastoral	National
	Fowler	2013	Pastoral	Regional; Hawke's Bay
Implications	Renwick	2013	Cross-sector	National
	Lieffering	2016	Pastoral, drystock	Regional; Hawke's Bay, Southland
	Lee	2013	Dairy	National
Decisions	Rosin	2015	Pastoral	National
	Cradock-Henry	2015	Pastoral	National
	Gray	2011	Dairy	Regional; Hawke's Bay
Actions	-	-	-	-

IIDA	Lead author	Year	Sector	Scale/location
Impacts	Fowler	2013	Pastoral	Regional; Hawke's Bay
	Keller	2014	Pastoral	National
	Lieffering	2016	Pastoral; drystock	Regional; Hawke's Bay, Southland
	Zhang	2007	Pastoral	National
Implications	Lee	2013	Dairy	National
Decisions	Gray	2011	Dairy	Regional; Hawke's Bay
Actions	-	-	-	-

There is no research on the ability of the primary sector to adapt to the increase in range across all climate impacts nor on the impacts of compounding hazards. For example, in the Hurunui the adverse effects of extended drought conditions were exacerbated by the November 2016 earthquake. At the time of the earthquake, pastoral farmers in North Canterbury had been under considerable stress due to long-term (> 3 years) drought conditions. Impacts of the earthquake compounded existing stresses relating to personal well-being, animal health, productivity, and yield (Stevenson et al. 2017).

Biosecurity

Climate change will create significant biosecurity challenges for New Zealand's primary sector by allowing the establishment of new exotic pests, weeds and diseases, which is currently prevented by New Zealand's current climatic conditions. The potential establishment of subtropical pests and current seasonal immigrants is of greatest concern, along with taxa that are already recognised as high risk (Kean 2015). Climate is just one of

several factors that affect invasion potential, and others – such as import pathways, border management and host suitability – may also change in the future (ibid).

There is limited information about the biosecurity impacts, implications and necessary adaptations to climate change for the primary sector (Table 8). There has only been one SLMACC project on the topic (Kean 2015) and there is no published New Zealand literature.

Table 8. SLMACC research: biosecurity and adaptation knowledge

IIDA	Lead author	Year	Sector	Scale/location
Impacts	Kean	2014	-	National
Implications	-	-	-	-
Decisions	-	-	-	-
Actions	-	-	-	-

Crops

There has also been limited research on arable cropping through the SLMACC programme. Results from those projects suggests that climate change is likely to be generally positive for arable cropping in New Zealand. Higher temperatures will allow earlier sowing of crops, and they will generally reach maturity faster – depending on sowing time. Higher temperatures could lead to decreased yields, but the fertilising effect of higher levels of carbon dioxide will potentially offset this, resulting in yield increases for temperate crops such as wheat and barley (Trolove et al. 2008).

Table 9. SLMACC research and published literature: crops and adaptation knowledge

IIDA	Lead author	Year	Sector	Scale/location
Impacts	Howlett	2013	Crops	National
	Trolove	2008	Crops	National
Implications	Clark	2008	Crops	National
Decisions	-	-	-	-
Actions	-	-	-	-
IIDA	**Lead author**	**Year**	**Sector**	**Scale/location**
Impacts	Orwin	2012	Cross sector	National
Implications	-	-	-	-
Decisions	-	-	-	-
Actions	-	-	-	-

This assessment however is based on a small body of SLMACC-funded research and limited published literature (Table 9). Some of the work described previously in relation to pastoral farming may be relevant here as well. In terms of adaptation in the sector, climate change may present new opportunities: longer growing seasons and increased forage crop yields achieved through radical changes in forage germplasm and management (Trolove et al. 2008), if the sector can adapt to the increased frequency of heavy rainfall and wind events. It is important to note however that the impacts of climate change will

affect all primary industries, and many impacts will be coincident (e.g. warmer temperatures may also result in more intense storms, and/or new pests and diseases). The extent to which arable cropping – or any other sector – will be able to adapt or realise opportunities, will be contingent on other factors.

Horticulture and viticulture

High-value horticulture and viticulture are among the fastest-growing primary industries, and along with commercial vegetable production are exposed and sensitive to climate variability and extremes. Climate change is expected to have impacts for management and production outputs. For some fruit crops, warmer temperatures may result in higher yields and fruit size, but this may be offset by increased water demands and increased competition for available water; changes in frost frequency and loss of winter chilling; and an increase in pests and disease. Extreme weather events – including ex-tropical storms, extreme temperatures and wind events – may also pose risks to production.

There has been limited work on the impacts and implications of climate change for horticulture through the SLMACC programme (Table 10). Horticultural research has focused on changes in bee and insect pollination (Howlett et al. 2013) and has considered the prevalence of horticultural diseases (e.g. apple black spot) (Beresford & McKay 2012). Work on decision-making and adaptation in the kiwifruit industry has also been undertaken through the SLMACC programme. Kenny (2011) examined the effect of climate change on kiwifruit growers, and identified and evaluated potential adaptive strategies.

Table 10. SLMACC research and published literature: horticulture and viticulture, and adaptation knowledge

IIDA	Lead author	Year	Sector	Scale/location
Impacts	Beresford	2012	Horticulture	National
	Sturman	2015	Viticulture	Regional; Marlborough
Implications	Clark	2012	Cross sector	National
	Kenny	2008	Horticulture	Regional; Bay of Plenty, Hawke's Bay
Decisions	-	-	-	-
Actions	-	-	-	-

IIDA	Lead author	Year	Sector	Scale/location
Impacts	Sturman	2013	Viticulture	National
Implications	-	-	-	-
Decisions	Cradock-Henry	2016	Horticulture	Regional; Bay of Plenty
Actions	-	-	-	-

Wine and grape growing is New Zealand's fastest growing primary industry. Viticulture is extremely sensitive to climate change due to grape phenology, and the long lead times required to establish vines and build market share.

There has been some work on climate change impacts for the New Zealand wine industry through the SLMACC programme, but no work on adaptation. Sturman and colleagues (2014; 2015) examined the relationship between climate variability and viticulture production in New Zealand. Their work has generated new understanding of climate variability within vineyard regions, and provides the basis for assessing the impact of longer-term climate change at the global and regional scale (ibid.). However, additional work is needed to better understand the range of impacts, the potential implications, and the extent of adaptive capacity within the sector.

There is some published literature that extends or builds on the projects described above, including Sturman and Quénol (2013) for the wine industry, and Cradock-Henry (2016). Cradock-Henry (2016) develops and applies a 'bottom-up' contextual vulnerability assessment and applies it to the kiwifruit industry in the Bay of Plenty. Findings show that climate and market risks are the main sources of exposure for growers, with sensitivity moderated by location. Growers employ mostly short-term, reactive adaptive strategies to manage climate exposure and sensitivity, but have less capacity to respond to market-related stressors (ibid).

Cross-sector adaptation science

The most significant SLMACC project is the sizeable multi-sector report edited by Clark and Nottage (2012) examining impacts, implications, decisions and actions across the full range of primary industries (Table 11). This project – the largest single SLMACC investment – summarises climate change projections and identifies adaptation options for a range of land-based industries (dairy, sheep and beef, cropping, horticulture, and forestry). The report provides review and synthesis of existing scientific, professional and experiential knowledge. The research also engages with advanced risk analysis by applying production modelling to individual production units to create primary sector adaptation scenarios (ibid).

Table 11. SLMACC research: cross-sector science and adaptation knowledge

IIDA	Lead author	Year	Sector	Scale/location
Impacts	Zemansky	2012	Cross-sector	National
Implications	Clark	2012	Cross-sector	National
	Renwick	2013	Cross-sector	National
Decisions	Burton	2008	Cross-sector	Regional; North Otago, South Canterbury
Actions	Dunningham	2015	Cross-sector	National

Other projects looking at climate change impacts and implications for primary industries include Zemansky et al. 2010, which identifies trends in hydrological systems in conjunction with climate change predictions, and Renwick et al. 2013, which considers the implications of 4 degrees warming. There is one 'action-oriented' SLMACC project that focused on tools and mechanisms used to effectively communicate and motivate adaptation in the primary sector (Dunningham et al. 2015). There is no published literature on cross-sector adaptation in the primary industries.

Climate variability and extremes

Daily temperatures and rainfall extremes have changed over the last 70 years. The probability of extreme warm days has increased and the probability of extreme cold days has decreased during this time (Ministry for the Environment 2018). There is also clear evidence of a decreasing number of frosts, and some evidence for increasing numbers of very warm days, with regional variations. These changes have significant impacts on the primary sector through their impact on water availability during drought, increased soil erosion due to heavy rainfall events, heat stress for crops and animals, and increasing the likelihood of pests and disease.

SLMACC adaptation projects have concentrated on the impacts of extreme events on erosion (Basher et al. 2012); flood (McMillan et al. 2010), and wind (Mullan et al. 2011) (Table 12). There is one study on implications: catchment-scale modelling to predict the effects of climate change on weather elements, surface water flows, and groundwater flows (Bright et al. 2008). No published literature on the impacts of climate variability and extremes and the primary industries was identified in the literature review.

Table 12. SLMACC research: climate variability and extremes and adaptation knowledge

IIDA	Lead author	Year	Sector	Scale/location
Impacts	Basher	2012	Extremes	National
	McMillan	2010	Extremes	Regional; Waikato, Gisborne
	Mullan	2011	Extremes	National
Implications	Bright	2008	Extremes	Canterbury
Decisions	-	-	-	-
Actions	-	-	-	-

Other adaptation research funding

Other sources of research funding (e.g. Sustainable Farming Fund) may also have supported projects on climate change adaptation and/or resilience, even if they have not been directly identified in those terms. Research on managing climatic variability, sustainability more generally, or dealing with specific pests and diseases for example, can contribute to greater understanding of system processes, key vulnerabilities and mitigation and management strategies. Although this work is not called adaptation, the ideas and outcomes contribute directly towards understanding the suite of options and alternatives available to industries to cope with a changing climate.

The Sustainable Farming Fund in collaboration with New Zealand Winegrowers, for example, has delivered a number of projects on sustainability in the wine industry. This has included work on disease, vine yield, energy efficiency and sustainability accreditation (Allen et al. 2014). Later projects have purposefully built on the extension and engagement efforts of earlier projects, enabling further development and helping to build industry resilience to a range of stressors.

Identifying and evaluating all these projects is beyond the scope of this review, but will be important when next steps for each sector or region are considered.

6 Knowledge Gaps: what do we not know?

The review of adaptation projects reveals clear knowledge and science-knowledge gaps across NZ primary industries with respect to climate change adaptation. These gaps have been highlighted by overlapping the results of the multiple lines of enquiry applied in this research, cross-referenced against the requirements for successful adaptation, and the published literature. Our results show:

- **A clear majority of climate change adaptation research has been geographically and sectorally focused.** Several SLMACC funded projects provide either national level data or focus on Hawke's Bay, Bay of Plenty, and to lesser extents, Marlborough and Canterbury, with an emphasis on pastoral production. There is less information for Northland, Auckland, Taranaki, Manawatu, Wellington, Tasman, West Coast and Otago that is sufficiently specific and easily accessible. Although there are lessons to be learnt from single region studies that benefit other regions, it would also be valuable to provide fewer concentrated analyses and more comparative assessment across the different, region-specific climates and growing paradigms in New Zealand, as well as cross-sectoral studies. Breadth and depth are required.
- **There is limited climate change adaptation research on biosecurity, wine and grape growing, arable farming and high-value horticulture.** Climate change can be expected to have impacts and implications for these industries and issues. However, the pastoral sector has secured most SLMACC adaptation research funding to date. While there is some SLMACC research on these topics, it has been limited to understanding the impacts, and not the full range of climate related risks, or cascading implications triggered by impacts or adaptation in other sectors, including the nexus between water quantity, quality and implications for all primary industries.
- **There is limited research on climate change adaptation decision-making and action.** Past research has primarily focused on understanding the impacts of climate change, with some attention given to implications, but proportionally little given to deciding and acting. Primary industries have not made significant progress in terms of preparing for, and adapting to climate change.

It will be necessary to address these knowledge gaps we have identified to ensure climate-resilient primary industries. Adaptation science that moves beyond a limited focus on impacts alone is vital to enhancing capability and capacity for strategic responses in the sector.

The following section discusses these gaps in more detail. We begin by briefly introducing the critical components of successful adaptation, followed by a review of the empirical and methodological gaps. It should be noted that the following is our own assessment of research gaps based on published literature and SLMACC reports. An exhaustive accounting of all that is not known about climate change adaptation for the primary sector is beyond the scope of this review. Readers are directed to the recent adaptation stocktake report for additional and supplementary insights (Ministry for the Environment 2018), as well as the review of the Sustainable Farming Fund (Oakden et al. 2014).

6.1 Information needs for climate change adaptation

Agricultural adaptation can be differentiated according to form (managerial, technical and financial), scale (local, regional and global) and the actors involved (farmers, industries and governments). Four main categories of adaptation are also identified: (1) farm production practices, (2) farm financial management, (3) technological developments and (4) government programs and insurance (Reidsma et al. 2010).

The first step towards identifying the gaps in climate change adaptation knowledge for the NZ primary sector is to reflect on what steps and types of knowledge are necessary for effective, ongoing, and dynamic adaptation. While there are multiple approaches to adaptation planning including vulnerability assessment, resilience assessment, dynamic adaptive pathways planning and more, they share a number of features, including a focus on stakeholder involvement in the assessment process; an open-ended exploration of multiple futures; and an emphasis on starting with understanding stakeholders' concerns, rather than the anticipated impacts of climate change (van Aalst et al. 2008).

This type of adaptation research has been conducted internationally, as well as in New Zealand for sea-level rise and flood risks (Lawrence & Haasnoot 2017), and for a limited number of primary industries (e.g. Cradock-Henry 2016). There is a parallel SLMACC project currently underway that is using this approach to develop a regional adaptation strategy for Hawke's Bay (Cradock-Henry et al. 2018a) which we draw on for some of the following discussion.

The latest adaptation science uses a pathways approach to identify how best to adapt to future climate change. Rather than being limited to identifying the best single set of adaptation options for a limited set of climate change scenarios, it enables decision makers to consider a range of possible adaptation options, how they will be impacted by various climate change scenarios through time, and whether any options have a "sell by date" (i.e. a point in time at which they are no longer viable). It also enables decision makers to explore what combination of options (described as pathways) are most suitable for adapting to future climate change.

Developing an adaptation pathway focuses on identifying, appraising and sequencing options through a participatory process (Figure 5). It begins with understanding the aims and objectives of the analysis, and determining what stakeholders value in terms of the productive landscape (e.g. profitable and sustainable primary industries, or reducing climate change vulnerability for wine production in the Hawke's Bay region). This establishes the boundaries of the analysis. The second step is to understand the current situation: what are the main risks? What is exposed and sensitive? In what ways, and how? With an understanding of what is at risk, the projected impacts and implications of climate change for the region, sector or activity in question can be introduced. On the basis of likely impacts and implications, adaptation options can be identified, pathways developed and choices evaluated. Robust monitoring and evaluation systems can then be put in place to determine at which point different adaptation strategies will need to be implemented, and ensure feedback loops are maintained to keep track of new information.

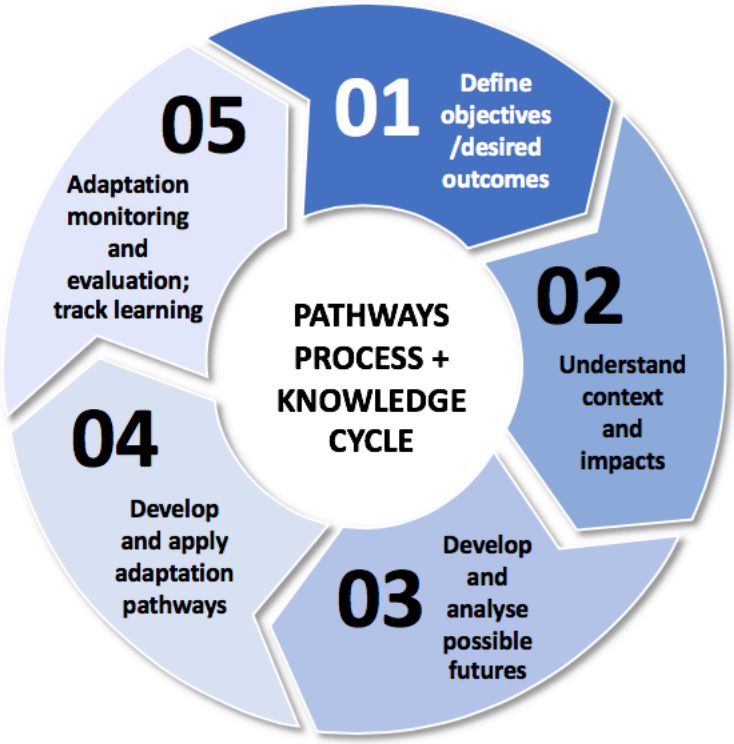

Figure 5. Applied adaptation pathways process for primary industries (Cradock-Henry et al. 2018a).

The resulting output is referred to as an "adaptation pathways map" (Figure 6).

The process of developing and graphically presenting an adaptation pathway can help with preparing an adaptation plan and informing decision making.

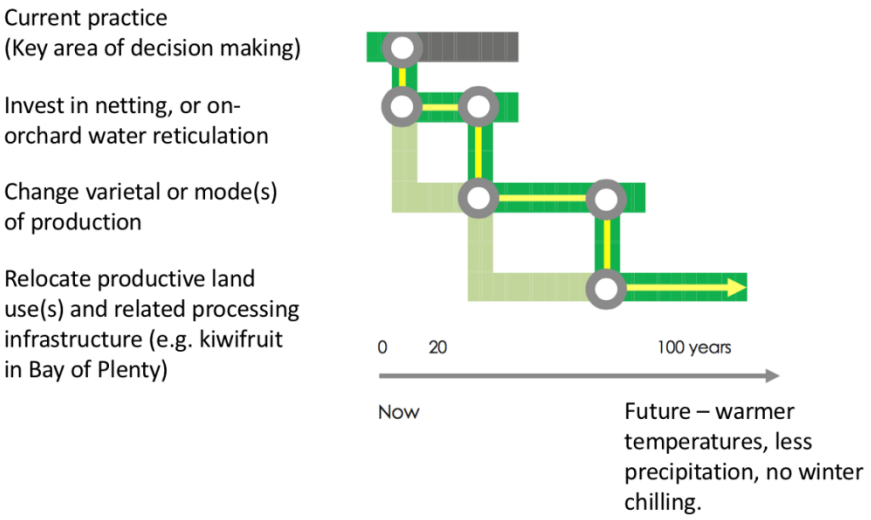

Figure 6. Example of an applied adaptation pathways map.

The results of our review highlight several critical empirical and methodological gaps. The most significant is that SLMACC research has focused almost exclusively on more detailed

understanding of the impacts and implications of climate change. There is limited social science research and few interdisciplinary studies of adaptation decisions and actions.

In brief: most of the research to date has been focused on understanding the current exposure and sensitivity of primary industries. Consequently, we have a limited knowledge base to draw on for the development of possible futures. Information about adaptation options is similarly constrained. This means there are very few insights into ways in which to enable robust decision making, and promote adaptation actions (Figure 7).

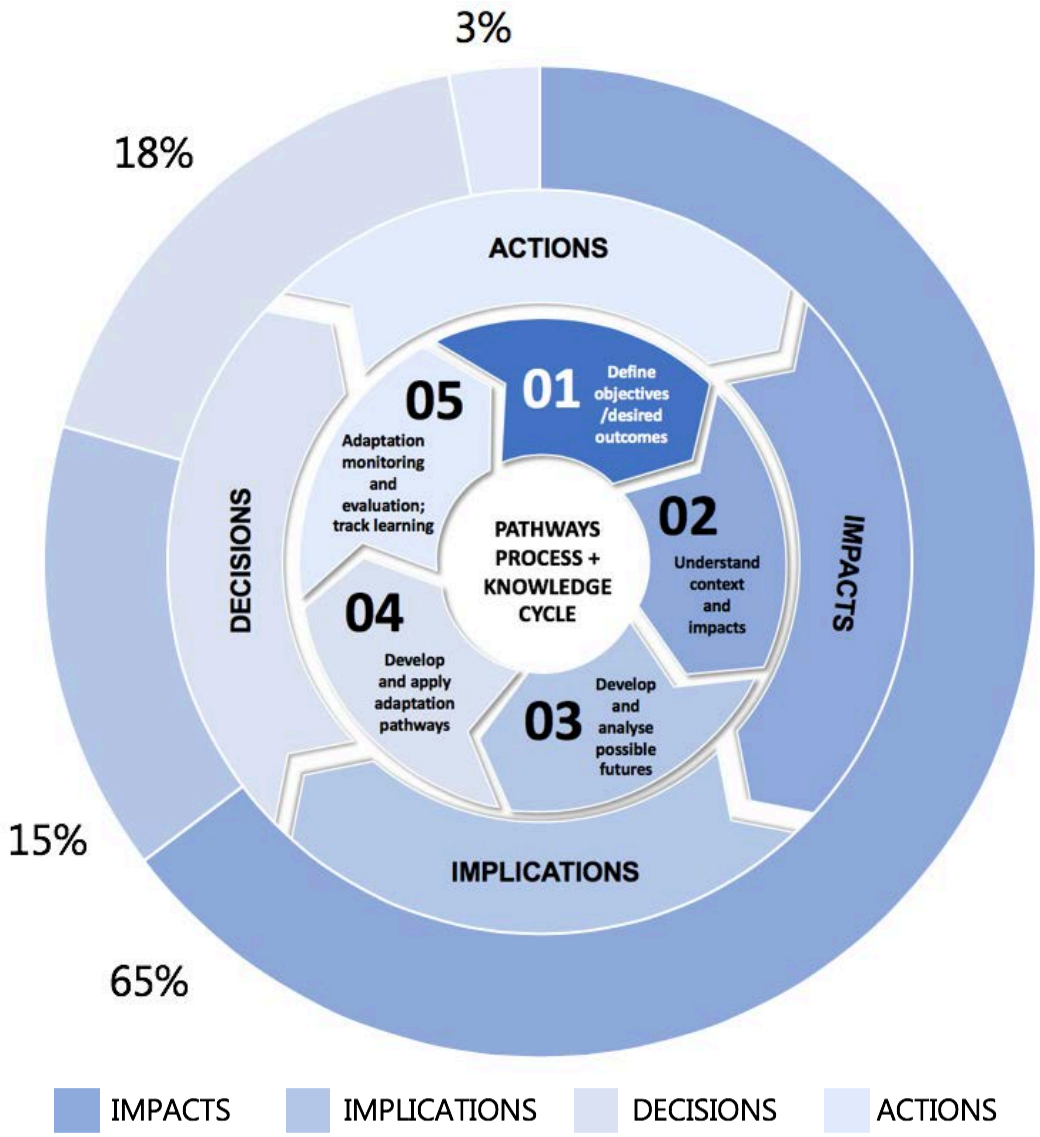

Figure 7. Applied adaptation pathways process and Adaptation Knowledge Cycle.

Classifying research outputs in this way shows a significant emphasis to date in SLMACC research and the published literature on probabilistic and biophysical modelling of climate change impacts. Most SLMACC adaptation projects to date have focused on understanding the impacts and implications of climate change (65%, and 15% respectively). There is less information about the management implications of climate change, and very little information on decision-making or how best to enable adaptation action.

To address the adaptation deficit – the difference between what we know about the impacts and action to address it – new insight into primary industries' thinking, planning and acting for climate change is urgently needed.

The following discussion focuses on two types of knowledge gaps we have identified in relation to SLMACC climate change adaptation projects:

- **Empirical gaps** are those where additional data collection, modelling and analysis could narrow knowledge gaps for different sectors, places and/or issues. The resulting improved knowledge and empirical experience could assist decision-making on climate change adaptation and policies. To some extent, these gaps are reflected in the uncertainty statements in this report, particularly in relation to other adaptation research that may have been conducted elsewhere (e.g. Sustainable Farming Fund) but that has not been published in the literature, or are framed as 'living with climate variability' rather than adaptation.
- The results of the analysis show that a limited range of approaches have been used in SLMACC adaptation projects leading to a series of **methodological gaps**. We highlight the opportunities to develop and apply new conceptual and theoretical frameworks, research approaches, tools and processes that can enhance our understanding of climate change adaptation and support new knowledge generation for adaptation decisions and actions.

6.2 Empirical gaps

New Zealand's climatic and topographical diversity creates regional and local variation in physical climate factors (e.g., rainfall, diurnal temperature range, maximum temperatures, length of growing season, frost days) and soil types (e.g., volcanic sedimentary, peat soils etc). The success of certain primary industries in particular places can be attributed in part to the favourable combination of climate, soils, biosecurity system, a reliable supply of water and access to necessary physical infrastructure, economic and social capital to provide inputs (labour, goods and services) and move the products along the value chain to market. For example, nearly 90 percent of NZ's $2 billion kiwifruit industry is in the western Bay of Plenty (Cradock-Henry 2016).

This also means however that each region and industry has the potential to be differentially affected by climate change because of biological, socio-cultural and economic characteristics. For example, changes in temperature and carbon dioxide levels have the potential to affect land use, as shown by a study of shifts in the balance between C3 and C4 grasses (Dodd et al. 2009). This may affect northern regions more than the southern regions, accelerating demand for regionally based seed solutions. Climate modelling shows a general decrease in precipitation for eastern New Zealand, which will have very different impacts and implications for irrigated dairying and other water intensive industries, while western dairying regions may be faced with heavier rainfall events, leading to problems with flooding and soil erosion. Northern parts of the East Coast may face the combined pressures of water limits and pasture species changing simultaneously (Kenny 2011).

Industry-specific, regionally based options and pathways

Given the above, **there is a need for industry-specific, regionally based options and pathways to support adaptation.** Research suggests successful adaptation requires contextually sensitive, industry-specific, regional or local solutions. It is unlikely that many universal solutions can be identified as farming and growing practices, social norms and values, aspirations, access to resources, and infrastructure all vary throughout New Zealand. There is no such thing as a 'one size fits all'-capacity to adapt. The determinants of adaptive capacity vary "from system to system, sector to sector and region to region" (Yohe & Tol 2002: p.25). Instead, adaptive capacity is best reflected by a broad 'coping range', which is location-specific, group-specific, and time-specific (Smit & Pilifosova, 2003). System characteristics that reflect on adaptive capacity are resilience, stability, robustness and flexibility (Smit & Pilifosova 2003, p. 22).

This is reflected in feedback from the workshop. As noted by one participant sector needs vary and are dependent on *"sensitivity to the climate and how much long term planning they need to do".* For example, kiwifruit production requires winter chilling to achieve bud break. In the absence of frosts, hydrogen cyanamide can be used, but this may be a sensitive issue for overseas consumers (Cradock-Henry 2016). Fruit production and the associated cool store and export infrastructure may need to migrate south over time to remain within optimal growing conditions. Kiwifruit vines, however grow quickly and root stock can be re-grafted with new varieties and be returned to full production within several years (Dunningham et al. 2015).

In contrast, the wine industry is also sensitive to small changes in temperature and the length of the growing season. Each grape variety is affected differently which may have implications for production with the current varietal distribution. As one winemaker put it, when discussing adaptation research needs and issues for Central Hawke's Bay:

Climate change is a double-edged sword for our sector in Hawke's Bay - on the one hand warming could make it easier to grow grapes in Central Hawke's Bay and to ripen warmer climate varieties more reliably on the Heretaunga Plains but on the other hand it may quite quickly make the Plains unsuitable for growing cool climate varieties and an increase in late season humidity & extreme weather events could be detrimental to quality.

Of course, there is also the issue of increase in summer drought and increase in evapotranspiration leading to higher irrigation requirements, against a backdrop of increasing community concern around water allocation.

For wine producers, climate change – and any adaptation that involves changing varietal for example – will have market implications, as provenance – including branding, reputation and sustainability credentials takes years to establish. Marlborough is associated with Sauvignon Blanc for example, but that market profile is the result of years' worth of investment.

Although adaptation is local and potentially a sector-specific endeavour, it will require industry (e.g. sector bodies) and institutional support (e.g. local and central government) at different scales, to be efficient and effective. Regional (and sometimes national) adaptation strategies must be developed in concert with other industries (see Cradock-Henry et al. 2018a) to avoid maladaptation, realise synergies and optimise cross-sectoral

adaptive capacity. Narrowly focused actions may not create an adaptive sector (if it does not account for opportunities, challenges, and preferred adaptations elsewhere).

For example, water use adaptation at the farm scale, will be underpinned by sound regional policy and strategies, which in turn is enabled by national guidance and policy. Without this co-ordination across governance scales, individuals, industries and regions could compete for scarce resources in a detrimental way.

Regional research distribution

Results of the analysis also show that the majority of SLMACC adaptation projects have taken a broad, national scale focus. At a regional scale, Hawke's Bay is the most studied in terms of climate change impacts and adaptation. Between both SLMACC projects and the published literature, there have been 11 studies on climate change for Hawke's Bay (Table 13 and Table 14), with a smaller number of studies for Marlborough, Bay of Plenty and Canterbury. There is no SLMACC research or published literature on impacts, implications, decisions or actions focused on Northland, Auckland, Taranaki, Manawatu, Wellington, Tasman, West Coast or Otago. However, even in the most studied regions, the Adaptation Knowledge Cycle is not complete. Impacts and Implications-focused research dominates. Importantly, this would suggest that no single region currently has all the information needed for the five steps required for successful adaptation planning. The largest evidence gap is in the field of action, with only a single national level study (Dunningham et al., 2015).

Table 13. Distribution of SLMACC outputs by region and adaptation knowledge

Scale/Region		Impacts	Implications	Decisions	Actions
National	National	15	4	2	1
North Island	Northland	1			
	Auckland				
	Waikato	1			
	Bay of Plenty			2	
	Gisborne	1			
	Hawke's Bay	1		1	
	Taranaki				
	Manawatu				
	Wellington				
South Island	Marlborough	1			
	Tasman				
	Canterbury	3	1	1	
	West Coast				
	Otago				
	Southland				

Table 14. Distribution of published literature by region and adaptation knowledge

Scale/Region		Impacts	Implications	Decisions	Actions
National	National	4	3		
North Island	Northland				
	Auckland				
	Waikato			1	
	Bay of Plenty			3	
	Gisborne	1			
	Hawke's Bay	3		6	
	Taranaki				
	Manawatu				
	Wellington				
South Island	Marlborough			4	
	Tasman				
	Canterbury				
	West Coast				
	Otago				
	Southland	1			

Industries and issues research distribution

Another interpretative lens which informs the identification of knowledge gaps is the distribution of research across different primary industries and industry issues such as biosecurity (Table 15 and Table 16).

Table 15. SLMACC projects: primary industry, issues and adaptation knowledge

		Impacts	Implications	Decisions	Actions
Sector	Cross-sector	2	3	1	1
	Pastoral	9		2	
	Dairy			1	
	Kiwifruit	1		1	
	Viticulture	3			
	Horticulture	2			
Theme	Biosecurity	1			
	Extremes	3	1		

Table 16. Published literature: primary industry, issues and adaptation knowledge

		Impacts	Implications	Decisions	Actions
Industry	Cross-Sector		1		
	Pastoral	3	1		
	Dairy		1	3	
	Kiwifruit			2	
	Viticulture	1			
	Horticulture	1			
Theme	Biosecurity				
	Extremes				
	Indigenous knowledge[1]	1			
	Ecosystem services[1]	1			
	Farmer behaviour[1]			4	

[1]Research outputs for this theme only in the published literature. There is no literature on adaptation 'action' for primary industries in New Zealand.

As shown in the data above: there is an urgent need to identify specific local climate change impacts and implications for these under-represented industries and issues. Industries and industry issues that have received little or no attention in SLMACC climate change adaptation research include: biosecurity, the wine industry and grape growing, arable farming and horticulture. For each of these industries and issues, knowledge does not appear to extend beyond a few studies on the impacts of climate change. Research on implications, decisions and actions is largely absent in SLMACC adaptation projects and the published literature. Some of this information may have been generated elsewhere – through Sustainable Farming Fund or industry group research – however, we have limited this review to SLMACC.

Overall this is not surprising. The Adaptation Knowledge Cycle and pathways process is essentially a logical sequence of steps, building a shared understanding through a collaborative and participatory process, from impacts and implications through to understanding choices, leading to adaptation action. It is reasonable to expect that for industries with limited resources, the focus will necessarily be on impacts; an essential first step. Nevertheless, progression through the cycle over time is fundamentally required for effective adaptation.

As one adaptation workshop participant said, "There is a need to move beyond knowing about the impacts of climate change towards better understanding its decisions implications and actions that can reduce vulnerability".

From the farm gate to the port, systems thinking is urgently needed to connect the dots across rural value chains to widen the scope of adaptation research and highlight robust options for climate-resilient futures. Farms, orchards, vineyards; the supporting industries that harvest, process, and distribute agricultural products in a region, nationally, and internationally, are part of an interconnected system [of production, processing, marketing and distribution]. Nearly all the SLMACC adaptation research we reviewed takes a narrow

view, focusing on one aspect of the value chain, and therefore may fail to adequately account for interconnected climate risks; non-climatic stressors – such as changes in policy or legislation governing the production of commodities – or cascading implications triggered by impacts elsewhere. Interactions with other goals, particularly emissions reduction in the agricultural sector, but also water or soil quality, as well as productivity, should also be considered.

Identifying some of these interactions, co-benefits and trade-offs between different elements of the system will allow more effective and efficient decisions to be made, avoiding maladaptation. In other words, climate change adaptation takes place within a system. Adaptation decisions therefore both influence the system, and in turn are influenced by feedback because of those choices, and needs to be considered.

6.3 Methodological gaps

As shown in the preceding sections, SLMACC adaptation projects have been dominated by efforts to understand only the impacts of climate change for primary industries. There has been some research on implications and decisions, but only one project on climate change adaptation action. As a result, there are a number of methodological gaps in our knowledge. The gaps we have identified are based on our analysis and review of the SLMACC adaptation projects. Where appropriate, we also refer to the published literature on climate change adaptation in New Zealand primary industries and climate change research more generally.

Research has been either top-down or bottom-up

The SLMACC adaptation projects we reviewed typically took a top-down and/or bottom-up approach, viz. they began with modelling projected impacts of climate change on a particular sector or activity (Clark & Tait, 2008; Newton et al. 2011), or they began from the perspective of stakeholders and end users who identified the most relevant impacts of climate change (e.g. Burton & Peoples 2008; Kenny & Porteous 2008; Cradock-Henry & Mortimer 2013; Cradock-Henry & McCusker 2015). However, both are necessary, particularly with respect to the development of policy initiatives to support adaptation planning and action. **Input from both directions can enable integration of stakeholders' needs and preferences at different scales with current policy frameworks and their implementation.**

In the analyzed adaptation projects, we observed a stronger emphasis on either one or the other. Top-down projects were associated with a focus on quantitative probabilistic or biophysical modelling. When top-down approaches were dominant, adaptation planning was led by scientists (typically agronomists, climate scientists or biophysical modellers) and often resulted in technical recommendations and/or sector specific adaptation strategies, rather than place-based or multi-sector ones. In some cases, these approaches were opened up to bottom-up stakeholder involvement and/or input in the final stage(s) of the project, or when communicating research findings.

With bottom-up projects, the result was typically a product of robust and rich participatory and collaborative processes comprising farmers, producers, growers and industry groups working with researchers. These initiatives primarily focused on identifying at-risk and

vulnerable activities and places, outlining potential impacts of climate change on agriculture and the consequences for farmers. Most of these projects were small case studies, which while they have not resulted in sector-wide adaptation strategies being adopted, do show evidence of progress in terms of collaboration across stakeholders subsequently moving towards engagement with policy-makers to involve them in debates on adaptation priorities, needs and strategy development. This work also often provided a forum – in the form of resilience or adaptation workshops – to bring together experiences of farmers and other stakeholders, which tend to occur at a local level and otherwise may not be obvious to policy-makers at a regional and/or national level (Naess et al. 2005).

Our research suggests that **the interplay between bottom-up initiatives and top-down approaches is crucial in adaptation planning**, as bottom-up approaches provide impetus for stakeholders' self-organization to provide inputs on specific actions, feasible implementation and relevant monitoring indicators. At the same time, top-down approaches assist by legitimizing and prioritizing strategy and policy development and ensuring access to high-level decision makers and associated funding.

Identifying robust adaptation options

A second methodological gap – and related challenge for research – is to balance the call from stakeholders for more integrated research, with the needs of policy-makers. As one stakeholder said, we need to know:

> *the impact of different scenarios on proposed climate change adaptations and how they affect producer and industry resilience… Adaptation strategies and behaviours are still skinny. We need better regionally-based adaptation strategy development - this requires first some more detailed likely scenario planning to stimulate and lead adaptation strategy development.*

On the other hand, policy-makers have a different set of information needs and must reconcile narrowly defined and often technical adaptation measures with the addressing of broader questions to ensure that agriculture meets multiple goals and incorporates cross-sectoral issues, such as water management, provision of multiple ecosystems services, and food security.

Climate change adds an additional level of complexity for decision making in agriculture. Given the projected impacts of climate change, some areas currently used for agriculture – such as low-lying coastal areas, which may be subject to more frequent flooding, sea-level rise and saltwater intrusion – may not be able to fulfil those functions as the climate pressures mount. New options will need to be considered: developing new varieties of crops and fruits, shifting to new areas, and/or developing new livelihoods. In addition, the agricultural sector is increasingly involved in the mitigation side of climate change response, with a need to contribute to emissions reductions.

In this context, then new methodologies are required, including tools, processes and frameworks for identifying, assessing and implementing robust adaptation options.

Combining model-based insights with knowledge gained though social science and applied research methods can advance our understanding of all aspects of climate change

adaptation. While we continue to develop probabilistic assessments of climate futures to gain greater understanding of climate change impacts, primary industries will to be required to adapt to the changes already underway. In short, they need to prepare for climate change using what is already known and continue to adapt as the climate continues to change.

Impacts and adaptation research through the SLMACC programme has focused in large part on the development of model-based studies or application of a reductionist approach – focusing on small scale interactions. Social science studies are in the minority. However, all forms of knowledge are needed to address the adaptation challenge. Climate change presents policy and decision makers, end users and land managers with all the features of a wicked problem: an interacting set of policy, cultural, social, technological and scientific dimensions, ill-suited to being addressed by a single discipline or approach.

A suite of tools is evolving within multiple social science disciplines to enable industries to adapt under conditions of continuing uncertainty. For example, dynamic adaptive pathways (Lawrence & Haasnoot 2017; Cradock-Henry et al. 2018c) and applied adaptation pathways which are being developed and applied at a regional scale in a SLMACC adaptation project (Cradock-Henry et al. 2018a); real options analysis; integrated socio-economic, policy and climate change scenarios; and resilience assessment. These approaches can help widen the choices for primary industries facing uncertainty.

Failure to advance adaptation science beyond a narrow focus on impacts will result in maladaptation, and failure to adapt. Successful adaptation will require in-depth understanding not only of the impacts of climate change, but also the risk management implications, decisions that need to be made to reduce exposure to those risks, and effective ways to motivate action across the primary industries.

Towards climate-resilient primary industries

Systems thinking and resilience science can provide can provide conceptual and methodological tools for identifying thresholds. As one survey respondent said, "*Climate change adaptation is nascent in the [dairy] industry and irrigation is not a sustainable adaptation option. More emphasis on environmental thresholds and ways of managing productivity within them is sorely needed.*"

Building resilience is promoted as one way to deal with climate change impacts. It describes the ability of a system and its component parts to anticipate, absorb, accommodate or recover from the effects of a hazardous event in a timely and efficient manner, including through ensuring the preservation, restoration or improvement of its essential basic structures and functions.

Rising temperatures and extreme weather events have negative impacts on the productivity of crops and livestock. The changing climate also influences the emergence and re-emergence of biosecurity risks. The management of agricultural systems and natural resources needs to be urgently improved to ensure that farming communities and practices are sufficiently resilient and sustainable to cope with the impacts of climate change.

Systems thinking and resilience science provide conceptual and methodological tools to focus on the ways in which different primary industries are affected by and respond to climate change. Resilience assessment, for example, can be helpful in identifying thresholds within primary industries – conditions which may require radical changes in land use or re-organisation of productive systems to operate within environmental limits. Furthermore, framing resilience as a capacity not only 'to recover', but also 'to adapt', 'to learn', 'to transform', and 'to re-organise', opens opportunities to move towards continually improved systems. Finally, with its origins in ecology and systems thinking, resilience-based approaches can be an effective tool for identifying and assessing linkages between different primary industries, and the ways in which adaptations in one area might have an influence elsewhere.

Overall a more complex take on adaptation can yield positive results for the sustainability of primary industries and advance interdisciplinary, scientific knowledge on how to advance, monitor and evaluate adaptive capacity in New Zealand. **A depth and breadth of knowledge from multiple perspectives is urgently needed to play a critical role in complex adaptation and problem solving.**

Resourcing knowledge gaps in adaptation research

Finally, this review highlights **the funding gap between mitigation and adaptation: adaptation research is still the 'poor cousin' to mitigation.** Between 2007 and 2016, of the approximately $51 million that has been invested in SLMACC projects, approximately $25 million has gone to mitigation; $10 million forestry-related research, and only $7 million to fund adaptation science. The result is an imbalance in terms of knowledge about mitigation and the knowledge base for developing adaptation strategies for New Zealand primary industries. This leaves the primary sector with less knowledge about the impacts of climate change and possible adaptation options. With primary industries worth $38 billion annually, there is an economic imperative to enhance climate resilience and ensure effective adaptation.

This imbalance is compounded by the emphasis on impacts-focused research. Total investment in adaptation research in the primary industries, as we have shown, has been largely driven by model-based impacts assessment, and there has been little work on understanding adaptation actions, decisions and implications. The primary industries have more information on what could happen and what it might mean, but significantly less information that can be used to equip and prepare end users for climate change. Given the changes already occurring, information to support adaptation actions now is critical or maladaptation is the more likely outcome.

There is nonetheless, significant adaptation research capability and capacity. As shown in Section 5, the SLMACC fund has fostered a growing community of adaptation researchers in New Zealand. These researchers are actively involved in current SLMACC adaptation projects, Deep South and Resilience to Nature's Challenges National Science Challenges.

We conclude that far more **coordinated efforts are required to encourage investments in adaptation research and realise the potential for world-leading science for climate-resilient primary industries**, including alignment between SLMACC and other MPI-administered funding, the National Science Challenges, and the Crown Research

Institutes' Strategic Science Investment Funding (SSIF). Small investments can catalyse interdisciplinary collaborations, enhance cooperation and leverage additional funding for critical areas. Current research often remains fragmented and sectoral in their nature. In the concluding section we thus offer some key recommendations for areas of future progress.

7 Barriers and enablers: what do we need to know?

The results of the review, survey findings and workshop discussions revealed several barriers to and enablers of more effective adaptation and implementation of SLMACC research findings.

The greatest barriers to climate change adaptation we identified appear to be:

- psychosocial factors, including uncertainty in climate projections and projected impacts, as well as scepticism regarding climate science;
- limited coordination between SLMACC adaptation funding and other research pathways; and
- resource constraints, which limit linked-up and systems approaches to impacts and adaptation research.

To overcome these barriers, we identified four key enablers and strengths of SLMACC:

- depth and breadth of adaptation research;
- decision support in the face of uncertainty;
- novel communications to enhance impact and uptake; and
- better integration between social and physical sciences.

We begin by discussing the barriers to adaptation action, and enhancing the impact of SLMACC adaptation research, and then present the strengths and opportunities.

7.1 Barriers

7.2 Adaptation is limited by uncertainty, resources and psychosocial factors

Climate change is making a difference to New Zealand now, affecting our droughts and our rainfall extremes (Harrington et al. 2014). These are having a disruptive effect on current production, and without adaptation, will have an even greater impact on primary industries. One of the most frequently cited barriers to adaptation relates to psychosocial factors including prioritisation of short term, or tactical management of existing climate variability, at the expense of longer-term planning; and skepticism regarding projected impacts. Both are compounded by significant uncertainty and the need to plan for multiple possible futures.

In decision-focused adaptation projects, for example, while climate change was identified as a risk, land managers often referred to other, more pressing concerns relating to farm performance, production and yield, and profitability (Cradock-Henry & Mortimer 2013; Cradock-Henry & McCusker 2015; Dunningham et al. 2015). Climate variability was often identified as more significant than the long-term prospect of climate change (Cradock-Henry & Mortimer 2013). The net result is that management practices are focused on addressing immediate and short-term issues, rather than on adaptation. Furthermore, for much of the time covered by the review (2007–2016), strategic, long-term consideration of climate change and its impacts for primary industries has been hampered by scepticism

within rural communities and industries regarding anthropogenic climate change (Reisinger et al. 2011).

Adaptation planning is also associated with a high degree of uncertainty. Future climatic conditions in New Zealand for example, will be a function of emissions pathways, social and economic changes and policy responses – not only domestically but internationally (Cradock-Henry et al. 2018c). Different responses might also be preferred depending on how the climate (and other non-climate parameters such as population or social values) change through time. As interviewees in one adaptation project asked: *"How do we know the climate will change? When can we expect to see an increase in storm events?"* (Cradock-Henry & McCusker 2015). Adaptation planning therefore must allow for a range of possible futures.

Given this complexity, working out what to do now to adapt to climate change can be overwhelming. Where stakeholders and end users perceive there is uncertainty and complexity it makes decision making more difficult, and some may postpone adaptation decisions and actions altogether (Dunningham et al. 2015).

We suggest there is a need to **better understand decision-making processes that enable change in management practices to improve environmental, social and economic outcomes**. *"Access and use does not imply that it was all [research] that is needed. Most SLMACC information is quite high level and more emphasis is needed on monitoring the usefulness of the information and whether it has actually changed practice on the ground,"* said one survey respondent.

In this context, this could include better understanding of the psychological components of (mal) adaptation and the ways in which values might motivate action. Regulatory incentives for example aimed at promoting adaptation need to act on beliefs, values and preferences that farmers hold (Buelow & Cradock-Henry 2018). Gaining insight into measurable and alterable psychosocial factors that contribute to complex decision-making under uncertainty may help overcome barriers to inaction.

Identifying and supporting factors that encourage the voluntary adoption of sustainable practices is also required. Successful adaptation is as much a product of individual willingness to adapt as it is the result of decision contexts that encourage adaptive behaviour. When the factors enabling adaptive decision-making process are better understood, it may be possible to stimulate adaptation action and support primary producers better.

Governance to support transformations for adaptation

Small scale and 'tactical' responses to existing climate variability are likely to be insufficient but continue to be the basis for much of the response to climate change within the primary industries (Clark & Nottage 2012).

"All [SLMACC] research should be centred around how the data can be made 'real' and used to support adaptation activity," stated one workshop participant. This will require **significant innovation and transformation to transition to the changing environment.** As discussed in Section 5, much of the SLMACC adaptation research to date

has been national-level efforts at focused on understanding impacts. This type of research is reactive and often fails to address region-specific planning requirements.

Transformation involves widespread change to existing decision-making processes and patterns. One aspect of this can include involving affected stakeholders in designing and deciding on future options. This in turn can empower them to develop inclusive solutions and enhance resilience. Communities of practice can develop location-specific, group-specific and time-specific planning pathways. Evidence from work in New Zealand on collaborative processes for freshwater management, for example, demonstrates the positive learning outcomes associated with developing community experience with dealing with complex problems (Cradock-Henry et al. 2017). Embracing such opportunities—for example an exchange on regional and local best-practice examples of adaptation—can in turn lead to a transformation of habits.

Related to this, flexible governance can support place-based solutions. This includes better understanding of social processes, leadership, agents, networks, institutions and organisations that can work effectively within contexts of change and uncertainty. Instead of focusing on system control, learning from how farmers and industry groups have responded to extreme events – such as floods or earthquakes – can illuminate lessons for strategic planning in uncertain environments (e.g. Cradock-Henry et al. 2018b) and identify characteristics that can enable flexible responses.

Research is constrained by poor coordination and limited resources

Finally, the third barrier to enhancing the impact of SLMACC adaptation research and other work more generally, is the limited coordination between SLMACC adaptation funding and other research pathways, and the comparatively small scale of funding.

As one workshop participant noted: *"The small pot of money for specific projects does not result in understanding the big picture system."*

As noted earlier, there has been $7 million invested in impacts and adaptation research through the SLMACC programme, as well as other funding for adaptation research through the Sustainable Farming Fund (Oakden et al. 2014). Crown Research Institutes have also directed and/or leveraged SLMACC funding into supporting adaptation projects, or fundamental science – such as improved climate projections – which can be used in impacts and adaptation research.

There is a small, but growing community of researchers focused on climate change adaptation – several of whom have been supported through SLMACC adaptation funding at various points in time – however there remains little coordination of adaptation research activity nationally. Furthermore, the results of the stakeholder survey show relatively low levels of awareness of previous SLMACC adaptation research outside of central government (Payne et al. 2018b).

Climate change adaptation transcends boundaries, sectors, scales and levels of interaction. To overcome this, the analysis has also highlighted the need for greater integration and coordination across primary industries to address adaptation needs. While there are well-developed knowledge and practice networks to share insights, advances

and practice change for mitigation, there is no corollary in adaptation research. There is an opportunity, therefore, to build on the example of mitigation science in New Zealand, to **develop an adaptation knowledge network**, to realise greater synergy between sectors to share lessons and best practice, and to coordinate actions at the local and regional scales.

As one stakeholder said: *"Turn the science into a useable form – provide advice to sector landowners to make decisions."* A survey respondent suggested:

> *How [is] this information… being used in a practical way? The information from adaptation for example, how will it help industry make decisions and investments in the future? Case studies would be good. Practical examples are also useful for generating discussion and can be used for monitoring purposes.*

Specifically, the SLMACC programme should continue to encourage collaboration in adaptation projects between science, policy, industry and society. This could include requirements for co-design of projects or shared leadership models; developing an adaptation strategy for primary industries with specific actions at regional, local and sectoral levels for supporting adaptation capacities and allocating budgets for knowledge exchange and evaluation of effectiveness of the adopted actions.

The size of adaptation projects also appears to be a barrier to more significant research impact. As discussed earlier, the majority of SLMACC adaptation funding has gone to top-down, impacts-focused projects. These projects have also been – on average – better funded per project, and typically longer (2-3 years on average). **The average value of impacts-focused projects (2007-2016) was $333,586.80, with a median value of $307,934 compared to an average/median value of $182,052.60 and a median value of $150,000 for work focused on decisions and/or actions.** The smaller funding allocated to these projects has also resulted in fewer publications on these topic areas, and most projects were just one year in duration.

Results from the systematic review found only 22 journal papers in the international literature focused on adaptation in New Zealand primary industries between 2007 and 2017. This is compared to 224 journal papers relating to mitigation in New Zealand over this same period; 26 of which were direct outputs from SLMACC projects alone (Fleming & Preston 2017).

If funding for SLMACC adaptation projects were to remain at current levels, increasing the value – and length – of each project may result in higher impact, greater collaboration across disciplines and greater stakeholder and industry engagement. Not surprisingly, the most effective adaptation project was the Clark and Nottage (2012) review and synthesis of adaptation for land-based primary industries. The three-year, $1.5 million project continues to be widely referenced and regarded. As one survey respondent said:

> *I have the 2012 [report on] impacts of climate change on the land-based sectors and adaptation options as a baseline document when undertaking impacts and implications research. Getting further understanding of how the options have been taken up would be useful.*

The report was highly rated across nearly all evaluation criteria, supported PhD students through scholarships and aligned funding, involved biophysical modellers, climate scientists and some social scientists.

7.3 Enablers

To overcome some of these barriers, we identified key strengths and enablers from SLMACC adaptation projects to date. Building on these existing strengths can help to support strategic adaptation planning efforts and avoid maladaptive responses that lock in today's assumptions about climate and continue to expose the sector to change outside the experienced range.

Key strengths and enablers of SLMACC adaptation projects are:

- depth and breadth of adaptation research
- decision support in the face of uncertainty
- novel communications to enhance impact and uptake

Depth and breadth of adaptation research

Disciplinary boundaries become increasingly unclear when grappling with climate change adaptation both in theory and practice. It is a classic 'wicked problem', which presents a complex set of policy, cultural, technological, and scientific dimensions.

The results of the analysis show that the SLMACC programme has been highly successful in building adaptation research capability and capacity. A key strength of this has been the way in which the programme has provided protected 'niche' spaces to enable early-career researchers to develop and experiment with novel approaches, tools and frameworks (e.g. Cradock-Henry & Mortimer 2013; Dunningham et al. 2015). This has helped to develop some "T-shaped" adaptation researchers in New Zealand, i.e. individuals with a depth and breadth of expertise who are being called upon to play a critical role in complex problem solving.

While researchers and practitioners with specific, disciplinary expertise are still necessary, adaptation research requires a diversity of approaches. When trying to grasp the complexity of adaptation to climate change, mono-disciplinary approaches are required to reduce complexity to achieve clarity.

A strength of more recent SLMACC adaptation projects has been the use of interdisciplinary researchers. The programme has encouraged this through support for best teams, expectations of co-funding or aligned support from end users and stakeholders and its development of early-career researchers, who may be more comfortable with working in interdisciplinary teams (Brown et al. 2015). The programme has promoted adaptation research and opportunities to collaborate that overcome fragmentation of approaches.

Interest in interdisciplinary and applied work in climate change continues to grow, resulting in growing investment in research centres and programmes that involve different disciplinary perspectives as well as practitioners' input.

Future SLMACC investment in adaptation research might build on this, by advancing synthesis of disciplinary and stakeholder knowledge on climate change adaptation. This broadens our understanding of managing diverse unknowns and provides integrated research support for policy and practice change.

This might include collaborative research projects involving a variety of stakeholders and different disciplinary perspectives, and that use co-development processes and exchange best practice solution, or that facilitate adaptive decision-making to develop sustainable pathways for the primary sector industries.

Decision support in the face of uncertainty

While uncertainty does present a challenge for climate change adaptation decisions, considerable advances have recently been made in supporting decision-making under uncertainty. Many of these approaches involve incorporating principles of robustness, diversity, flexibility, learning, or options assessment. Many of the approaches to handling uncertainty in the climate change space have built on the principles of adaptive management, which uses an assessment, monitoring, evaluation and learning process (cycle) to improve future management strategies (Tompkins & Adger 2004). More recently, these approaches have been advanced in the form of dynamic adaptation pathways based on making short-term decisions that do not close off future adjustments and can thus avoid path dependency.

SLMACC currently is investing in research on tools and processes to support decision-making under conditions of uncertainty. In Hawke's Bay researchers are working with Hawke's Bay Regional Council and regional and national primary industry sector groups on applied adaptation pathways at a regional scale (Cradock-Henry et al. 2018c). In Greater Wellington, Real Options Analysis is being considered for its utility for adaptation planning in the context of flood and coastal hazards management (Greater Wellington Regional Council 2015).

In economics, alternative decision-making approaches are also being applied in the context of primary industries. Working with water managers, the aim is to better incorporate uncertainty while still delivering adaptation action by selecting projects that meet their purpose across a variety of plausible futures. These 'robust' decisions allow adjustments to be made as the climate changes.

Instead of planning for one specific scenario, a range of possible futures are explored: robust approaches do not assume a single climate change projection, but integrate a wide range of climate scenarios through different mechanisms to capture as much of the uncertainty on future climates as possible.

The growing interest in these emerging approaches is reflected nationally – particularly with respect to coastal hazards – and there is considerable support for them in the New Zealand primary sector. This work can provide a prototype for adaptation planning and addresses some existing research gaps.

Novel communications and enhanced engagement

Finally, new forms of communication and enhanced engagement can leverage investment in adaptation research and enhance primary industries' adaptive capability and capacity.

Several stakeholders commenting on existing SLMACC research criticised the lack of dissemination of results. This is reflected in the survey data gathered as part of the evaluation (Payne et al. 2018b). As noted by respondents (bolding added):

I hope that **more work is done to communicate the findings of this research** with industry. Industry are the best placed to action the research, so it is important that they are on board with it.

> *The research that is undertaken* ***needs to be accessible and usable****.*
>
> *Use stakeholder engagement to* ***promote the reports to target sectors*** *once they have been released.*

Communication of science and research is important. There needs to be **better access for stakeholders to this information**. There is a wealth of it, and it is excellent but I suspect **for many 'non-scientists' quite overwhelming**.

As the comments above highlight, communication of results is currently a part of SLMACC research that is largely missing. Participants from our stakeholder survey indicated that there needs to be a mechanism to 'make data real' for stakeholders, end users and next-users of information provided by research projects. Simply providing access to information is not enough. While SLMACC findings are published online they can be difficult to find.

We recommend assessing strategic science investment, communication and integration, identifying drivers, and new idea generation in the context of future SLMACC funding rounds. Instead of just a few engagement events, a communication plan could be provided by researchers that goes beyond articles and reports and uses different forms of communication and visualisation that clarify issues (e.g. film clips and other forms of story-telling) to create bridges for understanding. As one participant remarked, *"transparency of information lends credibility."* To provide such credibility, multiple communication channels and ways of interaction are needed.

8 Synthesis, recommendations and conclusions

The insights gained throughout this review have informed the following recommendations that we believe would accelerate adaptation research in New Zealand, provide a foundation for overcoming some of the barriers discussed in this report and harness research capability and capacity. We recommend the following actions to maximize the future value and usefulness of SLMACC funding research.

8.1 Closing knowledge gaps requires cross-cutting and targeted research

A key finding of the review is that **most SLMACC adaptation research investment has been empirically and methodologically limited.** The majority of SLMACC adaptation projects have been focused on better understanding the broad, national-scale impacts and implications of climate change for pastoral farming. This work has primarily used top-down, biophysical and climate impacts modelling to assess the ways in which climate change will affect productivity and yield. It has been geographically focused on Hawke's Bay and Bay of Plenty, with smaller amounts of research on Canterbury and Marlborough, but many other NZ regions have had little or no context-specific or focused study.

Assessing SLMACC adaptation projects against the Adaptation Knowledge Cycle also shows that there has been considerably less work done on adaptation decisions and only one study on adaptation actions. As one workshop participant noted, we need to *"understand decision-making processes for people when faced with need to adapt."*

These gaps therefore suggest a case for **more targeted research investment in social science and interdisciplinary engagement to complete the Adaptation Knowledge Cycle and support proactive adaptation as a more effective and sustainable strategy.** Gaining insight into the barriers and enablers of adaptation action, expanding the focus of future research to explicitly include new conceptual and methodological approaches and analysis of decision-making could enhance the impact of research on stakeholders, provide better value for money and build resilience.

A key step in adapting to climate change is understanding what is vulnerable and at-risk regions and sectors, knowing how climate change will interact with other socio-economic and environmental stressors, and identifying options to build near- and long-term resilience to current and projected changes.

We also recommend future investment focus on integrated, cross-sectoral approaches to adaptation, and targeted research to meet urgent empirical and methodological gaps including underrepresented industries and regions and adaptation knowledge. This is based on our assessment that narrowly focused actions may not create an adaptive sector (if it does not account for opportunities, challenges, and preferred adaptations in other sectors). To support horizontal integration, research investment through the SLMACC program should focus on cross-sectoral approaches. Such an approach would help decision makers to prioritize specific adaptation actions that could contribute to the provision of multiple ecosystem services.

8.2 Improved coordination between adaptation science, policy and practice

Coordinated action on adaptation at the national, sectoral and programme/project levels is crucial for successful implementation of adaptation measures and actions. SLMACC impacts and adaptation research has helped increase research capacity, and it has the potential to help clarify and resolve problems, catalyse innovation, identify adaptation options and choices for effective decision making, and educate end users. To make climate science relevant for stakeholders however, it may not be enough to rely only on existing collaborations and networks (Moser 2005, Nelson et al. 2010).

A number of SLMACC adaptation projects that we reviewed (especially from 2012 onwards) tried to enhance collaboration between scientists, policy-makers and farmers' and industry groups. This was evident in both top-down projects, such as Sturman et al. (2015), who worked with stakeholders in the Marlborough wine industry to on develop modelling and analytical tools to help improve adaptation to current and future climates; as well as bottom-up projects. Cradock-Henry and McCusker (2015) for example, worked with Beef + Lamb, Hawke's Bay Regional Council, Rural Support Trust (South Canterbury) and Northland Regional Council on a series of resilience workshops for sheep and beef farming.

These two-way exchanges of information between stakeholders have played a critical role in advancing climate change adaptation planning. Specifically, the role of science in the process was to provide information on climate change impacts and possible adaptations, assist with improving capacities of farmers, growers and policy-makers to learn about adaptation (which was new to many of them) and, finally, address questions that arise.

In some cases, this has led to new networks between researchers and policy-makers who are engaged in adaptation planning. Much of the research focus in Hawke's Bay for example, can be traced back in part to pioneering work by Kenny and Robertson (2005) on adaptation in eastern New Zealand. Subsequent SLMACC research by Cradock-Henry and Mortimer (2013) and Cradock-Henry and McCusker (2015) furthered key relationships within the region, and the Hawke's Bay Regional Council is now a research partner – and co-funder – of currently funded SLMACC adaptation research (Cradock-Henry et al. 2018).

The results of our review and analysis suggest that **successful adaptation planning begins with creating strong connections across decision makers and diverse stakeholder groups to build adaptation capability and capacity, to enable strategic thinking and promote adaptation as a planning priority**. At the same time, it is crucial for sectoral planning to ensure flexibility at the horizontal and vertical level to bring together multiple objectives across strategies and plans developed for agriculture, regional planning, environment and natural resources and others, and across often cross-cutting goals and mandates of institutions at different levels of governance.

Creation of stronger linkages between sectors and science providers therefore is strongly encouraged. This might be addressed through formal collaborations (cross-sectoral partnerships, working groups and committees), joint research proposals including co-leadership of major projects, and communities of practice. Cross-sectoral horizontal collaborative networks might be established to connect agriculture with diverse sectors, such as those coping with natural resources, environment and conservation, infrastructure

and transportation, trade and commerce. Physical and/or virtual innovation spaces could be established to explore adaptation options.

As one workshop participant said, "I would like to see how this information is being used in a practical way. The information from adaptation for example, how will it help industry make decisions and investments in the future? Case studies would be good. Practical examples are also useful for generating discussion and can be used for monitoring purposes." Another commented that *"demonstration farms could be used to show the potential of different strategies."*

Despite the challenges of cross-sectoral integration, such processes have the potential to improve understanding of needed adaptation actions by placing agricultural priorities in context with other needs, whilst being more aware of potential trade-offs/synergies.

Finally, climate change adaptation planning could be enhanced by skills development and mutual learning across stakeholder groups, and through interactive development of institutional capabilities on an ongoing basis.

8.3 Enhancing adaptation communication and knowledge exchange

Communication and knowledge exchange are also critical for successful adaptation planning. Our stakeholder survey indicates that SLMACC projects have been less likely to be used by practice partners; however, projects that interact and engage with industry score remarkably higher in this category, such as the influential report by Clark and Nottage (2012) which summarised climate change data for New Zealand and identified various adaptation options for land-based industries. Results from the survey and workshop show that **sector-specific information has been useful, useable and used. Adaptation information generated by the SLMACC programme is in demand, it has enhanced awareness, and increased understanding.**

The challenge with knowledge gaps, therefore, is to produce and integrate knowledge from multiple sources incorporating the perspectives of various stakeholders, and allow for the smooth access and uptake of relevant information by decision-makers at different levels for effective adaptation policy, planning and implementation.

To enhance stakeholders' understanding of adaptation, future adaptation projects should be required to demonstrate a robust plan for adaptation communication and knowledge exchange. Where appropriate, **sufficient resourcing should be provided to research projects as part of operational requirements as a central component of project delivery.**

As one stakeholder said:

> *"Access and use does not imply that it was all that is needed. Most SLMACC information is quite high level and more emphasis is needed on monitoring the usefulness of the information and whether it has actually changed practice on the ground… there needs to be a focus on education and knowledge dissemination for any research to be valuable and the benefits maximised."*

More time is needed to improve understanding of adaptation, particularly in cross-cutting projects or those where the focus is on jointly-developed strategies. For example, work on regional applied adaptation pathways planning for Hawke's Bay primary industries (Cradock-Henry et al. 2018a). This might include additional resourcing for diverse outputs including policy briefs, fact sheets and manuscripts. Where appropriate, researchers might also work more closely with outreach and extension experts to enhance the effectiveness of communication and knowledge transfer.

If research is designed in a way that is both relatable and relevant to stakeholders and end users, outcomes and impacts can be broadened beyond the science and governmental sphere. This highlights the relevance of scale, of integration engagement, and tools for effective engagement with stakeholders and their differing needs. Novel communication methods such as infographics and short video communications have also demonstrated their potential in reaching diverse audiences.

8.4 Innovative methods for adaptation monitoring and evaluation

There is an urgent need to **develop tools and processes for monitoring and evaluating the impacts of adaptation science, and methods to track progress in adaptation in the primary industries**. While conducting this review, we found that the lack of good monitoring data, inconsistencies in record keeping and few available methods for attributing impact of SLMACC adaptation projects, was a constraint to more rigorous analysis.

Adaptation tracking seeks to characterize, monitor, and compare general trends in climate change adaptation over time. It is essential for evaluating adaptation progress, yet there have been few attempts to develop systematic approaches for tracking adaptation. Evaluation and monitoring for adaptation purposes are best suited to more adaptive or developmental evaluation approaches as opposed to more traditional fixed outcomes methods because of the changing nature of climate risk and the need for continual adaptation over unknown timeframes.

As our review has shown: existing data on adaptation is often limited, too broad, or insufficiently tailored for longitudinal studies of adaptation or hypothesis-testing. Additionally, adaptation datasets tend to be overly static, capturing only a small timeframe whereas tracking needs a strong temporal dimension. The application of systematic data collection techniques provides opportunities to build comprehensive adaptation datasets that support more complex research designs.

This suggests a critical need for MPI to establish monitoring and evaluation for adaptation projects that are sufficiently robust as to cope with both the demands of tracking project outcomes and impacts, but also contributing meaningfully towards tracking broader adaptation progress for the primary sector.

Monitoring and evaluation for adaptation requires less focus on achieving fixed static outcomes. Because climate change is dynamic, greater emphasis is required on measuring ongoing actions which seek to reduce the exposure of our natural, built, social and economic systems to the impacts of climate change; and ensuring these systems have sufficient adaptive capacity.

At a project level, monitoring and evaluation requirements need to be fit for purpose, cognisant of, and appropriate, to the questions posed in relation to the Adaptation Knowledge Cycle. Monitoring and evaluation for impacts-focused research might track knowledge transfer and uptake; while research in the action phase of the cycle, changes in adaptation behaviour would be more appropriate. To implement this, future calls for proposals might expressly state where in the Adaptation Knowledge Cycle projects are expected to fit, and bespoke monitoring and evaluation can be designed accordingly from the outset.

Innovative methodological approaches, used to understand and track progress towards adaptation outcomes, can improve the ability to design effective policy interventions and demonstrate the impact of adaptation science, supporting the transition towards climate-resilient primary industries.

8.5 Refocusing the adaptation research agenda

There is growing evidence of a sea change in terms of adaptation research in New Zealand's primary industries and in society more generally. When primary industry bodies were recently asked where science and research was most needed from the National Science Challenges, 'Adapting to climate change' was the top priority (ahead of biosecurity, greenhouse gas emissions and water quality) (Angela Halliday, *pers. comm*). Furthermore, the Farming Leaders Group has acknowledged the need to reduce GHG emissions from the primary industries and ensure rural communities are able to thrive. The Climate Commission and recent reports from the Technical Working Group on Climate Change Adaptation also suggest an opportunity to harness this shift in priorities and refocus the adaptation research agenda.

We recommend **there is much is to be gained by refocussing SLMACC research agendas within priority Research Theme 1.** Framing adaptation future adaptation research around "problem first" might help to prioritise targeted study on vulnerability, resilience and adaptive capacity, and the economics of adaptation.

A "problem first" – rather than "science first" – approach might help target research and understanding where it is really needed. While it is still necessary to understand the likely impacts, a problem first approach structures the problem, then proposes adaptation options, and assesses these against scenarios and trade-offs between options (Ranger et al. 2010). Working together with industry to structure the problem (recognising that industry may not always be aware of the future challenges of climate change), and develop potential adaptation strategies together is likely to be more effective than first assessing the climate change impacts.

Considerable research on climate and climate change for primary industries has already been conducted through the SLMACC programme, with studies typically focusing on the physical environment in terms of experienced and projected impacts. To initiate adaptation actions, decision makers need to know the nature of vulnerability in terms of who and what are vulnerable, to what stresses, and in what way, and also what is the capacity of human systems such as primary industries, to adapt to changing conditions

SLMACC can positively influence resilience by identifying vulnerabilities, not just in the primary sector but across sectors, and communicating pathways for adapting to those in a region, time, and context specific manner. Being vulnerable as a farm means being unable to protect crops, livestock, infrastructure, and people from harm by adverse effects, such as surprising extreme weather events, climate variability and overall climatic changes. It is the "characteristics of communities, countries, and regions that influence their propensity or ability to adapt" to climate change (IPCC 2001, p.181).

Modifications of climate policies do not simply happen as a reaction of policy makers to newly emerging problems or because new facts are becoming available. Rather, they are brought about because certain types of knowledge, perceptions, awareness, interests, and values are negotiated and become powerful in public discourses (Canon & Müller-Mahn (2010). SLMACC - with its capacity to leverage additional funding and foster collaboration between researchers, industries and policy – can be a valuable complement to such processes. In this way **investment in adaptation research is a boundary object: mediating between agenda-setting and problem identification.**

Furthermore, **analyses that go beyond impacts and discuss different adaptation actions and transformative potential provide insights into thresholds and interconnected and cascading impacts.** These insights in turn can inform the design of urgently needed tools, processes and practices to support adaptation planning. The amount of change different sectors are able to withstand in each region, i.e. how capable they are to adapt and manage the interaction and effects from multiple stresses, differs with composition of stakeholders, and the environment in the context of policy/governance, regulation, markets etc.

Decisions on climate change are placed in an encompassing political, economic and social context where patterns of adaptation are the product of many individual decisions (Smit & Skinner 2002). Subsequently, researchers highlight the "need for co-management, particularly adaptive co-management, with a co-requisite of social learning as a necessary response" (Sharma-Wallace et al. 2018, Booth & Halseth 2011). This learning process aims to grant stakeholders that are affected or somehow involved in decisions the opportunity to express themselves and exchange opinions, knowledge, and ideas. As we pointed out in section 7, insights into individual level processes of decision making are also crucial for our understanding of why and how people adapt. In this context, we point to the need for a **systematic examination of policy-specific and sector-specific characteristics of adaptation governance**.

How can adaptation be initiated, communicated and sustained? Another crucial step in understanding decisions to adapt is to close the gap between knowledge and practice on adaptation by translating scientific evidence into decisions and actions. Changes in the primary sector need to involve researchers, producers, policy makers and consumer voices, to reflect a networked effort to sustain the sector's profitability and sustainability. This could include increasing the 'socialising' of SLMACC outputs, increased collaboration and exchange around best-practice and success stories, or mainstreaming discussion on climate change into other conversations, e.g. during workshops on topics like animal genetics, erosion control, nutrient management, and irrigations schemes, as is done in other parts of the world (e.g. Wamsler & Pauleit 2016).

Other areas with very limited current information relate to the economics of adaptation. A greater understanding of what adaptation may cost – at the farm and sector level – is required to support decision-making. Some limited information is available about the value of the benefits of adaptation, primarily from farm level modelling studies.

However, **a greater understanding of the scale and magnitude of the benefits over time would allow a wider perspective.** Estimating these is challenging, however recent advances in adaptation economics provide interesting avenues to pursue.

Finally, there is a complete separation between mitigation and adaptation research. This is not helpful for land managers who are receiving a range of messages regarding actions to address climate change. Developing greater understanding regarding the interactions between adaptation and mitigation, harnessing the synergies and identifying and avoiding the trade-offs, will allow more efficient action to be taken. Including additional considerations – such as water quality, as well as productivity - allows a much more comprehensive picture to be formed, and may help to avoid unintended consequences of actions and maladaptation.

8.6 Bridging funding gaps to address the adaptation deficit

Finally, we would recommend that **increased funding for adaptation research is urgently required.** Climate change is a focus in the Deep South ("Our Changing Climate") National Science Challenge (NSC); there is work on issues facing the resilience of rural regions, communities, and primary industries in Resilience to Nature's Challenges NSC, and Our Land and Water NSC has a broad remit exploring various aspects of land use, sustainability and natural resource management. However, there is currently poor alignment between current and proposed research in the NSCs, as they relate to adaptation. The Deep South Challenge, for example, in their proposed 2019-2024 strategy, maintains a focus on climate change impacts; the High Impact Weather programme in Resilience to Nature's Challenges focuses on current climate variability and extremes – not adaptation; and there is very little evidence of climate change adaptation research in the second phase of Our Land and Water.

We see a valuable role for SLMACC to bring together disparate research activities in each of the NSCs, and catalyse collaboration through a targeted, interdisciplinary science programme and/or investment.

To advance and progress the momentum of adaptation research in New Zealand, it is essential for SLMACC to continue with at least the same funding level, or ideally increased funding. The SLMACC programme as we have shown, is one of the few dedicated funds for adaptation research in New Zealand. Despite the relatively small size of most projects, and the short-term funding (1-2 years), SLMACC adaptation research has had a demonstrated impact.

As one survey respondent from local government put it:

> *SLMACC is my absolute favourite research fund. The findings from SLMACC inspired me to move to NZ and I tend to find that whatever NZ climate change mitigation/adaptation research I find online (that is actually useful) is*

connected to some SLMACC research programme or another. I think there needs to be a lot better management of previous work and results and better coordination between old and new work. Last but not least, please continue the focus on social science work.

With additional funding and better alignment between science investment and knowledge gaps, research insights can begin to move on from the impacts research to implications and applications; preserve a legacy of science excellence in impacts modelling, particularly systems models, and support the further development of an adaptation community in New Zealand, focused on delivering actionable information for climate-resilient primary industries.

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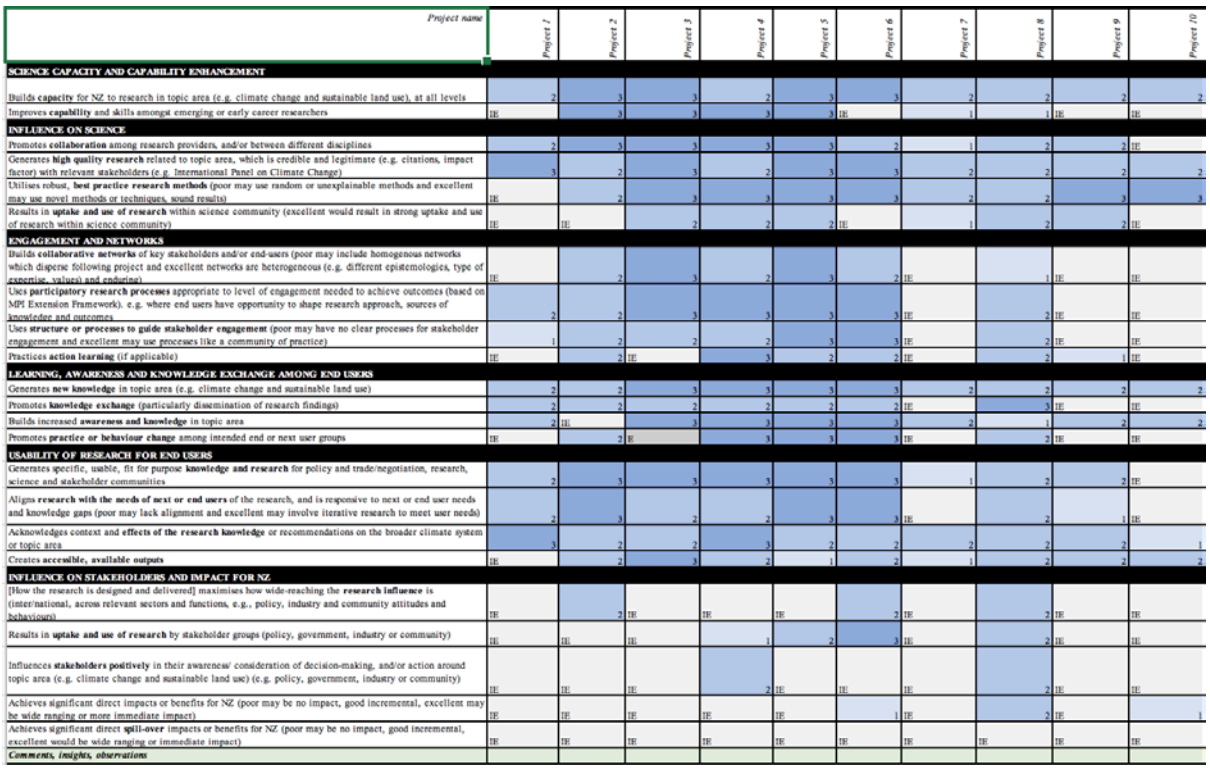
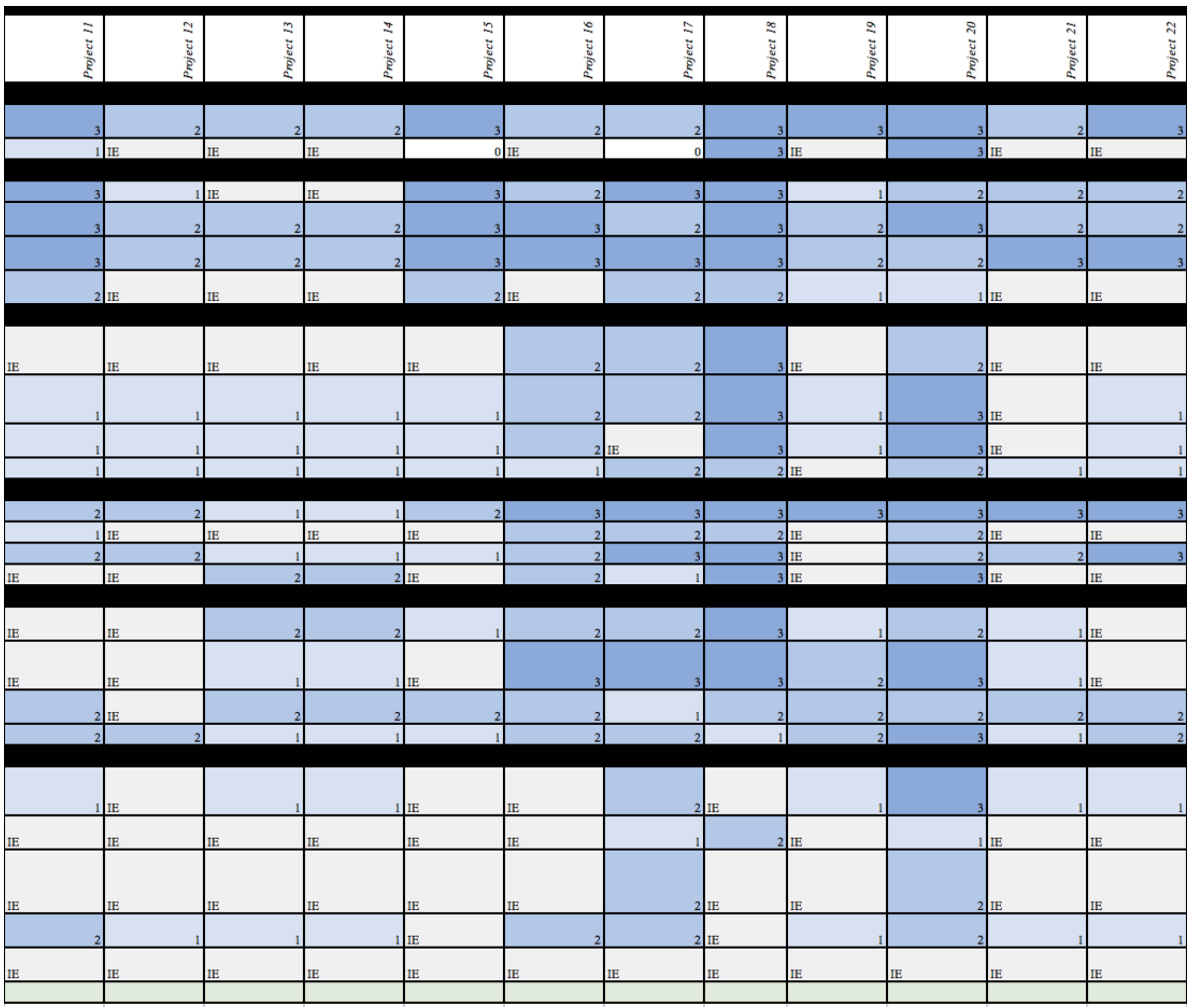
Appendix A - Rubric evaluation

Rubric attached as .XLSX owing to formatting limitations.



Project name	*Project 1*	*Project 2*	*Project 3*	*Project 4*	*Project 5*	*Project 6*	*Project 7*	*Project 8*	*Project 9*	*Project 10*
SCIENCE CAPACITY AND CAPABILITY ENHANCEMENT										
Builds **capacity** for NZ to research in topic area (e.g. climate change and sustainable land use), at all levels	2	3	3	2	3	3	2	2	2	2
Improves **capability** and skills amongst emerging or early career researchers	DE	3	3	3	3	DE	1	1	DE	DE
INFLUENCE ON SCIENCE										
Promotes **collaboration** among research providers, and/or between different disciplines	2	3	3	3	3	2	1	2	2	DE
Generates **high quality research** related to topic area, which is credible and legitimate (e.g. citations, impact factor) with relevant stakeholders (e.g. International Panel on Climate Change)	3	2	3	2	3	3	2	2	2	2
Utilises robust, **best practice research methods** (poor may use random or unexplainable methods and excellent may use novel methods or techniques, sound results)	DE	2	3	3	3	3	2	2	3	3
Results in **uptake and use of research** within science community (excellent would result in strong uptake and use of research within science community)	DE	DE	2	2	2	DE	1	2	2	DE
ENGAGEMENT AND NETWORKS										
Builds **collaborative networks** of key stakeholders and/or end-users (poor may include homogenous networks which disperse following project and excellent networks are heterogeneous (e.g. different epistemologies, type of expertise, values) and enduring)	DE	2	3	2	3	2	DE	1	DE	DE
Uses **participatory research processes** appropriate to level of engagement needed to achieve outcomes (based on MPI Extension Framework), e.g. where end users have opportunity to shape research approach, sources of knowledge and outcomes	2	2	3	3	3	3	DE	2	DE	DE
Uses **structure or processes to guide stakeholder engagement** (poor may have no clear processes for stakeholder engagement and excellent may use processes like a community of practice)	1	2	2	2	3	3	DE	2	DE	DE
Practices **action learning** (if applicable)	DE	2	DE	3	2	2	DE	2	1	DE
LEARNING, AWARENESS AND KNOWLEDGE EXCHANGE AMONG END USERS										
Generates **new knowledge** in topic area (e.g. climate change and sustainable land use)	2	2	3	3	3	3	2	2	2	2
Promotes **knowledge exchange** (particularly dissemination of research findings)	2	2	2	2	2	2	DE	3	DE	DE
Builds increased **awareness and knowledge** in topic area	2	DE	3	3	3	3	2	1	2	2
Promotes **practice or behaviour change** among intended end or next user groups	DE	2	DE	3	3	3	DE	2	DE	DE
USABILITY OF RESEARCH FOR END USERS										
Generates specific, usable, fit for purpose **knowledge and research** for policy and trade/negotiation, research, science and stakeholder communities	2	3	3	3	3	3	1	2	2	DE
Aligns **research with the needs of next or end users** of the research, and is responsive to next or end user needs and knowledge gaps (poor may lack alignment and excellent may involve iterative research to meet user needs)	2	3	2	2	3	3	DE	2	1	DE
Acknowledges context and **effects of the research knowledge** or recommendations on the broader climate system or topic area	3	2	2	3	2	2	2	2	2	1
Creates **accessible, available outputs**	DE	2	3	2	1	2	1	2	2	2
INFLUENCE ON STAKEHOLDERS AND IMPACT FOR NZ										
[How the research is designed and delivered] maximises how wide-reaching the **research influence** is (inter/national, across relevant sectors and functions, e.g., policy, industry and community attitudes and behaviours)	DE	2	DE	DE	DE	2	DE	2	DE	DE
Results in **uptake and use of research** by stakeholder groups (policy, government, industry or community)	DE	DE	DE	1	2	3	DE	2	DE	DE
Influences **stakeholders positively** in their awareness/ consideration of decision-making, and/or action around topic area (e.g. climate change and sustainable land use) (e.g. policy, government, industry or community)	DE	DE	DE	2	DE	DE	DE	2	DE	DE
Achieves significant direct impacts or benefits for NZ (poor may be no impact, good incremental, excellent may be wide ranging or more immediate impact)	DE	DE	DE	DE	DE	1	DE	2	DE	1
Achieves significant direct **spill-over** impacts or benefits for NZ (poor may be no impact, good incremental, excellent would be wide ranging or immediate impact)	DE	DE	DE	DE	DE	DE	DE	DE	DE	DE
Comments, insights, observations										

Figure A 1. Rubric Evaluation, Projects 1-10.



Project 11	*Project 12*	*Project 13*	*Project 14*	*Project 15*	*Project 16*	*Project 17*	*Project 18*	*Project 19*	*Project 20*	*Project 21*	*Project 22*
3	2	2	2	3	2	2	3	3	3	2	3
1	IE	IE	IE	0	IE	0	3	IE	3	IE	IE
3	1	IE	IE	3	2	3	3	1	2	2	2
3	2	2	2	3	3	2	3	2	3	2	2
3	2	2	2	3	3	3	3	2	2	3	3
2	IE	IE	IE	2	IE	2	2	1	1	IE	IE
IE	IE	IE	IE	IE	2	2	3	IE	2	IE	IE
1	1	1	1	1	2	2	3	1	3	IE	1
1	1	1	1	1	2	IE	3	1	3	IE	1
1	1	1	1	1	1	2	2	IE	2	1	1
2	2	1	1	2	3	3	3	3	3	3	3
1	IE	IE	IE	IE	2	2	2	IE	2	IE	IE
2	2	1	1	1	2	3	3	IE	2	2	3
IE	IE	2	2	IE	2	1	3	IE	3	IE	IE
IE	IE	2	2	1	2	2	3	1	2	1	IE
IE	IE	1	1	IE	3	3	3	2	3	1	IE
2	IE	2	2	2	2	1	2	2	2	2	2
2	2	1	1	1	2	2	1	2	3	1	2
1	IE	1	1	IE	IE	2	IE	1	3	1	1
IE	IE	IE	IE	IE	IE	1	2	IE	1	IE	IE
IE	IE	IE	IE	IE	IE	2	IE	IE	2	IE	IE
2	1	1	1	IE	2	2	IE	1	2	1	1
IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE	IE

Figure A 2. Rubric Evaluation, Projects 11-22.

Project 23	Project 24	Project 25	Project 26	Project 27	Project 28	Project 29	Project 30	Total	Count (with	Average (O
3	3	3	3	3	2	3	2	69	26	2.7
2	1	IE	IE	IE	3	IE	IE	24	9	2.7
2	3	2	2	2	3	2	IE	54	22	2.5
3	3	3	3	3	2	2	2	68	26	2.6
3	3	3	3	3	3	3	2	70	25	2.8
2	2	2	1	2	2	IE	IE	30	16	1.9
1	2	3	IE	3	2	IE	IE	31	13	2.4
1	3	3	1	3	3	1	1	46	22	2.1
1	2	2	1	3	2	1	1	39	21	1.9
1	2	2	1	2	3	1	1	34	21	1.6
2	3	3	2	3	3	3	1	66	26	2.5
3	2	2	1	3	2	IE	IE	35	16	2.2
2	2	2	2	3	3	3	1	54	24	2.3
IE	2	2	1	3	3	IE	2	34	14	2.4
1	2	2	1	2	3	IE	2	46	22	2.1
1	2	3	IE	3	2	IE	1	44	19	2.3
2	3	3	IE	3	3	2	2	53	24	2.2
2	2	2	IE	2	2	2	1	45	24	1.9
1	2	2	1	2	IE	1	1	25	16	1.6
1	IE	2	1	2	1	IE	IE	18	10	1.8
IE	IE	2	1	3	2	IE	IE	14	7	2.0
1	1	2	1	2	IE	1	1	25	18	1.4
IE	IE	IE	IE	IE	IE	IE	IE	0	0	N/A

Figure A 3. Rubric Evaluation, Projects 23-32

Appendix B - Project summaries

Impacts of climate change on land-based sectors and adaptation options

Key organisation: NIWA
Total funding: $1,493,333
Named partners: Dairy NZ, Plant and Food
Duration: 2010-12
Main audience: Land Management Professionals and producers
Project code: C01X0901
Lead author: Clark, A

Summary

The report considers the impacts of climate change on land-based sectors and adaptation options. The project examines all primary industries excluding mining. The research looks at the impacts as well as the implications of climate change.

The work was captured in the project leader survey. Research expertise included climatologists, climate modellers, hydrologists, plant, farm and forestry scientists, as well as some social science expertise. Results there show that this project was reported to be well connected to other SLMACC projects, had high stakeholder engagement, and produced outputs over several channels including journal articles, national and international conferences and a stakeholder focused report. The reported main purpose of the work was to review the existing science and knowledge for stakeholders.

Project components

The work summarises existing data on climate change and then offers adaptation options for a range of land-based industries (dairy, sheep and beef, cropping, horticulture, and forestry). The report provides and synthesis of existing knowledge through providing integrated reviews of existing scientific, professional and experiential knowledge. The research also engages with advanced risk analysis by applying production modelling to individual production units to create primary sector adaptation scenarios.

Outcomes

The research categorised adaptation options into tactical, strategic and transformational. Adaptation options – termed tactical – are already part of day-to-day practice, and can help counter low to moderate impacts expected in the future. Prime examples include increasing fee flexibility, adjusting cropping schedules and improving irrigation efficiency. Strategic adaptation practices will counter expected moderate impacts, and some higher level impacts. Examples include diversifying production option in the sheep and beef sector, and finding new plantation sites for the forest sector. Transformation options are best suited to extensive climate change and cumulative impacts. These might include shifting the regional concentration of a sector, changing infrastructure to respond to production changes, or novel uses.

The project produced a technical and stakeholder report. The technical report provides a detailed synthesis of scientific, professional and experiential knowledge about impacts and adaptation. The stakeholder report is a more streamlined version of the review, synthesising key concepts and outcomes.

Innovative and targeted mechanisms for supporting adaptation in the primary sector

Key organisation: Scion Forest Research
Named partners: Landcare Research, NIWA
Main audience: Industry stakeholders
Lead author: Dunningham, A.

Total funding: $210,000
Duration: 2013-15
Project code: FRI 131412

Summary

This research reviews tools and mechanisms used in New Zealand climate change adaptation communication and research, and then identifies the motivating levers of decisive action at different scales across the primary sector activities. The intention being to identify communication mechanisms to support climate change adaptation in the primary sector. The report uses secondary data review and provides recommendations based on this review. The report focused on all primary industries excluding mining. The work has a strong focus on applied actions and on providing information to act and decide.

The report was captured in the project leader survey. Researchers with expertise in resilience, systems thinking, learning and pedagogy, and climate change impacts on primary production were involved in the project. The project engaged with stakeholders and end users to a large extent. Research was disseminated through presentation at an international conference. While the project was not formally connected to any other projects and programmes the research findings did influence how other programmes and projects were developed.

Project Components

The research focused on reviewing and evaluating existing methods, tools and mechanisms used in New Zealand climate change adaptation communication and research; identifying the motivating levers of decisive action and decision makers' information requirements at different scales across primary sector activities; and identifying communication mechanisms that might facilitate and support practice change in the primary sector, through knowledge co-development for adaptive action.

Outcomes

The research identified key drivers for primary sector businesses. Not unexpectedly, climate change was not considered separate to normal business operations and the influences of a range of externalities on them. At an individual farm and forest level, decision making processes regarding adaptation to climate change risks were characterised as complex and incorporated into key influential factors including information and advice; climatic risk; experience; and adaptability. At a wider primary sector systems level, decision-making processes were influenced by willingness and ability to act; diversification potential; and productivity. In addition, leverage points with which the uptake of climate change adaptation mechanisms could be progressed were identified. These include: creating more confidence in climate change adaptation options; progressing the ability to act under uncertainty; and enhancing the clarity of information provided.

Development of advanced weather and climate modelling tools to help vineyard regions adapt to climate change

Key organisation: University of Canterbury
Named partners: Plant and Food Research, MetService, NIWA, University of Rennes
Main audience: Industry/Government
Lead author: Sturman, A

Total funding: $500,000
Duration: 2013-15

Project code: UOC30915

Summary

This report provides evidence of how viticulture will react to difference climate change scenarios. It uses quantitative data analysis to test two grape models against collected quantitative data and climate change predictions. The report focuses on the impacts of climate change and does not look specifically at the implications of these impacts. The report is not captured in the project leader survey.

Project components

The main aim of the research was to provide new knowledge and develop practical tools to help the New Zealand wine industry adapt to climate change across a range of time and space scales. The research methodology involved analysis of existing temperature data for New Zealand's vineyard region for the 2013-14 and 2014-2015 growing seasons. The fieldwork included meteorological measurements obtained from a weather station network of more than 30 sites across the region. Observations in grapevine development were also made in selected vineyards, to allow monitoring of grapevine response to variations in weather throughout the growing season. High-resolution meteorological modelling was also undertaken using a state-of-the-art Weather Research and Forecasting (WRF) model. This advanced physics-based three-dimensional numerical weather and climate model that can be used to represent high-resolution (100s metres) spatial variation of weather and climate over complex terrain within vineyard regions of New Zealand. A new phenological model was also used to predict grapevine response in New Zealand climatic conditions. This grapevine response model was developed by a member of the research team based on thousands of measurements of almost 100 different grape varieties in vineyards across Europe. The coupling of the two models has provided a new innovative tool to analyse the effect of weather on grapevine development at high resolution within vineyard regions.

Outcomes

The project developed a new approach to investigating the relationship between climate variability and grapevine response. The results have demonstrated that this approach can generate significant new knowledge about climate variability within vineyard regions, and provides the basis for assessing the impact of longer-term climate change at the global and regional scale. Authors report that the innovative methodology developed in this research project can also be applied to a range of other crops with opportunities to extend the research into other agricultural areas

Evaluating Intensification Trajectories in the Context of Climate Change

Key organisation: ARGOS
Named partners:
Main audience: Pastoral Farmers
Lead author: Rosin, C

Total funding: $417,000
Duration: 2013-2015
Project code: ABDG30946

Summary

This report makes a series of recommendations for future-proofing New Zealand's pastoral farming from the effects of climate change. The report is not captured in the project leader survey. The work looks at decision-making and taking action in the face of climate change. The work builds research capacity in this topic area and is deemed to generate fit-for-purpose knowledge and research for policy and stakeholder communities.

Project components

Research methods included a literature review, semi-structured interviews with key stakeholders (farmers and sector facilitators), and economic scenario modelling. These findings from the literature review, interviews and modelling were then presented to 33 expert farmers, industry facilitators, researchers and policy makers from 21 organisations during three workshops. This workshop feedback enabled further testing and elaboration of promising policy pathways for climate-smart agricultural intensification.

Outcomes

Analysis of findings resulted in four promising response. These pathways were focused on: risk management; efficiency (expressed as eco-efficiency); habitat and biodiversity enrichment; and a value shift (in marketing pastoral commodities).

Conclusions suggest that no single intensification trajectory can future-proof New Zealand's pastoral farming. De-intensification will build resilience and reduce environmental risks in some locations and conditions, while accelerated intensification can deliver more resilient production in other locations if coupled with climate-smart mechanisms. A number of policy recommendations were generated from the research findings:

- Recognising the imperative to address climate change as a business risk – primarily in terms of facilitating adaptation and resilience in management systems, and also paying attention to eventual mitigations.
- Prioritising adaptation responses over mitigation, given the need to address the impacts of climate change and the more immediate interests of stakeholders
- Establishing a lexicon of terms related to intensification and climate change response, to ensure a consistent message, common understandings and coherent effort towards the goal of climate smart agriculture.
- Leverage existing initiatives to promote climate-smart agriculture, including risk management, adaptive management, efficiency, market and regulatory initiatives.

Operationalising resilience in dairy agroecosystems

Key organisation: Landcare Research
Named partners: Dairy NZ
Main audience: MPI
Lead author: Cradock-Henry, NA

Total funding: $150,000
Duration: 2011-13
Project code: LCR30847

Summary

The report develops a novel framework for assessing resilience in the dairy-agroecosystems. It uses an empirical case study and indicator approach. The study undertook a literature review of agricultural and resilience research and key informant interviews to develop a model of a resilient dairy farm to climate change based on draft set of key indicators. The indicators framework was operationalised for 15 dairy farms in the Bay of Plenty, using interviews, surveys, and farmer workshops. The report is not captured in the project leader survey. The research discusses actions and decision-making in light of climate change

Project components

The research aims to support the dairy sector in strategic risk identification and mitigation by: improving understanding of the vulnerabilities and resilience of Bay of Plenty dairy farms to the impacts of climate change with a focus on persistent drought; evaluating the comparative resilience between organic, low-input and high-input, intensive dairy production systems; and in addition, contributing to international research exploring resilience as a conceptual and methodological framework. To achieve these aims the study: identifies the key components of dairy farm systems that most influenced a farm's resilience to the impacts of climate change and more specifically to persistent drought; uses these components as indicators to compare resilience from difference farm production systems to the region-specific stressors related to climate change; develops, tests, and refines a conceptual model of farm level resilience that can be further tested on different pressure states (e.g. market, policy, or oil price shocks) and different agricultural farm types (e.g. sheep, beef, dairy).

Outcomes

The report findings demonstrated the need to support further research on adaptation at a local and regional level. The research has also alluded to the need for a bottom-up approach with respect to policy development. Many of the agricultural producers who participated in this research identified as a source of future risk the apparent disconnection between policy formulation and implementation.

Climate Smart Intensification options for New Zealand Pastoral Farmers: A farmer's guide to intensification options in the Context of Climate Change

Key organisation: Argos
Total funding: $471,168
Named partners: The AgriBusiness Group, Lincoln University, The University of Otago.
Duration: 2012-14
Main audience: Pastoral Farmers
Project code: ABGG20946
Lead author: McCusker, K.

Summary

The report offers a farmer's guide to intensification options in the context of climate change. The project collates data on the threats and opportunities of farm intensification in the context of climate change and promotes the practice of Climate Smart Agriculture (CSA). Farmers (47) and industry representatives (20) were interviewed as part of the project. Three regional workshops were also carried out involving key policy makers from government, industry and the farming community. They provided feedback on policy and on-farm practices to encourage climate smart farming. The report is not captured in the project leader survey. The research presents options for decision-making and taking action in response to climate change.

Project components

The primary research methods included semi-structured interviews with farmers and industry representatives and three regional workshops involving key policy makers from government, industry and the farming community, who provided feedback on policy and on-farm practices to encourage climate-smart farming.

Outcomes

The farmer guide provides a number of key messages based on the research including:

- A changing climate will bring both threats and opportunities for New Zealand farmers. Small changes in average temperature can lead to large changes in the frequency of extreme events (heavy rainfall, drought or very high temperatures).
- Given that climate variability is increasing, vulnerability to climate change will increase unless coupled with adoption of new strategies for Climate-Smart Agricultural (CSA) intensification.
- Increasing the intensity of farm production may create increased economic risks and exposure to additional impacts from more frequent extreme weather events. Dependence on externally sourced feed supplies may bring exposure to climate change and market pressures outside New Zealand farmers' control.

Detection of historical changes in pasture growth and attribution to climate change

Key organisation: AgResearch
Named partners:
Main audience: Academic audience (published in academic Journal)
Lead author: Newton, P

Total funding: $148,010
Duration: 2012-14
Project code: AGR30675

Summary

This academic research paper considers changes in pasture yield over the period of 1960-2004 in a dataset from a trial in New Zealand where management was constant over time. The modelling identified CO_2, soil properties and their interaction as the most influential variables. The results instil confidence in experimental estimates of the CO_2 fertilisation effect, particularly at low levels of CO_2 enrichment, and provide evidence that climate change impacts are already in progress. The journal publication is not captured in the project leader survey. The publication focuses on the impacts of climate change.

Project components

The data for the study are taken from an experiment on the Winchmore Irrigation Research Station, Canterbury, New Zealand. High quality plant, soil and climate data from 1960 to 2004 were used in the study. Consistent site management was maintained over the duration of the experiment. The experiment used a combination of on-site measurements and statistical analysis to analyse trends in the climate data that may have an explanatory value. A pasture growth model (*AgPasture*) was implemented in the Agricultural Productivity System Simulator (APSIM). This allowed the researchers to model temperate pastures with a mix of plant species.

Outcomes

The following high level results for the study were reported:

- The statistical modelling results report that pasture production in spring was consistently greater than in other seasons and contributed 56% on average to total annual production.
- The spring data showed a significant trend in atmospheric CO_2 concentration, an apparent but non-significant increasing trend in rainfall and no trends in minimum temperature, or radiation. Consequently it was not surprising that positive relationships between climatic variables and pasture yield were only evident for rainfall and CO_2.
- The modelling approach reported an overall positive trend in pasture yield during spring but the model output showed smaller year-to-year variations than the actual data.
- Soil properties were a stronger influence on pasture yield than CO_2, but the effect of combining both CO_2 and soil properties were more than additive.

Defining Climate Adaptive Forage Traits and Genetic Resources

Key organisation: AgResearch
Named partners:
Main audience: Pastoral and arable farmers
Lead author: Crush, J.

Total funding: $500,000
Duration: 2012-14
Project code: AGR 30811

Summary

The research records responses to eight different perennial ryegrass cultivars to elevated CO_2 levels. The results are designed to help with plant breeding strategies for different climate scenarios. Growth of the ryegrass was not changed under elevated CO_2 but flowering dates were altered substantially. The report focuses on the impacts of climate change.

This report was captured in the project leader survey. Core research expertise in the project was in plant physiology and genomic analysis. The project team reported moderate to low engagement with stakeholders throughout the project. The project used monitoring and evaluation during the project to adjust milestones, activities and outcomes. The project findings were presented at an international conference. Knowledge exchange beyond the life of the project was not reported.

Project components

Responses to elevated CO_2 were recorded for eight perennial ryegrass cultivars. The experiment was conducted at the Free-air CO_2 Enrichment (FACE) site at Flock House, in the Rangitikei. The site consists of experimental areas that are exposed to either ambient CO_2 or the CO_2 concentration of 500 ppm (considered a likely concentration level for 2050). In the experiment the effect of elevated CO_2 on growth and endophyte metabolites was tested for different ryegrass populations in a field experiment. Ryegrass shoot dry weights (DW) were recorded on 11 occasions between September 2013 and July 2014, by clipping, oven drying and weighing.

Outcomes

The analysis of shoot dry weight data over all harvests revealed no significant effect of CO_2 concentration, but highly significant effects of cultivar type, phosphate treatment and endophyte status. Analysis of the individual harvest date data for shoot DW showed that the CO_2 effect was significant on only one of the 11 dates and cultivar effects were consistently highly significant. Flowering dates were also measured on the cultivars ion the same experimental system. Plants were checked every second day for seed head emergence. The date when there were three seed heads per plant was recorded as the flowering or heading date. There was a significant cultivar and CO_2 level interaction for the time of flowering. The cultivars that headed earlier under ambient CO_2 tended to head even earlier under elevated CO_2, but the later flowering cultivars at ambient CO_2 levels delayed flower further under elevated CO_2. This increased the span of heading dates across the cultivars from about 10 to 26 days.

Effects of climate change on current and potential biosecurity pests and diseases in New Zealand

Key organisation: AgResearch
Named partners: Scion, Landcare Research, Plant & Food Research, NIWA
Main audience: All Primary Industries
Lead author: Kean, J

Total funding: $150,000
Duration: 2013-15

Project code: AGR131403

Summary

The research provides a summary of the potential impacts of climate change on exogenous pests, weeds, and diseases entering New Zealand. Research results were reported in a meaningful way that facilitated their use for biosecurity risk analysis. The authors created an online database of previously published CLIMEX models that allows potential species distributions to projected at high (~5 km) resolution under a range of current and future climate scenarios. The report focuses on the impacts of climate change.

This report was captured in the project leader survey. Core research expertise in the project was in biology; pest and weed ecologists across a wide range of terrestrial sectors. Climatologists were also involved in the project. There were high levels of stakeholder and end-user engagement reported during the question framing and design of the project. The project generated a web-based tool that spurred the development of a similar approach by a scientific software developer in Australia. It has also led to an international working group implementing a similar web database to capture and summarise knowledge. Some of the report suggestions for further work have been adopted by other research projects.

Project components

The work synthesises knowledge on the effect of climate change on current and potential biosecurity pests and diseases in New Zealand. This process was aided by a workshop held in 2014 involving experts from all of the land-based Crown Research Institutes, plus Lincoln University and the Ministry for Primary Industries (MPI).

Outcomes

The two main drivers for changes in biosecurity risks are shifts in introduction pathway and climate change. There is a need to continue to monitor and revise future climate projections to enable long-term planning for adapting to climate change. Biosecurity risks are also subject to other influences that may be more difficult to predict beyond one to two decades. A brief analysis of current trends in global and New Zealand trade speculates that north-east Asia is likely to dominate pest import pathways in the future, with increasing risks associated with India, South America and other emerging economies. General pathways risk management interventions were reported to have a reasonable change of successfully excluding many pest and diseases. However, there was an identified need for the specific consideration of some new taxa, especially “hitchhiker species, which are difficult to manage in this way.

Flood Risk under Climate Change

Key organisation: NIWA
Named partners: Victoria University of Wellington
Main audience: All Primary Industries (except mining)
Lead author: McMillan, H

Total funding: $150,000
Duration: 2008-10
Project code: C01X0815

Summary

This report presents a framework of climate scenarios and hydrological models combined to look at changes to frequency and strength of floods during climate change. Results of the modelling are presented through two case study catchments of the Waihou and Uawa rivers.

The research focuses on the impacts of climate change. The report was not captured in the project leader survey

Project components

The project developed a framework using dynamically-downscaled climate scenarios, together with precipitation and hydrological modelling, to predict changes in frequency and magnitude of floods under climate change. The project was intended as a pilot study to design and test the framework for use in New Zealand.

Outcomes

Summary results are provided for seasonal an annual rainfall trends; changes in seasonal extreme rainfall; and changes in flood frequency for 30 year and 1,000 year data. The results are based on A2 (high emissions) and B2 (moderate emissions) scenarios from a single Global Climate Model (HadCM3 from the UK Met Office). The authors indicate a need for further research to understand how the scenarios studies fit into the range of alternative climate scenarios and Global Climate Models.

In both case study locations studied annual and seasonal rainfall totals are expected to decrease under climate change between -5% and -20% of current totals. Spring rainfalls are predicted to be most severely reduced; while rainfalls during autumn and winter are predicted to be less severely affected.

In the Uawa catchment the overall pattern suggests a drier climate but with more severe storm and flood events. This is echoed in the Waihou catchment. However, under the more extreme climate scenario the Waihou catchment increase in rainfall extremes are less severe, which the authors' hypothesis may be due to an overall decrease in rainfall.

In both catchments flood return periods are seen to increase overall with variations dependent on scenario.

Scenarios of Storminess and Regional Wind Extremes under Climate Change

Key organisation: NIWA
Named partners:
Main audience: All Primary Industries (except mining)
Lead author: Mullan, B

Total funding: $150,000
Duration: 2009-11
Project code: WLG2010-31

Summary

This research report uses models to predict changes to frequency of extreme wind events under climate change. Results indicate that extreme winds will increase in all regions over winter, but will decrease over summer. The report is focused on the impacts of climate change. This report was not captured in the project leader survey.

Project components

The research used several parallel and complementary approaches involving low resolution global model pressure and wind fields, and high resolution three-dimensional dynamical output from the NIWA regional climate model (RCM). This approach allowed the authors to build up a picture of projected change in: prevailing winds and weather patterns, storm frequency and intensity, extreme winds, and severe convective weather.

Outcomes

The principle findings suggest that, based on multiple lines of investigation, the frequency of extreme winds over this century is likely to increase in almost all regions of New Zealand in winter, and decrease in summer especially for the Wellington region and the South Island. However, the magnitude of the increase in extreme wind speed is not large – only a few per cent by the end of the century under the middle-of-the-range A1B emission scenario. Furthermore, is it likely that there will also be an increase in cyclone activity over the Tasman Sea in summer and a decrease in activity south of New Zealand. Cyclone refers to a sub-tropical or mid-latitude low pressure centre and not a tropical cyclone in this report.

An increase in the frequency of summer extreme winds, associated with increased blocking weather types, could occur in Northland, Coromandel, Bay of Plenty, Gisborne and Taranaki. In winter, the reverse case is projected.

An analysis of cyclone frequency has confirmed results from previous studies showing that there is likely to be a poleward shift in the cyclone track in a future, warmer climate. In the New Zealand context, this equates to a reduction in the number of cyclones over the North Island and to the east of the country in winter, with the chance of slightly increased cyclone frequency to the south of the country. In summer, however, it is likely that there will be increased cyclone activity over the Tasman Sea and a decrease in activity south of New Zealand.

Four Degrees of Global Warming: Effects on the New Zealand Primary Sector

Key organisation: NIWA
Named partners: GNS Science, Landcare Research, Scion, Dairy NZ, Rezare Systems.
Main audience: All Primary Industries (except mining)
Lead author: Renwick, J

Total funding: $149,565
Duration: 2011-13

Project code: C01X1101

Summary

The research examines the impacts of climate change on the New Zealand Primary Sector and also explores the implications of those impacts. The report examines a number of issues under the assumption of a 4 degree rise in global average temperature by 2100. The work includes growing days and frosts, extreme rainfall and flooding events, pasture growth, forestry, and animal heat stress.

This report was captured in the project leader survey. Research expertise included climate scientists, agricultural modellers, forestry scientists, and expertise from the dairy sector. The project leaders reported low levels of stakeholder engagement. There were no identified early career researchers involved in the project. The research findings were disseminated through a conference in New Zealand.

Project components

The results from two global climate models exhibiting four degrees of global mean surface warming (over the coming century) were downscales for New Zealand and applied to a range of models relevant to the primary sector. The research covered: basic climate changes; growing degree-days and frosts; extreme rainfalls and river flow/flood flows; pasture growth; forestry; and animal heat stress.

Outcomes

The following headline results were reported:

- Temperature rises were projected to be largest in inland and eastern areas. Seasonally, temperature rises were projected to be largest in winter and smallest in summer.
- Overall, there were large increases in growing degree days and frost-free period. Frosts occurrence ceases at most lowland sites of both Islands.
- Extreme rainfalls were assumed to increase by between 50 and 150mm in many locations. The is driven by an 8% rise in saturation atmospheric moisture content per degree of global warming.
- Significant changes in seasonality of pasture growth are projected, generally with increases in winter (temperature rise) and decreases in summer (reduced soil moisture).
- Heat load is projected to increase to an extent that dairy cows would experience significant thermal stress in many dairying areas of New Zealand. Summers with 20 or more days of conditions that induce heat stress days are projected to become widespread.

Framework for Assessment of Climate Impacts on New Zealand's Hydrological Systems

Key organisation: GNS Science
Named partners:
Main audience: Freshwater dependent primary sectors
Lead author: Zemansky, G

Total funding: $150,000
Duration: 2008-10
Project code: C05X0901

Summary

The report identifies trends in hydrological systems in conjunction with climate change predictions. It develops a conceptual framework for assessment of climate change on hydrological systems, carries out a literature review of previously detected impacts, and includes an empirical case study to test its conceptual framework. This research is focused on the impacts of climate change and does not move into exploring implications or decision-making. This report was not captured in the project leader survey.

Project components

The objective of the research was to develop a conceptual framework for the assessment of the effect of climate change on hydrological systems in New Zealand. A literature review was first carried out emphasizing the types of impacts previously detected and methods for detecting and modelling impacts. The framework was developed and then applied to test catchment Waimea Plains to assess the effect of climate change. Hydrological and socioeconomic models were developed and implemented to relate possible climate change to derived changes in water availability and economic productivity within the test catchment. The conceptual framework included; analysis of historic time series climate and hydrological monitoring data; climate and hydrological modelling; and socioeconomic modelling.

Outcomes

The following recommendations were advanced:

- It is important to develop long-term climate, hydrological, and socioeconomic data sets for future analysis. Lack of such data at time of writing was considered a major limitation on the application of any conceptual framework for analysis.
- New modelling approaches should be incorporated into this conceptual framework as they become available. In particular, AI modelling techniques have a great potential to contribute to or replace mechanistic modelling approaches.
- The state of the art of socioeconomic modelling and the availability of relevant data are relatively poor compared to climate and hydrological modelling. Therefore, there is a need for greater effort to develop meaningful models and databases to use with them.
- A comprehensive land use database is a priority. Efforts in this area in other countries should be considered and, where appropriate, adopted for use in New Zealand.
- Measures should be instituted to ensure the quality of climate and hydrological databases.

Farm-level adaptive capacity to climate change: the role of financial strategies and financial institutions in Australia

Key organisation: Victorian Government's Department of Primary Industries
Named partners:
Main audience: Stakeholders interested in climate finance
Lead author: Fitzsimons, P

Total funding: $150,000 (linked with next report)
Duration: 2010-2012
Project code: C09X1005

Summary

This report identifies the opportunities and challenges to financial adaptation in Australia's primary industries. It uses Qualitative data to examine how Australian federal and state policy analysts view financial adaptation to climate change in Australia. This report discusses decision-making and taking action in the face of climate change. This report was not captured in the project leader survey.

Project components

This report focuses on the policy objectives of Australian governments and their support for institutions who are engaged in agriculture's adaptation to climate change, in particular, their financial adaptation. The views of Australian federal and state government policy analysts were sought through extensive one-on-one interviews, with the aim of providing insight into the key policies that influence financial adaptation to climate change in Australia. The outcome provides both a broad perspective on the overall strategic direction of government policy within Australia as well as providing an industry perspective particularly in dairy and horticulture.

Outcomes

Australian governments support agriculture's financial adaptation to climate change in a range of ways, either through market based mechanisms, such as water pricing policies or through extension activities such as the new pilot of drought reform measures being trialled in Western Australia.

The dairy and horticulture industries treat climate change as a subconscious issue but are pragmatically adopting adaptation initiatives driven by a short term focus on water allocation, water trading or heat stress initiatives rather than consideration of more long term strategic objectives. New water pricing reforms in Victoria have transferred the risk of managing water security onto farmers. Whilst this brings opportunities for farmers with a high risk threshold, this may bring additional stress to risk adverse farmers.

There are market tools available in the insurance industry but the uptake is limited, predominantly due to the high cost of the premiums and the exclusion of drought and floods.

There is a role for government to work with banks in managing the exit of farmers from the industry, whilst also providing climate data and developing their awareness of the profitability of a broad range of farm enterprises.

Impacts of climate change on erosion and erosion control methods - A critical review

Key organisation: Landcare Research
Named partners: NIWA, GNS Science, Plant and Food, AgResearch, Scion
Total funding: $150,000
Duration: 2010-12
Project code: C09X1102
Main audience: Stakeholders interested in land management (erosion)
Lead author: Basher, L

Summary

This report focuses on impacts of climate change on erosion and erosion control methods. The report identifies areas of New Zealand most susceptible to erosion given climate change predictions. It summarises literature which links erosion processes to climate drivers drawing on data on climate projections from NIWA. It does not look into decision-making and taking action. This report was captured in the project leader survey. The research team included geomorphologists, meteorologists, soil scientists, and erosion mitigation specialists. There were no identified early career researchers included in the project. The project outputs were disseminated through the final report and newsletter published on the MPI website. The aim of the report was to review existing science and knowledge for policy. The project outputs were used to inform a subsequent project focused on forest management approaches to steep hills.

Project components

The project includes a literature review on the impact of climate and climate change on erosion processes and erosion control in New Zealand, as well as relevant recent international literature on the topic. The research use data from the New Zealand Land Resource Inventory (NZLRI) to illustrate the distribution and severity of different erosion processes. Predictions of changes in rainfall, wind and drought with climate change were intersected with maps of potential forms of erosion from the NZLRI to identify areas most susceptible to climate change impacts in New Zealand.

Outcomes

The authors make a number of recommendations:

Erosion processes and modelling

- Improve probabilistic models for landsliding and rainfall to underpin quantitative assessments of the impact of climate change.
- Develop more reliable approaches for predicting likely changes to extreme rainfalls in drier areas and obtain better information on likely frequency and severity of extra-tropical cyclones with climate change.

Erosion control

- Develop and test on-farm watering systems to enhance survival of poplar and willow poles during the establishment years, or develop alternative establishment technologies.
- Identify alternative clones of poplars and willows, or alternative species that better cope with dry conditions.

Improving sustainable lifetime performance of pastures: Learning from extreme climatic events

Key organisation: AgResearch
Named partners: Landcare Research
Main audience: Pasture-based farmers
Lead author: Tozer, K

Total funding: $125,321
Duration: 2011
Project code: C10X0825

Summary

Projected increases in temperature and incidences of droughts and floods are likely to make pastures more vulnerable to weeds. The report authors cite evidence that increasing the diversity of sown pasture species can increase pasture resilience and resistance to invasion of weeds under different climatic conditions. The research tests that hypothesis that increasing diversity of sown species can reduce ingress of unsown species as pastures age.

The report findings suggest there is evidence that increasing species diversity improves persistence of sown species. The work is focused on climate change impacts. It was not captured in the project leader survey.

Project components

The project uses on-farm studies in different regions throughout New Zealand to investigate the relationships between sown functional diversity, pasture age and ingress of unsown species. Waikato's once is one hundred year drought (2007-2008) that was followed by an extremely wet winter (2008), also provided the researchers with a unique opportunity to assess the impact of these extreme climate events on between-year shifts in botanical composition. Thirty paddocks were selected in each of 4 regions: Northland (sheep, beef), Waikato (dairy), Taranaki (dairy) and North Canterbury (sheep, beef, deer), which ranged in age and in the sown mix (grasses and legumes vs. grasses and legumes and herbs). In each paddock, the botanical composition and dry matter content of the different pasture species was assessed. Soil nutrient status and endophyte presence was also assessed in a subsample of paddocks within each region.

Outcomes

There was evidence that increasing species diversity improved persistence of sown species in Northland, thus reducing the ingress of unsown species. This was further supported by the trend in Waikato pastures, inferring that increasing diversity may help to reduce weed ingress after severe climatic events, such as the severe Waikato drought.

Farmax DairyPro modelling also indicated that including a sown herb such as chicory in the pasture has the potential to provide high quality feed at a time of year when pasture growth is generally slow and of low quality. The models identified an increase in operating profit of $161/ha when chicory is included in the pasture mix. This increase in operating profit occurred due to a reduction in the use of high energy imported supplementary feed.

Tomorrow's pastures: subtropical grass growth under climate change

Key organisation: AgResearch
Named partners:
Main audience: Pasture-based Primary Industries
Lead author: Dodd, M

Total funding: $140,000
Duration: 2007-09
Project code: C10X0826

Summary

This report reports on experimental work and modelling assessing the impact of increased temperature and elevated atmospheric CO_2 on the germination and growth of C4 grass species relevant to New Zealand. The results showed a strong response, particularly of the kikuyu (*Pennisetum*), to temperature – largely through an increased mineralisation of Nitrogen (N) for plant growth. The effect of elevated CO_2 was to dampen the mineralisation response thus leading to a CO_2 and warming interaction that reduced the stimulatory effect of temperature change. The report looks at the impacts of climate change. It was not captured in the survey project leader survey.

Project components

The study consisted of two elements: a) a series of field experiments designed to assess the germination and early growth of three C4 grass species under varying conditions of temperature and CO_2. This experiment was located at the NZ FACE facility at Flock House, Bulls; and b) a modelling exercise examining the potential effect of elevated CO_2 and warming interactions on pasture growth and forage quality using the pastoral simulation model EcoMod.

Outcomes

Previous studies of C4 distribution and performance under climate change in New Zealand have focused on the impact of changes in temperature. Here the authors show in field experiments that the increase in elevated CO2, which is more certain than changes in temperature, interacts with temperature change indirectly though modifying plant N availability. With this response captured in an ecosystem model the research team are able to show that the outcome of increasing atmospheric CO2 is to reduce the future stimulation of C4 growth expected to result from global warming. In regions where C3 grasses dominate they show that this effect reduces the costs to a farming operation by two thirds. However, it is also important to recognise that in areas where C4 grasses dominate the CO2 × warming interaction will limit the potential benefits of increasing temperature unless additional N fertiliser is applied. These results are particularly useful as we move to complete detailed impact studies of climate change impacts on farming systems throughout New Zealand.

Impact of climate change on crop pollinators in New Zealand

Key organisation: Plant and Food Research
Named partners:
Main audience: Seed Crop Stakeholders
Lead author: Howlett, B

Total funding: $150,000
Duration: 2011-13
Project code: C11X1101

Summary

The work provides evidence of how bee and insect pollination will change given a climate change prediction of a 4 degree temperature rise in 100 years. The methods include statistical analysis of data-sets including seed crop observations combined with weather data. This is an impact focused report.

This report is included in the leader survey. Stakeholders consulted on the project include Smith Seeds NZ Limited, South Pacific Seeds NZ Limited, and Seminis Vegetable Seeds NZ Limited. The writing team included research expertise in pollination, taxonomy, statistical modelling, as well as crop growing expertise provided by farmers and industry representatives. There were no identified early career researchers involved in the project. The research findings were communicated through journal publication and conference presentations in New Zealand. The findings of the research have been used to develop new research proposals.

Project components

Different pollinators are active at different times of the day and under varying climatic conditions (activity windows). Climate change may impact pollinator activity windows by altering foraging periods and also their behaviour (e.g. time spent on flowers and distances moved within and between plants). The aim of this project was to test the hypothesis that pollinator activity windows differ with changing climate (specifically a 4oC increase in temperature, but also humidity, light intensity and wind). This leads to altered pollinator abundance and diversity, and pollinator behaviour and movement. The study used an existing dataset comprising of 85,000 individual observations collected across a number of important annual seed crops, along with additional data on behaviour of insect pollinators on the crops.

Outcomes

Apart from a few species-specific anomalies, changes in climate variables (particularly temperature) were found to affect pollinator activity windows leading to a change in pollinator diversity and abundance. These data confirmed a relationship between temperature and insect pollinator activity on crops, with time of day superimposed for honeybee activity.

Other climate variables (e.g. relative humidity and light intensity) also showed relationships with some taxa; however, there were strong correlations between climatic variables themselves. Therefore, it was not possible to determine the level of direct influence each climatic variable contributed to each insect taxa.

Climate change impacts on plant diseases affecting New Zealand horticulture

Key organisation: Plant and Food Research
Named partners:
Main audience: Horticulturists
Lead author: Beresford, R.

Total funding: $150,000
Duration: 2010-12
Project code: C11X1102

Summary

The research models how temperature increases in different regions of New Zealand will affect particular horticultural diseases (e.g. apple black spot, kiwifruit PSA). The findings suggest that only the most extreme climate change predictions for 2090 will cause a noticeable increase in disease risk. Central Otago is likely to experience the greatest relative increase in disease risk, which, for apple black spot and grapevine downy mildew, may result in risks similar to that currently experienced in eastern North Island areas at the present time. This report focuses on the impacts of climate change. This report is not included in the leader survey.

Project components

The research undertook a quantitative analysis examining key diseases affecting major horticultural crop sectors using disease risk models that are in use within those sectors. The purpose was to ascertain likely changes in regional disease losses and disease control requirements arising from climate change, to allow horticultural industry sectors to carry out more robust future planning. The authors simulated future climatic conditions by modifying current weather datasets. This approach had the advantage of providing variability in future weather to enable statistical comparison of disease risk between current and future climates.

Outcomes

The paper raises some important limitations of the study and considerations:

- The disease risk changes predicted in this study were quite small, even for the worst case upper limit climate prediction. Uncertainty in predicted rainfall, the main driver of disease risk, makes it challenging to recommend adaptation strategies.
- An increase in temperature could affect disease risk in ways other than its direct effect on infection risk. For example, for apple black spot, budburst date is important in determining when primary infection by V. *inaequalis* ascospores occurs. Budburst date is affected by winter chilling, which would decrease with increasing winter temperature.
- The predominant cultivars for any crop that will be planted in 2090, or even 2040, cannot be identified at present. As the climate change time frame is well within the time frame for breeding new crop cultivars, if fruit crop breeders were able to focus on developing cultivars with lower disease susceptibility, rather than restricting efforts to improved fruit quality, the impact climate change may have on disease risk could be greatly reduced.
- For rainfall, which is particularly important for plant diseases, increased occurrence of extreme events could greatly increase disease risk in some seasons. Thus the analyses may have underestimated increases in disease risk, particularly for the worst case of upper limit changes by 2090.

Learning from Past Adaptation to Extreme Climatic Events: A Case Study of Drought

Key organisation: AgResearch
Named partners:
Main audience: All Primary Industries
Lead author: Burton, R

Total funding: $65,063
Duration: 2008
Project code: 1243

Summary

The report examines the 'tacit' knowledge (instrumental, embedded knowledge) of farmers in New Zealand. It looks at past extreme weather events to see what the best coping strategies are for future droughts. This research starts with impacts and moves into exploring implications and the decisions and actions available in the face of climate change. This report is not included in the leader survey.

Project components

Understanding how New Zealand's farmers have historically adapted to extreme climate events will play a critical role in developing effective adaptation plans for the future. This report focuses on these past adaptations of farmers to the extreme drought events. The research explores the 'strategic responses' of farmers in the regions of North Otago and South Canterbury, areas which have previously experienced extreme drought events. Having gained an understanding of what farmers have done historically to cope with drought events, this research aims to use this knowledge to develop future adaptive and mitigation strategies for New Zealand's farmers.

Outcomes

The researchers examined drought management knowledge that is personal, experience based, and context dependent. Using semi-structured interviews the researchers sought to create a typology of drought response. Researchers discovered no "best strategy" for drought response but rather but rather a collection of strategies that dryland farmers in North Otago/South Canterbury have developed over many years in response to drought events. Three key issues farmers need to deal with to build a drought resistant farm were identified: (1) Farmers need to develop the farm such that it is able to resist drought (should it occur) as well as build up resources that may be needed to fight drought in future years; (2) Farmers need to develop a farming system that provides them with some flexibility to deal with drought when it occurs (to act immediately and effectively) and (3) Once the drought is perceived the farmer must have strategies capable of dealing directly with the drought situation and minimising the impact of the drought on livestock, capital and family.

Selecting the best strategies for any individual farm requires that the farmer considers the context of his/her own farm (climate, soils, labour supply, and so on). Additionally, Asking farmers to think back on historical droughts and discuss how they were affected (and responded) at the time revealed how important the context of the drought is on farmers' experience of drought.

Improved Field Facilities to Study Climate Change Impacts and Adaptations in Pasture

Key organisation: AgResearch
Named partners:
Main audience: All Primary Industries
Lead author: Lieffering, M.

Total funding: $51,030
Duration: 2008
Project code: 1253

Summary

The research aims to extend the understanding of climate change on New Zealand pastoral systems by introducing a warming element to the NZ Free-air CO_2 Enrichment (FACE) site at Flock House, in the Rangitikei. The researchers installed and tested a passive warming system for use in their grassland system. This is an impact focused research report.

This report was not included in the leader survey.

Project components

The project is concerned with the design, installation and testing of a passive warming system for use in grassland experimental system.

Outcomes

The system was deemed to warm to adequate levels in a biologically meaningful way that is cost effective and does not interfere with grazing protocols. The testing phase indicates that the levels of warming achieved will be up to 1 °C at 5 cm soil depth: this is in line with the most likely future climate change scenarios.

Enhanced modelling capability to conduct climate change impact assessments

Key organisation: AgResearch
Named partners:
Main audience: Pastoral and Arable Farmers
Lead author: Newton, P

Total funding: $61,314
Duration: 2008
Project code: 1263

Summary

The researches use farm-scale modelling to see how farms can remain profitable under climate change scenarios. The results are combined with farm nutrient model OVERSEER® to predict what the environmental impacts of these adaptations would be. This report focuses on the impacts of climate change. This report was not included in the leader survey.

Project components

The research uses an ecosystems mode and a farm systems model to examine adaptation options at a farm scale. The biophysical model, EcoMod, is used to project monthly pasture growth rates for future climate and CO_2 scenarios. A farm system model, FARMAX® suite, is then used to create pasture growth projections and explore detailed short and long term management options to crease profitable systems. Additionally the model OVERSEER® is used to determine the environmental impact of the adapted farm system.

Outcomes

The following summary results are presented:

- EcoMod now realistically represents the major emergent properties arising from climate change that have been documented in the literature. These include altered pasture composition, temporal shifts in pasture growth, altered water use efficiency due to changes in stomatal conductance, and reduced availability of mineral nitrogen.
- Existing features of the FARMAX® suite, and proposed developments, will allow researchers to easily determine the effect (production, economic and social) of climate change on sheep/beef and dairy systems and to explore the adaptive capacity of these systems. The environmental consequences of these adapted systems can then be determined using OVERSEER®.
- Features to facilitate the easier transfer of data from one model to the next have been developed or are under development. These include the integration of EcoMod into APSIM's framework which will ensure simulations with different weather files can run easily, and export pasture growth rates for integration into the FARMAX® suite.
- Further research is necessary to refine the ecosystem model projections and to include other factors such as impacts on pests and animal parasites but the components to establish the necessary framework and links are present and improvements can be made as new information becomes available.
- Farm-scale assessment will provide impact information unlike anything previously produced; this is a particularly powerful scale to explore because it is the scale at which farming decisions are made and therefore connects directly into adoption and adaptation.

Projected Effects of Climate Change on Water Supply Reliability in Mid-Canterbury

Key organisation: Aqualinc
Named partners:
Main audience: Canterbury Pastoral and Arable Farmers
Lead author: Bright, J

Total funding: $722,000
Duration: 2008
Project code: C08120/1

Summary

This project report provides estimates of the potential effects of climate change on weather elements (e.g. daily rain, temperature), mean daily river flows, irrigation water demand and water supply reliability for one catchment and associated irrigated area (Rangitata River in Canterbury). This report was not included in the leader survey. This is an impact focused research report.

Project components

The changes in climate are based on the average of 12 global climate models used for the Intergovernmental Panel on Climate Change (IPCC) Fourth Assessment Report. The climate change data for 2040 have been produced by statistically downscaling global climmodel output to the grid of New Zealand's Virtual Climate Network, thus providing data every day and approximately every 5km in the study area. More than 35 years of daily climdata and river flow data (at one location) were synthesised. These data cover both current climate and a future climate (A1B emissions scenario for 2040).

Outcomes

Research results for climate change projections for 2040 within the study area indicate:

- Annual average temperatures about one degree warmer than the average for 1980–99.
- Changes in annual average precipitation range from increases of up to 400mm/year in the Rangitata headwaters to little change on the Canterbury Plains.
- Changes in annual average potential evaporation for 2040 range from increases of 60mm/year on the Canterbury Plains, to small decreases in the headwaters of the Rangitata.
- In terms of seasonal changes, the largest projected increases in precipitation for the headwaters are in winter and spring, while small changes in seasonal rainfall patterns on the Plains are projected to occur. Seasonal warming is least in spring and early summer; otherwise the warming is uniformly distributed through the year. The increases in potential evaporation are largest in spring and summer on the plains.

Daily river flow time series are provided by using a Topnet model for the Rangitata catchment upstream of the Klondyke gauging station.

Vulnerability of New Zealand pastoral farming to the impacts of future climate change on the soil water regime

Key organisation: University of Auckland
Named partners:
Main audience: Pastoral Farmers
Lead author: Fowler, A

Total funding: $51,945
Duration: 2008
Project code: 1283

Summary

The research uses a 'bottom-up' alternative (through analysis of regional-scale impacts on hydrological cycle and soil water regime) to 'top-down' climate change models. Project results suggest that the proposed 'bottom-up' methodology is appropriate. The methodology, and the specific Daily Water Balance Model (DWBM) implementation, can reasonably be used to assess the sensitivity of pasture production to climate change. This report focuses on the impacts of climate change.

This report is included in the leader survey. The writing team consisted of climatologists and hydrologists. The project had very limited engagement with stakeholders or end users from initial conception to project completion. The project provided research opportunities for a number of early career researchers (masters level). The research findings were communicated through journal publication and conference presentations in New Zealand. The research has been cited in the literature a number of times (<5).

Project components

Core to research methodology used is the idea that the sensitivity of the soil water regime and pasture productivity to future climate change is best assessed within the context of natural climate variability. To facilitate this: Multi-decadal climate time series were used to drive a daily water balance model (DWBM) of near surface hydrology; pasture productivity was calculated from modelled evaporation (excluding interception); climate change impact assessment was undertaken by superimposing simplified scenarios of future climate change onto these response surfaces; and the significance of the potential impacts was then assessed by comparing the simulated impacts with inter-annual variability.

Outcomes

The findings concluded that the proposed 'bottom-up' methodology is appropriate. The methodology, and the specific DWBM implementation, can reasonably be used to assess the sensitivity of pasture production to climate change. Extension of the analysis to all New Zealand climate regions is recommended, following some specific refinements:

- Use of more sophisticated climate change scenarios that realistically envelop plausible future climates.
- Explicit testing and refinement of the pasture production model.
- Integration of the pasture production model into the DWBM, to circumvent time consuming and error-prone manual steps

Forage crop opportunities as a result of climate change

Key organisation: Crop and Food Research
NIWA, Foundation for Arable Research
Named partners:
Main audience: Arable Farming
Lead author: Trolove, S

Total funding: $74,341
Duration: 2008
Project code: 2161

Summary

This research contrasts existing crop models with simulated weather data to look at predicted changes to forage crop production between 2040 and 2090. The results suggest that climate change causes maize yields to decline slightly in the northern regions of New Zealand (from Hamilton north), change little in the central regions, and increase as it is grown further south, particularly in Gore. The warmer winters resulting from climate change increased the biomass of winter wheat by 13–19% by 2040, and 17–38% by 2090. This is an impact focused research report.

This report is included in the leader survey. The writing team consisted of crop modellers, agronomists, and plant physiologists. There were no identified early career researchers involved in the project. The work was disseminated through conference presentations in New Zealand and the final report.

Project components

The authors used existing crop models and simulated weather data to predict the likely changes in forage crop production in 2040 and 2090. The models grew maize silage over the summer, followed by winter wheat; the biomass was then summed to give total annual biomass production. Three different management practices (sowing dates for maize) were investigated. These studies were carried out for six regions of New Zealand, represented by weather data from Kaikohe (Northland), Hamilton (Waikato), Palmerston North (Manawatu), Masterton (Wairarapa), Lincoln (Canterbury) and Gore (Southland).

Outcomes

The following results were reported:

- Climate change is predicted to have little effect on total annual biomass yields in Kaikohe (a 2% increase by 2090), but should increase yields further south.
- In general, there was little difference in total annual biomass yields between sowing maize in September or in November.
- The more detailed modelling in Northland showed that the tropical hybrid was the most productive maize, with the short-maturing hybrid the least productive.
- The modelling simulations suggested that climate change may lead to increases in biomass production if maize can be sown in early September. However, in practice this may not be feasible due to the high August rainfall in Kaikohe and the heavy soils.
- Greater returns from maize silage will tempt farmers to plant as early as possible, but this must be balanced by the risk of frost and how quickly the soil dries out over winter.
- Further modelling studies are needed to understand the impacts on forage production of more extreme or more conservative emissions scenarios. These will help the government make the policy decisions now that are necessary for a sustainable future.

Drought, Agricultural Production & Climate Change - A Way Forward to a Better Understanding

Key organisation: NIWA
Named partners:
Main audience: All Primary Industries
Lead author: Clark, A

Total funding: $63,390
Duration: 2008
Project code: WLF2008 - 23

Summary

The aim of the project is to establish clear and practical directions that will improve drought and climate change analysis for New Zealand's agriculture. The rationale is to increase awareness of drought and climate change risks, and develop a mechanism that will improve the preparedness and adaptive capacity of the agricultural sector. The key insight emerging from this project is that while New Zealand has made excellent progress in developing methodologies in climate and agricultural sciences, further work can be done in terms of integration and some key areas of specialist research. This report examines the impacts of climate change and also begins to explore some of its implications. This report is not included in the leader survey.

Project components

The focus of this project is methodological and is guided by three interrelated objectives:

1 Develop a drought analysis methodology

2 Develop an agricultural production analysis methodology

3 Run an end-user linkage workshop: to ensure that the suggested scientific methodologies and timelines described in the reports stemming from objectives 1 and 2 are aligned with the practical and policy needs of end users of this information.

Outcomes

Based on an end user workshop and review of current methodologies, the report recommends that New Zealand develop a program of research that encompasses applied risk analysis and enabling science initiatives to maintain high levels of innovation. A draft research program is developed and presented, which proposes a number of projects as a way of progressing drought and climate change risk analysis for New Zealand.

Key enabling research projects include: developing a climate change database and toolkit suitable for use by agricultural researchers; developing a drought and climate change monitoring network; continued development and application of whole farm models and integration with macroeconomic modelling systems; and development of irrigation and groundwater resource modelling capacity.

To ensure high levels of integration a number of applied analysis projects are also proposed including: estimating of trends, production and economic impacts, including updating previous drought risk analysis under climate change; assessment of drought risk management practices to examine climate change resilience; the production of fact sheets documenting specific climate change adaptations; and a national audit of irrigation water resources.

Climate Change Risks to Pastoral Production Systems

Key organisation: Landcare Research
Named partners:
Main audience: Pastoral Farmers
Lead author: Guo, J

Total funding: $19,730
Duration: 2008
Project code: LC0708/173

Summary

The aim of the research is to determine whether additional evidence supports the initial observation that New Zealand's pastoral production systems may have a substantially reduced ability to cope with environmental stress under elevated CO_2 conditions likely to be encountered with global change. The research examines three grass species in conditions of elevated carbon dioxide. The findings conclude that enhanced stress on the plants due to elevated carbon dioxide only occurs at the end of the growth cycle. This report focuses on the impacts of climate change. The report is not included in the leader survey.

Project components

To better understand the issue of elevated CO_2-induced stress, the research team analysed data available from an initial study on three grass species under two nutrient treatments at an elevated CO_2 site in the USA.

Outcomes

Results found that:

- Long-term exposure to elevated CO_2 appears to confer no net long-term advantage to overall photosynthetic performance at the US site under low nutrient conditions. This is consistent with other results from the site, and also with New Zealand studies under elevated CO_2 but with considerable higher nutrient availability.
- Grasses adapted to lower nutrient environments under elevated CO_2 do not suffer stress levels beyond those under either non-elevated CO_2 conditions or higher nutrient conditions, when actively growing with the demand for photosynthetic products being relatively high (the conditions in the US study).
- Overall, taking also the previous New Zealand study into account, if appears enhanced stress due to elevated CO_2 is likely to be present only towards the end of a growth cycle, in the mature growth phase. The research thus finds that it is not expected to be a factor significantly limiting future pastoral production, because New Zealand pastures are not expected to spend much time in the mature growth phase (i.e. they generally will be grazed at or before that point).

Recommendations for future work suggested:

- Determining at what stage in the growth cycle that elevated CO_2-induced stress becomes apparent – in particular, could it affect production of silage or hay crops that develop further into the mature phase than encountered in a normal grazing situation?
- Is the capacity of grasses to tolerate normal environmental stress during the active phase of the growth cycle affected by the presence of elevated CO_2? Could the reduced demand for photosynthetic products during environmental stress initiate additional elevated CO_2-induced stress, and result in damage to the plant's photosynthetic system?

Adapting to climate change in the kiwifruit industry

Key organisation: Earthwise Consulting
Named partners: NIWA
Main audience: Kiwifruit Farmers
Lead author: Kenny, G

Total funding: $60,200
Duration: 2008
Project code: MAF POL_2008/25

Summary

The research examines the effect of climate change on kiwifruit growers, and adaptation responses which could be made. The results of this study, founded on engagement with key kiwifruit growers, strongly reinforce this view. This study has built on a foundation of work that has focused on climate change and kiwifruit, as well as previous adaptation work with farmers and kiwifruit growers. The kiwifruit industry is currently well placed to adopt a planned, proactive, approach to adaptation. This research starts with impacts and moves into exploring implications and the decisions and actions available in the face of climate change. The report not included in leader survey.

Project components

The first component of the project comprises of a review of the current state of the knowledge on kiwifruit and climate change focusing on climate variability and change; impacts on kiwifruit; and an overview of climate change adaptation key concepts. The second component comprises on in-depth consultations on adaptation. This consultation process with 18 active growers explores current climate challenges; management tools/systems to address current climate challenges; industry responses to support adaptation; and the role of regional and central government in the process.

Outcomes

The research team suggested some key areas that need further attention:

- Communication and education throughout the industry on climate change and adaptation with a focus towards practical solutions and actions.
- Long-term strategic research aimed at making the most of the climate resource in the future and minimising risks and costs. Breeding of new varieties that require less winter chilling and produce high quality fruit. Pest and disease issues, water and the evolution of management and post-harvest systems require attention.
- The identification and realisation of marketing opportunities. There is an opportunity for the kiwifruit industry to profile positive stories in relation to climate change and adaptation.
- Water allocation issues need to be resolved for the future. At time of writing Environment Bay of Plenty was working on a Water Sustainability Strategy for the region.

The author argues the wider relevance of this work is in the grounding of current scientific knowledge with practical, forward thinking people. On the one hand people on the ground are more informed about the science and able to make it relevant and real in what they are doing and in their future planning. On the other hand the information and thinking shared by people on the ground provides insight and direction that is very relevant for the policy and science communities. It provides the opportunity to be strategic, practical, efficient and effective with our resources.

Application of high-resolution climate measurement and modelling to the adaptation of New Zealand vineyard regions to climate variability

Key organisation: University of Canterbury
Named partners: Plant and Food Research
Main audience: Viticulturists
Lead author: Sturman, A

Total funding: $500,000
Duration: 2014
Project code: UOC30915

Summary

The paper presents initial results of research into the relationship between climate variability and viticulture production in New Zealand. The research involves application of advanced local and regional scale weather and climate models, and their integration with grapevine phenological and crop models. The aim was to produce information which could help grape growers avoid risk factors such as frost, and extreme temperatures. This report focuses on the impacts of climate change. The report is not included in leader survey.

Project components

The key aims of the research are to improve adaptation of grape varieties to fine scale spatial variations of climate, and reduce the impact of climate variation and risk factors such as frost, cool spells and high temperatures. Research methods includes the use of an enhanced network of automatics weather stations (AWS) in the Marlborough region and a Weather Research and Forecasting (WRF) model set up to run twice daily at a 1km resolution through the growing season.

Outcomes

Findings suggest that spatial patterns of predicted air temperature and bioclimatic indices appear to accurately represent the significant spatial variability caused by the complex terrain of the Marlborough region. The results demonstrate the feasibility of applying advanced weather/climate modelling techniques to improve understanding of the relationship between viticulture and the climatic environment, so that wine production can be better adapted to climate variability.

Impacts, indicators and thresholds in sheep-and-beef land management systems

Key organisation: Landcare Research
Named partners: Beef & Lamb NZ
Main audience: Sheep and Beef Farmers
Lead author: Cradock-Henry, N

Total funding: $ 150,000
Duration: 2014-15
Project code: LCR131408

Summary

The report draws on stability landscape model to characterise resilience in sheep-and-beef land management systems, and then develops indicators-based evaluation framework. This research starts with impacts and moves into exploring implications and the decisions and actions available in the face of climate change. The report is not included in leader survey.

Project components

The key aims were to produce insights into the resilience sheep and beef farming systems to climate change, by identifying farm level indicators using proxies or surrogates for resilience to expose farm-level exposure and sensitivity, creating a framework to assist farmers to monitor and evaluate their enterprises position with respect to critical decision thresholds and finally to exploring the practical application of resilience in place. The research was undertaken through deliberation and consultation with stakeholders and applied quantitative economic modelling, specially in Canterbury, Hawke's Bay and Northland

Outcomes

Key finding include the development of 19 quantitative indicators, based on surrogate measures for the resilience of social, economic, ecological and governance dimensions of farm operations. Indicators which could be applied by landowners, paid consultants or industry representative to assess future resilience of farm operations by providing insight into a farm's resistance, latitude and precariousness in relation to climate change. This assessment approach can help the sheep and beef sector identify system vulnerabilities and risks, and develop and support specific adaptation or resilience-building strategies.

In addition, the process of methodology development itself is of value to other sectors and regions.

Appendix C - Systematic review and annotated bibliography

Systematic Review of review of adaptation research in New Zealand primary industries

A systematic review of adaptation research in NZ primary industries was carried out and identified a totally of 22 research papers/reports met the requisite criteria (Table A1). Papers and reports meeting the criteria were drawn from four research databases.

Table A 1. Returns documented for ISI Web of Science, Climate Cloud, CAB Abstracts, and Academic Search Complete databases

	Databases			
Subset	ISI Web of Science	Climate Cloud	CAB Abstracts	Academic Search Complete
All returns	180	123	164	158
After de-duplication	180	123	159	158
After title screen	88	35	38	8
After abstract read/article scan	23	19	14	4
Final considered	12	8	6	3
Final considered once duplicates removed	22			

An iInitial summary analysis of the papers/reports (Table A2) ranks the papers in order of citation count as measured by Google Scholar. Lead authors are indicated as well as the year of publication and the journal where the paper was published. The largest number of papers are published in *Climatic Change* (4) and *Regional Environmental Change* (2).

Table A 2. Included studies in order of citation count (Highest to lowest as measured by Google Scholar as of June 9th 2017)

Author(s)	Title	Journal	Year	Citations
King et al.	Māori environmental knowledge of local weather and climate change in Aotearoa - New Zealand	Climatic Change	2008	57
Kalaugher et al.	An integrated biophysical and socio-economic framework for analysis of climate change adaptation strategies: The case of a New Zealand dairy farming system	Environmental Modelling and Software	2013	42
Niles et al.	How limiting factors drive agricultural adaptation to climate change	Agriculture, Ecosystems and Environment	2015	29
Kenny	Adaptation in agriculture: Lessons for Resilience from eastern regions of New Zealand	Climatic Change	2011	28
Lee et al.	Climate-change effects and adaptation options for temperate pasture-based dairy farming systems	Journal of British Grassland Society	2013	21

Zhang et al.	Spatially explicit modelling of the impact of climate changes on pasture production in North Island New Zealand	Climatic Change	2007	19
Sturman and Quenol	Changes in atmospheric circulation and temperature trends in major vineyard regions of New Zealand	International Journal of Climatology	2013	17
Sylvester-Bradley and Riffkin	Designing resource-efficient ideotypes for new cropping conditions: Wheat (*Triticum aestivum L.*) in the High Rainfall Zone of southern Australia	Field Crops Research	2012	17
Prokopy et al.	Farmers and Climate Change: A Cross-National Comparison of Beliefs and Risk Perceptions in High-Income Countries	Environmental Management	2015	14
Orwin et al.	Effects of climate change on the delivery of soil-mediated ecosystem services within the primary sector in temperate ecosystems: a review and New Zealand case study	Global Change Biology	2015	11
Niles et al.	Farmer's intended and actual adoption of climate mitigation and adaptation strategies	Climatic Change	2016	9
Manning et al.	Dealing with changing risks: a New Zealand perspective on climate change adaptation	Regional Environmental Change	2015	10
Cradock-Henry	Exploring Perceptions of Risks and Vulnerability To Climate Change in New Zealand Agriculture	Political Science	2008	7
Gray et al.	The management of risk in a dryland environment	Proceedings of the New Zealand Grassland Association	2011	7
Keller et al.	Grassland production under global change scenarios for New Zealand pastoral agriculture	Geoscientific Model Development	2014	5
Fowler et al.	Vulnerability of pastoral farming in Hawke's Bay to future climate change: Development of a pre-screening (bottom-up) methodology	New Zealand Geographer	2013	4
Hopkins et al.	Climate change and Aotearoa New Zealand	WIRES Climate Change	2015	4
Weller et al.	Retaining Adaptive Capacity in New Zealand's ecological systems	New Zealand Journal of Agricultural Research	2008	3
Weaver	Climate change and food security	Institute of Policy Studies Working Paper	2008	2
Cradock-Henry	New Zealand Kiwifruit growers' vulnerability to climate and other stressors	Regional Environmental Change	2016	1
Lieffering et al.	Exploring climate change impacts and adaptations of extensive pastoral agricultural systems by combining biophysical simulation and farm system models	Agricultural Systems	2016	1
Nettle et al.	Empowering farmers for increased resilience in uncertain times	Animal Production Science	2015	1

Annotated Bibliography

The following section provides an annotated bibliography of the 22 white literature papers listed alphabetically. For each paper the overall purpose, as well as a summary of research methods, and results are provided.

Cradock-Henry, N. (2016) New Zealand kiwifruit growers' vulnerability to climate and other stressors *Regional Environmental Change*

Purpose

Development and application of a ''bottom-up'' contextual vulnerability assessment concerning the, economically significant, commercial cultivation of kiwifruit on the North Island of New Zealand to complement existing linear outcome-orientated vulnerability frameworks.

Methods

In-depth, semi structured interviews with kiwifruit growers and orchard managers, workshops and analysis of secondary data.

Results

Climate and markets are the main sources of exposure for growers, with sensitivity moderated by location. Growers employ mostly short-term, reactive adaptive strategies to manage climate exposure and sensitivity, but have less capacity to respond to market-related stressors. Warmer and drier conditions are likely to have adverse effects for kiwifruit production and compound existing vulnerabilities. An ageing population and other processes of rural change may also constrain future adaptation. In order to realise opportunities and minimise losses, longer term strategic responses are required. The paper provides a basis for further consideration of multiple exogenous impacts in the industry and confirms the critical importance of qualitatively vulnerability assessments to determine spatially specific outcomes.

Cradock-Henry, N. (2008) Exploring Perceptions of Risks and Vulnerability To Climate Change in New Zealand Agriculture *Political Science*

Purpose

This paper aims to identify the vulnerabilities and adaptive capacities of agricultural producers in the Rangitaiki Plains area, in the Eastern Bay of Plenty on the North Island, in order to contribute to the development of effective strategies to assist farmers in adapting to climate change.

Methods

Interviews and focus groups documenting farmers' management decisions, and the forces and pressures underlie them. Recruitment of interviewees was through farm and industry organisations. The approach was based on agricultural decision-making, rather than a research framework explicitly considering climate change.

Results

The research documented the combined impact on farmers of the 2007/2008 drought and the unprecedented demand for dairy products that season. Many of the agricultural producers interviewed, in addition to perceiving a risk from climate change, felt threatened by a growing disconnect between decisions made by central government, and the farm-gate, where those policies have their biggest impact. Due to factors including rising fuel and fertilizer costs, increased competition from lower cost producers, stricter compliance rules for sale to export markets such as the European Union (EU), and carbon trading schemes interviewees indicated that agriculture in New Zealand faces a range of challenges on several fronts.

Fowler et al. (2013) Vulnerability of pastoral farming in Hawke's Bay to future climate change: Development of a pre-screening (bottom-up) methodology *New Zealand Geographer*

Purpose

Although future climate change will significantly affect New Zealand's climate, how regional climates will be changed remains highly uncertain. As a consequence, pre-screening sensitivity analysis was carried out in the Hawke's Bay for climate-sensitive activities in the pastoral farming sector.

Methods

A 'bottom-up' approach, in the context of non-irrigated pasture, was developed and demonstrated using a simple daily water balance model to simulate near-surface hydrological processes and empirical relationships between transpiration and pasture dry matter production.

Results

The key outcome for the end-user of this pre-screening sensitivity analysis study is determining to extent to which climate-sensitives occur in the region. It is noted that the 'non-specialist end-user' remains a scientist, although the need for specialist knowledge of climate change, soil hydrology and pasture growth (and the modelling of all three) is largely circumvented. The degree of climate-sensitivity discovered helps to decide if it is worth investing in a much more comprehensive and expensive analysis.

Gray et al. (2011) The management of risk in a dryland environment *Proceedings of the New Zealand Grassland Association*

Purpose

The research investigated how to improve the resilience of farming systems for a group of 24 Hawke's Bay hill country farmers.

Methods

The study generated an inventory of the farmers' risk management strategies, including analysis using descriptive statistics, through the issue of a detailed questionnaire, completed

during a face to face interview with each of the 24 farmers in the catchment. Information on the farmers, the farms' resources, farming systems, physical performance and the risk management strategies they used to cope with a dryland environment was obtained.

Results

There was considerable variation in the strategies adopted by the farmers to cope with a dryland environment, as farmers were coping with a range of drought conditions in addition to upside risk, where better than expected conditions occurred. Infrastructure was important in managing a dryland environment. Farmers chose between increased scale (increasing farm size) and geographic dispersion (owning a second property in another location) through to intensification (investing in subdivision, drainage, capital fertiliser, new pasture species). The study identified that there may be scope for further investment in infrastructural elements such as drainage, deeper rooting alternative pasture species and water harvesting, along with improved management of subterranean clover to improve flexibility. Many of the farmers used forage crops and idling capacity (reduced stocking rate) to improve flexibility; others argued that maintaining pasture quality and managing upside risk was a better strategy in a dryland environment. Supplementary feed was an important strategy for some farmers, but its use was limited by contour and machinery constraints. A large proportion of farmers ran breeding cows, a policy that is much less flexible than trading stock. However, several farmers had improved their flexibility by running a high proportion of trading cattle and trade lambs. To manage market risk, the majority of farmers sold a large proportion of their lambs and cattle prime.

Hopkins et al. (2015) Climate change and Aotearoa New Zealand *WIRES Climate Change*

Purpose

In this review paper, adaptive responses to climate change in New Zealand are considered in connection to key industries (agriculture, tourism) and communities (coastal, Maori). The devolved structure of adaptation is also explored.

Methods

This research is based on a desktop review of the relevant literature and reports.

Results

The paper argues that Zealand's agricultural systems have been successful in their adaptation to variable weather, although whether such experience is sufficient to deal with changing weather patterns likely to occur with climate change is questionable. Regions with a high dependency on agriculture for employment may be disproportionately affected by negative impacts of climate change. Regionally, extreme weather events have raised awareness of climatic variability and encouraged the adoption of more resilient farming practices including lucerne fodder crops, increased reliance on supplementary feeds which can buffer shortfalls in local feed production, agro-forestry plantings for soil conservation and water retention and increased use of irrigation systems. Diversification of agricultural product and spreading risk appears to be a particularly popular approach to risk reduction for farmers. In addition, strategies such as purchasing supplementary feed during a drought are often considered a

short-term tactical response; these actions are potentially a long-term strategy involving forward contracts or changes to the production practices of the farm. Recent deliberations of the Ruataniwha irrigation scheme (among others) also demonstrate the tensions between efforts to develop climate change adaptation strategies and the impact of such projects on the environment and the economic costs to local communities. The knowledge gaps identified in this review, particularly relating to the full range of possible biophysical and socioeconomic outcomes, the impact of global perceptions, and consumer behaviours and preferences, create added complexity. By increasing knowledge in these, and other areas, New Zealand will be in a better position to engage social actors, and increase support for more proactive government responses.

Kalaugher et al. (2013) An integrated biophysical and socio-economic framework for analysis of climate change adaptation strategies: The case of a New Zealand dairy farming system *Environmental Modelling and Software*

Purpose

This paper is contains a mixture of empirical work and literature review to critique and develop current methods and practice. Its aim is to outline a more in-depth understanding of farming systems and their adaptive potential by attempting to fill the gap between bottom-up, qualitative social research with farmers and communities, and top-down, quantitative biophysical modelling through an integration of both methods, as demonstrated in a New Zealand context.

Methods

A Mixed Methods Framework is presented, using examples from a pilot study of a New Zealand dairy farm in the Waikato region of the North Island. The research used a combination of quantitative model outputs and semi-structured interviews with the case study farmer to co-generate adaptation options. By presenting this methodology in a specific context, the review offers a theoretical basis for a practical way to integrate quantitative and qualitative research for climate change adaptation research.

Results

The paper expounds on the value of the methodological approach rather than providing specific results. The authors position the quantitative model in the context of a wider system that includes both soft (qualitative) and hard (quantitative or numerical modelling) elements means that the quantifiable aspects of the system can be measured without losing sight of the softer aspects, which can then be analysed using social science research methodologies. While challenging in practice, efforts towards such integrated approaches will arguably generate much more grounded and realistic information about potential adaptation responses and improve the flexibility in response to climate change variables and associated impacts of society.

Keller et al. (2014) Grassland production under global change scenarios for New Zealand pastoral agriculture *Geoscientific Model Development*

Purpose

This paper aims to model possible changes to the productivity of New Zealand's pastoral agriculture systems under a range of future climate scenarios employing integrated modelling assessments that also account for economic, and land management factors.

Methods

The paper adapts and integrates the Biome-BGC and Land Use in Rural New Zealand (LURNZ) models to simulate pastoral agriculture and to make land-use change, intensification of agricultural activity and climate change scenario projections of New Zealand's pasture production at time slices centred on 2020, 2050 and 2100, with comparison to a present-day base-line.

Results

The results suggest that high-fertility systems such as dairying could be more resilient under future change, with dairy production increasing or only slightly declining in all of our scenarios. Results show up to a 10 % increase in New Zealand's national pasture production in 2020 under intensification and a 1–2 % increase by 2050 from economic factors driving land-use change. Climate change scenarios using statistically downscaled global climate models (GCMs) from the IPCC Fourth Assessment Report also show national increases of 1–2 % in 2050, with significant regional variations. Projected out to 2100, however, these scenarios are more sensitive to the type of pasture system and the severity of warming: dairy systems show an increase in production of 4 % under mild change but a decline of 1 % under a more extreme case, whereas sheep/beef production declines in both cases by 3and 13 %, respectively. As of time of publication these were the first national-scale estimates using a model to evaluate the joint effects of climate change, CO2fertilisation and N-cycle feedbacks on New Zealand's unique pastoral production systems that dominate the nation's agriculture and economy. Model results emphasise that CO2fertilisation and N-cycle feedback effects are responsible for meaningful differences in agricultural systems. More broadly, the authors demonstrate that the model output enables analysis of decoupled land-use change scenarios: the Biome-BGC data products at a national or regional level can be re-sampled quickly and cost-effectively for specific land-use change scenarios and future projections.

Kenny (2011) Adaptation in agriculture: Lessons for Resilience from eastern regions of New Zealand *Climatic Change*

Purpose

This paper aims to present a comprehensive picture of farm resilience in New Zealand evolved from the earlier, top-down, climate impact assessments that arguably provide a limited view of 'smart farmer' adaptation.

Methods

The paper engages with participatory research methods to in eastern regions of New Zealand, beginning in the Hawke's Bay, as documented through a number of research projects spanning eight years. Farmer interviews and workshops were used to gather the research data.

Results

The results reflect a strong belief from real-world smart farmers that there is sufficient knowledge and experience to adapt to climate change. The research documents that proactive farmers are already reading multiple signals, including changes in climate, and are responding. The farm resilience picture provides a foundation for exploring alternative adaptation options and pathways for agriculture. A smart farming approach, focused on resilience, provides the basis for development of a response capacity, with potentially significant co-benefits in terms of adaptation and mitigation to climate change. It is apparent from this work that ongoing engagement with smart farmers, focused on resilience, can contribute significantly to development of a coordinated 'bottom up' and 'top down' response capacity. Addressing the psychology of change is a fundamental need to ensure wider engagement.

King et al (2008) Maori environmental knowledge of local weather and climate change in Aotearoa - New Zealand *Climatic Change*

Purpose

The aim of this research paper is to document the wealth of Māori environmental knowledge (MEK), incorporated into traditional and modern practices of agriculture, fishing, medicine, education and conservation. This knowledge includes the use of a vast indigenous nomenclature for local weather and climate phenomenon, the oral recording of weather and climate based events and trends, and the identification of environmental indicators to forecast weather and climate.

Methods

The paper uses a Kaupapa Māori based research approach and semi-directive interviewing, to develop an intimate understanding of local weather and climate was demonstrated by elders from Te Whānau-ā-Apanui.

Results

From local weather and climate nomenclature, to the oral recordings of extreme events and the use of environmental indicators to predict changes in weather and climate, this MEK reflects an acute awareness of local weather and climate phenomena. The application of this knowledge offers insight into how Māori adjusted to past weather events and climate episodes as well as reveals the convergence that exists between MEK and western science. Approaches that regard these knowledge systems as complementary sources of wisdom are likely to benefit from the knowledge offered by both MEK and western scientific understanding.

Lee et al (2013) Climate-change effects and adaptation options for temperate pasture-based dairy farming systems *Journal of British Grassland Society*

Purpose

This review paper describes predicted changes in climate in NZ and southeast Australia, likely effects on the feedbase used in the pasture-based dairy industry and the flow-on effect on milk-solids production and profitability.

Methods

The methods comprised of a desktop review of relevant literature and reports.

Results

The review findings indicate that potential adaptation options (in both New Zealand and southeast Australia) will allow farmers to take advantage of new opportunities and minimize any negative impacts of climate change. It suggests that farmers' adaptation options could include the strategic use of supplementary feed, reduced stocking rates, irrigation or sowing alternative plant species with greater drought tolerance. It concludes that pasture-based dairy systems have high levels of adaptive capacity, and there are opportunities to continue to improve production efficiencies particularly where rainfall change is small. Further investigation into possible adaptation options is required to determine their impact on milk-solids production and profitability, as well as to identify additional options. The authors also suggest that future research should consider the greenhouse gas mitigation profile of adaptations on dairy farms, arguing that, ideally, the innovations could focus the dual objective of reducing direct vulnerabilities and lowering greenhouse gas intensity of the dairy system.

Lieffering et al. (2016) Exploring climate change impacts and adaptations of extensive pastoral agricultural systems by combining biophysical simulation and farm system models *Agricultural Systems*

Purpose

This paper models the impacts and tests the effects of potential adaptations to climate change for two New Zealand sheep and beef grazing enterprises located in regions that have contrasting climate change projections.

Methods

For both enterprises six management systems varying in farming intensity and the tactics used to respond to changes in feed supply and demand were examined. To explore the impacts of, and adaptation to, climate change in New Zealand hill country farms, two farm types that are representative of this farming system and in locations with different climates and climate change projections were selected. The farms were located in a) Southland, a cool, moist area and in b) Hawke's Bay which is warmer and drier. A range of climate scenarios were modelled using Regional Climate Models (RCMs) as generated by NIWA and then used to drive a multi-species AgPasture module operated in APSIM (Agriculture Production System Simulator) to project changes in pasture species growth while the whole-farm system model

Farmax® Pro examined economic implications. The effects of the impacts and adaptations were determined by examining the economic viability of the systems. The authors modelled pasture growth over two20-year periods centred on 1990 and 2040 using downscaled climate projections and a pasture simulation model.

Results

The results indicate generally positive or neutral outcomes of climate change for pasture growth in two regions of New Zealand in terms of total annual production though there are projected to be marked changes in the seasonality, notably earlier spring growth. These changes in seasonality present substantial challenges to farm management in dealing with both excess feed and feed shortages. The research found little difference between farming systems differing in intensity and tactical management in terms of their ability to meet these challenges. An initial exploration of the extent of adaptation that will be required to maintain or increase farm profitability was made; further progress will require feedback from land managers who will be faced with these new challenges. The analyses should be interpreted as snapshots of the impacts and potential adaptations of enterprises in two regions taken in isolation.

Manning et al. (2015) Dealing with changing risks: a New Zealand perspective on climate change adaptation *Regional Environmental Change*

Purpose

This paper uses an empirical research approach to consider New Zealand's adaptive capacity by working with government practitioners at three levels and with Māori communities. Climate-sensitive primary industries were identified as a significant component (almost 50%) of the total Māori asset base.

Methods

A household survey of 190 residents of the Hutt Valley, Wellington, interviews of sixteen local government officials, and complimentary workshops, were used to analyse the factors influencing adaptive decisions specifically in relation to sea level rise and river flooding.

Results

Very different perceptions of risk and structural inertia in planning processes have emerged as key issues for implementing adaptation responses. In particular, the use of static frameworks biases responses towards retrospective, rather than anticipatory analysis. Ongoing socioeconomic changes in New Zealand also raise the risk of structural effects caused by climate change impacts becoming unevenly distributed across society. The analysis indicates that a national and regional strategic approach, centred on a dynamic view of climate risk, is necessary for effective decisions at the local government and community level. In addition, effective adaptation requires better identification of barriers and opportunities for addressing changing risk, together with more effective and continuous social engagement.

Nettle et al. (2015) Empowering farmers for increased resilience in uncertain times *Animal Production Science*

Purpose

This research paper aims to determine if current ways of doing and organising RD&E in the dairy sector in New Zealand and Australia contribute to supporting farm adaptability. The paper reports on results from an examination of case studies of challenges to resilience in the dairy sector in Australia and New Zealand (i.e. dairy farm conversion, climate-change adaptation, and consent to farm) and the contribution of dairy RD&E in enhancing resilience of farmers, their farms and the broader industry.

Methods

The paper uses a comparative case-study approach (using three case studies) to enable patterns of data to emerge to facilitate the triangulation of key observations. Semi-structured interviews, guided by the use of an empowerment framework, were used to gather the necessary data. Cases were chosen for addressing three scales of interest in examining empowerment and adaptability, i.e. farm families, RD&E projects, and a community or regional problem or issue.

Results

The results indicate that that, currently, agricultural RD&E supports adaptability in general, but varies in the strength of its presence and level of activity in the areas known to enhance adaptability. Through the application of an empowerment framework across three case studies of resilience challenges in the Australian and New Zealand dairy industries, the conclusion can be drawn that agricultural RD&E is contributing to the adaptability of farmers and their resilience. Five common strategies for supporting adaptability were identified across the cases; fostering social networks, acknowledging diverse roles and knowledge integration mechanisms, representing and valuing farmer knowledge in the formation of adaptation strategies, supporting collective learning to address resilience challenges, and practicing a degree of flexibility in governance arrangements.

Niles et al. (2016) Farmer's intended and actual adoption of climate mitigation and adaptation strategies *Climatic Change*

Purpose

Applying the Theory of Planned Behaviour this paper aims to assess whether different factors affect intended versus actual adoption of climate behaviours among farmers in New Zealand.

Methods

Data were collected through mixed methods (37 interviews and a telephone survey of 490 farmers) in two regions of New Zealand 2010–2012. Through multiple regression models the authors test hypotheses related to the Theory of Planned Behaviour around the role of attitudes, subjective norms, and perceived capacity in affecting intended and actual adoption.

Results

Results suggest that there are different drivers of intended and actual adoption of climate change practices. Climate change attitudes and belief is only associated with intended not actual adoption. No evidence that subjective norms (climate change policy support) significantly influence either intention or actual adoption was found. Only perceived capacity and self-efficacy were important predictors of both intended and actual adoption. These results suggest a disconnect between intended and actual behaviour change and that using data about intention as a guiding factor for program and policy design may not be prudent. Furthermore, fostering perceived capacity and self-efficacy for individuals may be crucial for encouraging both intended and actual adoption of climate adapting and mitigating behaviours.

Niles et al. (2015) How limiting factors drive agricultural adaptation to climate change Agriculture *Ecosystems and Environment*

Purpose

This paper aims to develop a theoretical approach to connect agro-ecosystem diversity with farmer decision-making in the context of agricultural adaptation to climate change.

Methods

Research methods combined the ecological principle of Liebig's Law of the Minimum with the Psychological Distance Theory to suggest how adaptation behaviours vary across regional contexts. The authors argue with their limiting factors hypothesis that limiting factors within a farm system (water or temperature impacts) influence the adoption of adaptation practices differently across regions and farm systems. Limiting factors varied across farm systems and regions, based on historical climate changes, agro-ecological contexts, infrastructure and adaptation capacity.

Results

Using farmer survey data from New Zealand the authors show that limiting factors mediate the effect of past climate experiences on the adoption of adaptation strategies differently in two regions with water acting as a limiting factor in Hawke's Bay and water and temperature as a limiting factor in Marlborough. This suggests that farmers perceive and respond to climate change in part due to their personal experiences with climate change and the limiting factors within their system. Such results are relevant for the development of regional adaptation strategies, effective policies and targeted climate change communication.

Orwin et al. (2015) Effects of climate change on the delivery of soil-mediated ecosystem services within the primary sector in temperate ecosystems: a review and New Zealand case study *Global Change Biology*

Purpose

This paper examines current knowledge on the likely response of soil-based ecosystem services to climate change in temperate ecosystems. The work focuses on mechanisms that are likely to underpin differences in climate change responses between four primary sector

systems: cropping, intensive grazing, extensive grazing and plantation forestry. The paper then illustrates how the findings can be applied to assess service delivery under climate change in a specific region, using New Zealand as an example system.

Methods

Desktop review of the current state of the knowledge, in conjunction with the use of climate change scenario projections, and conceptual models that explicitly incorporate supporting and degrading processes, soil natural capital and accounts for interactions among soil biota, chemistry and physics.

Results

Differences in the climate change responses of carbon and nutrient-related services between systems will largely be driven by whether they are reliant on externally added or internally cycled nutrients, the extent to which plant communities could influence responses and variation in vulnerability to erosion. The ability of soils to regulate water under climate change will mostly be driven by changes in rainfall, but can be influenced by different primary sector systems' vulnerability to soil water repellency and differences in evapotranspiration rates. These changes in regulating services result in different potentials for increased biomass production across systems, with intensively managed systems being the most likely to benefit from climate change. A quantitative prediction of net effects of climate change on soil ecosystem services remains a challenge, in part due to knowledge gaps, but also due to the complex interactions between different aspects of climate change. The current levels of uncertainty regarding the impacts of climate change on soil services represent a significant impediment to the generation of policy that will adequately address the positive and negative impacts of climate change. Reducing this uncertainty is vital to ensure successful adaptation to climate change.

Prokopy et al. (2015) Farmers and Climate Change: A Cross-National Comparison of Beliefs and Risk Perceptions in High-Income Countries *Environmental Management*

Purpose

Looking across six study sites—Scotland, Midwestern United States, California, Australia, and two locations in New Zealand this paper explores farmers' beliefs and concerns about climate change in order to develop appropriate policies and communication strategies.

Methods

This study used review methods to compare varying surveys from the six different locations. The farmer surveys were all conducted for different purposes in these regions but the authors deemed that they contained similar enough questions that a comparison is useful and informative. The information analysed in this review covers farmer perspectives across a range of production types and markets.

Results

The results indicate that over half of farmers in each location believe that climate change is occurring. However, there is a wide range of beliefs regarding the anthropogenic nature of climate change; only in Australia do a majority of farmers believe that climate change is anthropogenic. In all locations, a majority of farmers believe that climate change is not a threat to local agriculture. The findings also suggest that information needs to be better disseminated to the agricultural community to induce and guide adaptive measures. The different policy contexts and existing impacts from climate change are discussed as possible reasons for the variation in beliefs.

Sturman and Quenol (2013) Changes in atmospheric circulation and temperature trends in major vineyard regions of New Zealand *International Journal of Climatology*

Purpose

This paper contributes to knowledge of the impact of global warming on viticulture, using major vineyard regions of New Zealand as a case study to illustrate regional disparities in climate change impacts resulting from downscale effects of larger scale atmospheric circulation.

Methods

Applied techniques from meteorological and climate science were used to interpret and analyse a range a of climatic data, including air temperature data from the New Zealand climate station network, obtained from the National Climate Database managed by NIWA, and Southern Annular Mode (SAM) data.

Results

The results show that significant regional variations in the impact of global warming can occur over areas of complex terrain such as New Zealand. Observed differences in local temperature and frost trends can be caused by the interaction of changing weather systems with mountainous terrain. These changing weather systems themselves are seen to be the result of major shifts in the larger scale atmospheric circulation. These results are important for assessing possible impacts on viticulture and in developing adaptation strategies for agriculture in response to predicted future climates.

Sylvester-Bradley and Riffkin (2008) Designing resource-efficient ideotypes for new cropping conditions: Wheat (*Triticum aestivum* L.) in the High Rainfall Zone of southern Australia *Field Crops Research*

Purpose

This paper proposes and tests modelling procedures to optimise wheat phenology according to risks of abiotic damage (frost, heat and drought) to seedling establishment and grain set. The ultimate aim of the research is to develop a Crop Design Tool that will specify resource-efficient ideotypes for any environment.

Methods

The methods include the growth and analysis of wheat under various field and laboratory conditions.

Results

The main uncertainties in the estimation procedures arose from poor quality wind data, a poorly quantified association between stem material density and stem strength, and lack of data on maximum capacity to store redistributable stem dry matter (DM). Sensitivity analysis showed grain yields of ideotypes to depend on maximum wind gusts during grain production as well as on plant-available water. The most effective single means of increasing potential grain yields was predicted clearly to be through increasing the conversion of radiation to DM.

Weaver (2008) Climate change and food security *Institute of Policy Studies Working Paper*

Purpose

This working paper explores the global trends associated with food security and climate change and the linkages between them, with consideration given to the implications for New Zealand.

Methods

This high level desktop review paper examines demand and supply side trends to inform a coordinated response to the emerging issue of global food security in light of climate change.

Results

The projected impacts on New Zealand are associated with losses in crop productivity in eastern regions that become warmer and dryer, regions that are likely to suffer from increased incidence of flood damage, and coastal regions that are vulnerable to sea level rise combined with storm surges during cyclone events. The paper also raises a number of relevant policy questions for consideration:

- What are the potential opportunities and/or risks to New Zealand arising from global food price inflation?
- Should New Zealand take precautionary measures to forestall risk exposure arising from likely increasing production costs (e.g. driven by longer term trends in oil price) in agriculture and fisheries?
- Are there opportunities to minimise future risk associated with highly variable international commodity prices?
- Is there potential to export agricultural production innovations to developing nations in most need of assistance to increase their food security from local production?
- Is there an opportunity for New Zealand to play a leadership role in international policy in this area?

Weller et al (2008) Retaining Adaptive Capacity in New Zealand's ecological systems *New Zealand Journal of Agricultural Research*

Purpose

This short opinion piece aims to make the argument that in addition to the conservation of biological diversity for aesthetic, ethical or psychological reasons it is also important for retaining and underpinning adaptive capacity.

Methods

This opinion piece draws on the existing literature to make its argument.

Results

Biological diversity plays a significant role in sustaining the resilience and adaptive capacity of ecosystems, which perform vital functions like pollination, nitrogen fixation, spread of seeds, decomposition and generation of soils in agro-ecosystems. Functional groups made up of several species that perform similar functions respond to environmental changes in different ways, thereby increasing the reliability of ecosystem processes. Erosion of functional diversity and response diversity leads to vulnerability and alterations in the capacity to supply essential ecosystem services, which severely affects the ability of ecosystems to reorganise after disturbance. Retention or enhancement of biodiversity within production landscapes may increase the ecological resilience and adaptive capacity of agro-ecosystems, allowing them to better cope with shocks and systemic change such as climate change, invasive species and intensification.

Zhang et al (2007) Spatially explicit modelling of the impact of climate changes on pasture production in North Island New Zealand *Climatic Change*

Purpose

The aim of this paper is to assess the potential impact of climate changes on pasture production in the North Island, New Zealand.

Methods

Eight climate scenarios of increased temperature and increased (or decreased) rainfall were investigated by integrating a polynomial regression model for pasture production with a Geographic Information System (GIS).

Results

The results indicated that the climate change scenarios assuming an increase in temperature by 1–2°C and a rainfall change by−20 to +20% would have a very significant impact on pasture production with a predicted pasture production variation from−46.2 to +51.9% compared with the normal climate from 1961–1990. Increased temperature would generally have a positive effect on pasture production in the south and southeast of the North Island, and increased rainfall would have a positive effect in the central, south and southeast of the North Island and a negative effect in the north of the North Island. The interaction of decreased rainfall and increased temperature would have a negative impact for the whole

North Island except some central areas with high rainfall. Relevant management practices for coping with potential climate change include the development and use of more drought tolerant species and cultivars and an adjustment to stocking policy and practice.

Preliminary analysis and discussion

This section presents a preliminary analysis of the selected white literature papers considering year of publication, institutional affiliation, and the research methods employed in each paper.

Year of publication

Adaptation has become an increasingly important part of debates and discussion on climate change. Internationally, since the early 2000s, the number of publications on adaptation has increased dramatically (Giupponi and Biscaro 2015) with vulnerability and resilience prominent terms within the literature. In NZ however, we see no discernible increase in the adaptation literature.

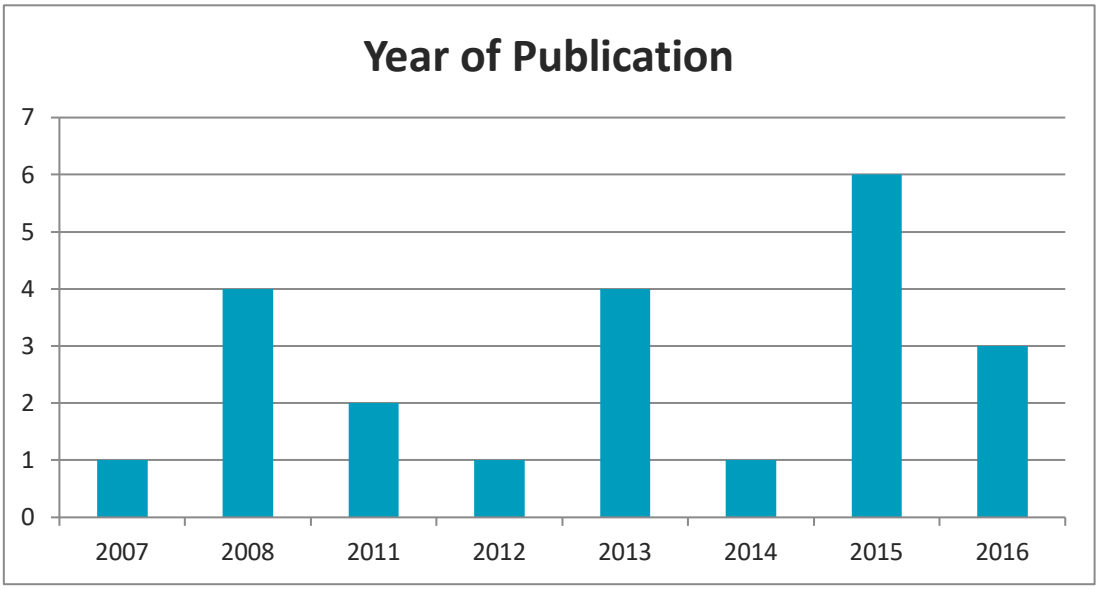


Figure A 4. Year of Publication for considered studies

Institutions

Institutions, countries and cities associated with each lead author at time of publication are provided in Table A3. Unsurprisingly 17 of the 22 paper have lead auuthors affiliations in New Zealand, 4 are with the US, and 1 each with Australia and the UK. Fifteen are associated with universities and the balance are associated with Crown Research Institutes or other research entities.

Table A 3 Institution, city and country affiliations of lead authors

Author	Institution	City	Country
	UNIVERSITY		
Cradock-Henry	University of Canterbury	Christchurch	New Zealand
Fowler	University of Auckland	Auckland	New Zealand
Gray	Massy University	Palmerston North	New Zealand
Hopkins	University of Otago	Otago	New Zealand
Kalaugher	University of Waikato	Hamilton	New Zealand
Manning	Victoria University of Wellington	Wellington	New Zealand
Nettle	University of Melbourne	Melbourne	Australia
Niles	University of Vermont	Burlington, VT	USA
	Harvard University	Cambridge, MA	USA
	University of California Davis	Davis,CA	USA
Prokopy	Purdue University	Lafayette, IN	USA
Sturman	University of Canterbury	Christchurch	New Zealand
Weaver	Victoria University of Wellington	Wellington	New Zealand
Weller	University of Otago	Dunedin	New Zealand
Zhang	Massey University	Palmerston North	New Zealand
	CROWN RESEARCH INSTITUTE AND OTHER		
Cradock-Henry	Landcare Research	Lincoln	New Zealand
Keller	GNS Science	Lower Hutt	New Zealand
Kenny	Earthwise Consulting	Hastings	New Zealand
King	NIWA	Auckland	New Zealand
Lee	Dairy NZ	Hamilton	New Zealand
Lieffering	Ag Research	Palmerston North	New Zealand
Orwin	Landcare Research	Lincoln	New Zealand
Sylvester	ADAS (Environmental Consultancy)	Cambridge	UK

Research methods

The selected white literature papers used a range of qualitative and quantitative research methods (Table A4). Interviews, workshops and focus group research tools were used in 9 of the 22 papers. Desktops review methods were used in 5 of the papers, quantitative modelling was used in 8 of the papers, and survey or questionnaire instruments were used in 4 of the papers. In some instances papers used a combination of these research methods.

Table A 4 Summary of research methods used

Author(s)	Title	Method/s
Cradock-Henry	New Zealand Kiwifruit growers' vulnerability to climate and other stressors	In-depth, semi structured interviews with workshops and analysis of secondary data.
Cradock-Henry	Exploring Perceptions of Risks and Vulnerability To Climate Change in New Zealand Agriculture	Interviews and focus groups
Fowler et al.	Vulnerability of pastoral farming in Hawke's Bay to future climate change: Development of a pre-screening (bottom-up) methodology	'Bottom-up' approach using a simple daily water balance model to simulate near-surface hydrological processes and empirical relationships between transpiration and pasture dry matter production.
Gray et al.	The management of risk in a dryland environment	Inventory of the farmers' risk management strategies, including analysis using descriptive statistics, through the issue of a detailed questionnaire, completed during a face to face interview
Hopkins et al.	Climate change and Aotearoa New Zealand	Desktop review of the relevant literature and reports.
Kalaugher et al.	An integrated biophysical and socio-economic framework for analysis of climate change adaptation strategies: The case of a New Zealand dairy farming system	Mixed methods framework using a combination of quantitative model outputs and semi-structured interviews with the case study stakeholder
Keller et al.	Grassland production under global change scenarios for New Zealand pastoral agriculture	Adapted and integrated land use models with climate change scenario projections
Kenny	Adaptation in agriculture: Lessons for Resilience from eastern regions of New Zealand	Participatory research methods including interviews and workshops
King et al.	Maori environmental knowledge of local weather and climate change in Aotearoa - New Zealand	Kaupapa Māori based research approach and semi-directive interviewing
Lee et al.	Climate-change effects and adaptation options for temperate pasture-based dairy farming systems	Desktop review of relevant literature and reports
Lieffering et al.	Exploring climate change impacts and adaptations of extensive pastoral agricultural systems by combining biophysical simulation and farm system models	Climate scenarios modelling , economic modelling, and pasture growth modelling
Manning et al.	Dealing with changing risks: a New Zealand perspective on climate change adaptation	Household survey, interviews and complimentary workshops
Nettle et al.	Empowering farmers for increased resilience in uncertain times	comparative case-study approach using Semi-structured interviews, guided by the use of an "empowerment framework"
Niles et al.	Farmer's intended and actual adoption of climate mitigation and adaptation strategies	Mixed methods using interviews and a telephone survey in conjunction with multiple regression models testing hypotheses related to the Theory of Planned Behaviour

Niles et al.	How limiting factors drive agricultural adaptation to climate change	Research methods combined the ecological principle of Liebig's Law of the Minimum with the Psychological Distance Theory to suggest how adaptation behaviours vary across regional contexts.
Orwin et al.	Effects of climate change on the delivery of soil-mediated ecosystem services within the primary sector in temperate ecosystems: a review and New Zealand case study	Desktop review of the current state of the knowledge, in conjunction with the use of climate change scenario projections, and conceptual models
Prokopy et al.	Farmers and Climate Change: A Cross-National Comparison of Beliefs and Risk Perceptions in High-Income Countries	Comparative review of review existing surveys from the six different locations
Sturman and Quenol	Changes in atmospheric circulation and temperature trends in major vineyard regions of New Zealand	Applied techniques from meteorological and climate science were used to interpret and analyse a range a of climatic data
Sylvester-Bradley and Riffkin	Designing resource-efficient ideotypes for new cropping conditions: Wheat (*Triticum aestivum L.*) in the High Rainfall Zone of southern Australia	Growth and analysis of wheat under various field and laboratory conditions
Weaver	Climate change and food security	High level desktop review
Weller et al.	Retaining Adaptive Capacity in New Zealand's ecological systems	Opinion piece drawing on the existing literature to make its argument
Zhang et al.	Spatially explicit modelling of the impact of climate changes on pasture production in North Island New Zealand	Climate scenarios investigated by integrating a polynomial regression model for pasture production with a Geographic Information System (GIS).

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Appendix D - Adaptation timeline

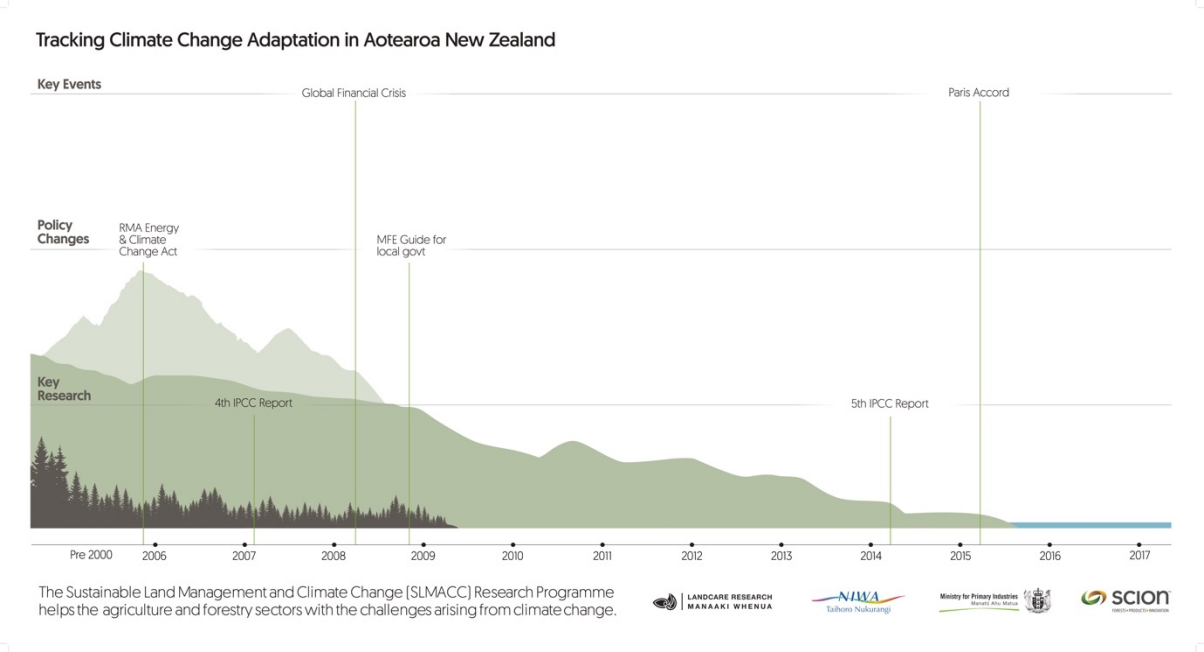

Figure A 5. Adaptation timeline.

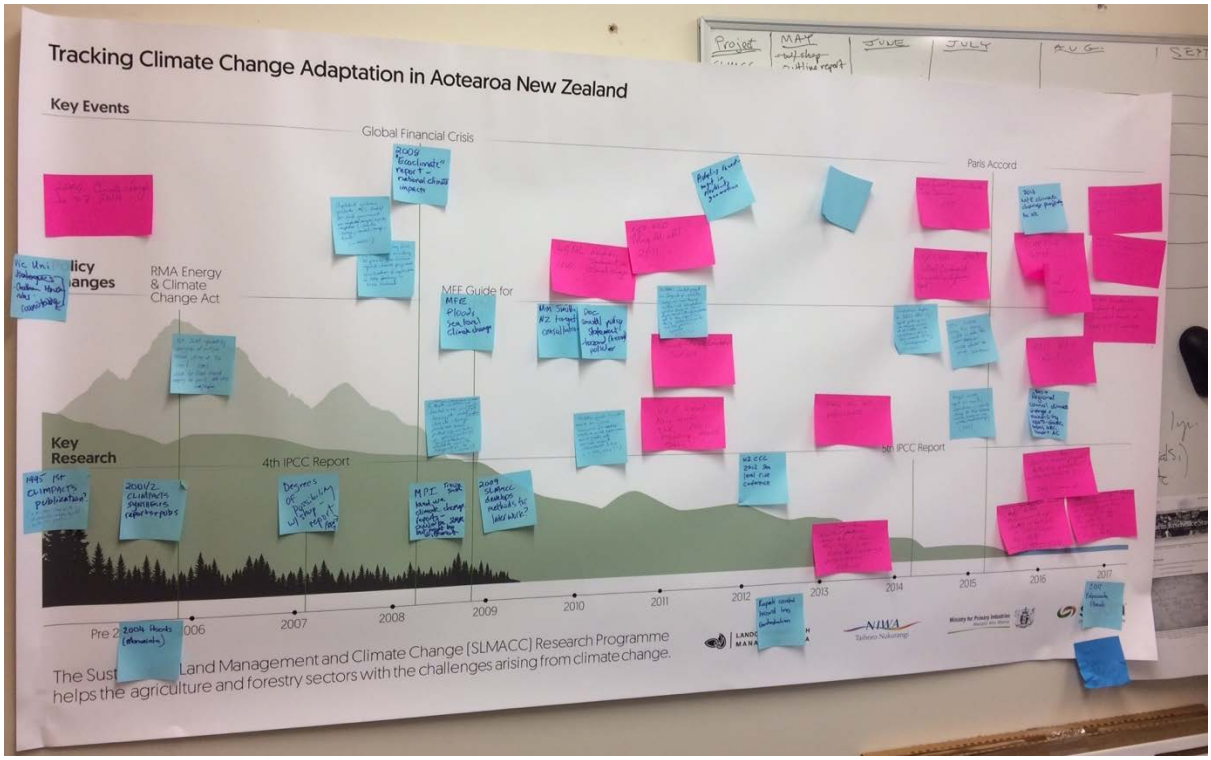

Figure A 6. Completed Adaptation timeline.

Appendix E - Potential value for money assessment

Introduction

In this section we present an analysis of the potential value for money of the SLMACC research in adaptation in New Zealand. As highlighted previously, the SLMACC fund has provided the major, and in some areas, the only funding of climate adaptation research in New Zealand until recently. Without the understanding generated through the resulting research, the primary sector would have a much weaker recognition of the likely impacts occurring as a result of climate change, or the potential options available to adapt to those impacts.

Assessing value for money is a complex exercise however, and in the case of research into climate change, even more so. The impacts of climate change may not occur for several years after the research has finished, meaning that the benefits of the research also do not occur until much later. Furthermore, attributing any change in practice or outcome to a particular piece of research even without this delay in realisation, is almost impossible.

Nonetheless, it is important that the fundamental value of research in supporting an industry is highlighted. The primary sector contributes $42.6 billion to the country's export earnings (MPI 2018). Climate change has the potential to disrupt production in NZ's primary sector, unless appropriate adaptation occurs. Understanding what the likely future impacts might be, where and when they may occur and what action can be taken to reduce them, can make an important difference to the economy. Making changes now can provide benefits in the current climate as well. The SLMACC research to date has enabled the different industries within the primary sector to begin thinking, planning and acting for climate change.

In the subsequent sections, we outline the approach we have taken and identify very clearly the assumptions that have been made.

Methodology

Value for money is a key part of evaluating efficiency. It compares the outputs, outcomes, impacts or changes brought about by the work (value) compared with the resources used (money).

A range of assessment tools are available to provide analysis and information to support good judgement in decision making. In the initial research proposal we suggested conducting a Basic Efficiency Resource Analysis (BERA) for this work, which compares perceived investment against perceived impact for each project. However, during the stakeholder workshops it became apparent that while stakeholders were familiar with the body of work they were less familiar with individual projects, particularly those that were conducted in the earlier years of SLMACC. A BERA would only be effective if respondents were very familiar with the research in question.

Additionally, other review projects were conducting some form of Cost-Benefit Analysis (CBA) so for consistency it was decided to also conduct a CBA for the adaptation research. It is necessary to make a number of assumptions in order to do this, which are clearly identified.

CBA is a method for comparing the future stream of benefits and costs associated with a particular investment.

The costs and benefits are discounted to calculate the Net Present Value (NPV) of the project. In order to perform a CBA of the SLMACC research, the costs of the research must be identified. In this case these are the amounts invested by MPI. The benefits of the research must also be identified, which is much more challenging. Figure 1 illustrates conceptually how the benefits can be calculated. If the climate changes and no adaptation occurs, the primary sector is likely to experience increasing costs over time (the top line in the figure). If adaptation occurs, these costs will be reduced (the middle line in the figure). The difference between these two lines provides us with the benefits of adaptation. The costs of no climate change are represented in the bottom line, which reflects current weather variability, and the increasing value of assets exposed. In this study we make the assumption that as a result of the SLMACC research in this area, and the increased knowledge and understanding of impacts and adaptation options, adaptation occurs throughout the pastoral sector resulting in a reduction in the climate impacts.

In the following sections we describe our assumptions regarding the creation of these curves.

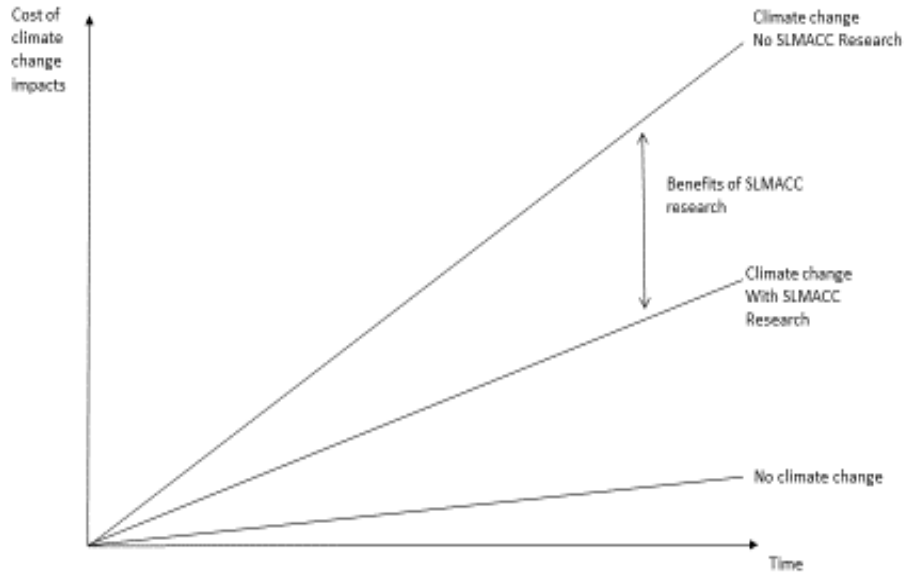

Figure A 7. Stylised representation of the costs of climate change over time, with and without adaptation, and the benefits of adaptation.

Assumptions and data

Project focus and investment costs

We limited our analysis to a sub-group of the SLMACC adaptation research. Looking across the funding allocated to the different sectors over the course of the SLMACC fund, a considerable amount is allocated to the pastoral sector. Studies looking at pastoral only (including dairy), came to a total of $1.5 million. With the inclusion of studies that cover the entire primary sector, where pastoral is some proportion of this, the total comes to $3.9 million (out of a total of just over $8 million). Because of this dominance, we focus on the

value for money of the research in the pastoral sector. This value forms the cost component of the CBA.

We use all the projects identified as focusing on the pastoral sector or drought, as well as Clark et al. (2012) and Dunningham et al. (2015). For Clark et al. (2012) we estimate the proportion of the value dedicated to the pastoral sector as $426 000, based on the proportion of the report covering the sector. Altogether these research costs come to a total of almost $2.5 million NZD.

The benefits of the research can be diverse, intangible and continue to accrue for many years after the end of the project. They can include building capacity, capability, and networks which are important but difficult to value, and discussed in other parts of the report.

We assume for the sake of simplicity in this case that the primary benefits in this case are the financial value to the sector of the research. We calculate the value of the dairy, sheep and beef sectors under climate change with no adaptation, and compare that with the value when adaptation occurs – and *assume that the adaptation can be attributed to the SLMACC research*.

Costs and benefits are discounted at the rate of seven percent as recommended by the NZ Treasury for R&D investment[3].

Identifying the costs of climate change – the counterfactual scenario

In this part of the analysis, we identify the likely impacts climate change will have on the dairy and sheep and beef sectors in NZ, without any adaptive action.

Pasture growth is affected by temperature, CO_2 levels, water availability (both deficit and water-logging), botanical composition, nutritive value, pests and diseases, changing seasonality, and interactions between all the above. Considerable research has been conducted both through the SLMACC fund and other research to determine the effects of climate change on pasture growth (e.g. Newton et al. (2011, 2014), Tozer et al. (2011), Dodd et al. (2009), Fowler et al. (2008), Guo et al. (2008), Lieffering et al. (2008)). There appears to be a positive overall effect on pasture growth under climate change, but with considerable regional and seasonal variation. Dynes et al. (2010) estimate annual pasture production to be 12-13% greater in 2030 and 16 -22% greater in 2080 than in 2000, however with a lower nutritive content, resulting in reduced cow energy intake, and reduced milk solids per cow. This resulted in a loss of NZD306/ha by 2080. Stroombergen et al. (2008) find an average decrease in dairy production in NZ by the 2030s of 2 -4 % compared with a baseline period of 1972 – 2002, and a decrease of 6 - 9% in the sheep and beef sector, for the climate scenarios considered.

Pasture based systems such as dairy and sheep and beef are affected by more than just the pasture growth however, including the direct effects of climate change on the animals. Temperature increases and variability can have important effects on production, reproduction and animal health. Indirect effects such as variability in feed supply will also affect the

[3] https://treasury.govt.nz/information-and-services/state-sector-leadership/guidance/financial-reporting-policies-and-guidance/discount-rates

systems. Interestingly, given the dominance of livestock in NZ, much less research has been conducted on the direct effects of climate change on livestock.

Literature on the costs of climate change on the land-based sectors is sparse. Stroombergen et al. (2008) identify five studies that use historical data to estimate the effect of weather on economic activity, a further one that focuses on one drought event and several flood assessment reports. These provide useful information, although historical relationships can only go so far in providing understanding regarding the effect that future climate change will have on a sector. Saunders (2013) looked at the effect on NZ agricultural producer returns under climate change, considering the global effect on production and associated price effects. Because of the different scales, climate impacts, sectors and other assumptions used across these different studies, it is very difficult to draw out a generalizable picture of the effects of climate change on production.

Based on the body of work identified, we assume the following counterfactual scenario:

Dairy: Milk solids per cow decrease by 3% between 2020 and 2040. This is in the order of findings from Stroombergen et. al (2008), Tait et al. (2005) and Tweedie and Spencer (1981).

Actual data is used from 2008 – 2017, then the mean of actual data between 2008 and 2017 is used to 2020.

Sheep & Beef: Production decreases by 4% between 2020 and 2040, broadly based on Stroombergen et al. (2008), Agriculture NZ and Butcher Partners Ltd (2002), and Wallace and Evans (1985).

As with the dairy data, Actual data is used from 2008 – 2017, then the mean of actual data between 2008 and 2017 is used to 2020.

Data was obtained from Beef and Lamb NZ and Stats NZ.

We use this time period to capture some of the impacts of climate change, but limit the analysis to 2040 to keep the duration of the SLMACC research more realistic.

Identifying the benefits of research

As discussed previously in the report, the SLMACC research to date has very much focused on identifying impacts of climate change, with some work on implications. Some of the studies identify types of adaptations and options, but none of the studies focus on 'delivering' adaptation.

Importantly, the main climatic changes have not begun occurring in the time period of the SLMACC research, therefore there has not been any need for adaptation to occur yet. We therefore make the assumption that adaptation will begin to occur in future, and that some of that adaptation occurs as a result of the knowledge produced as part of the SLMACC research programme.

We make the very simple assumption here that because of future adaptation, the sector does not experience any declines in output over the period under consideration. As such, we hold the average of existing data from 2008 – 2017 constant from 2020 to 2040. This is

undoubtedly a very conservative estimate: Lee et al. (2012) show a median increase in operating profit of 8% across five dairy regions resulting from the implementation of adaptation. Lieffering et al. (2012) project a wide range in increase in operating profit resulting from adaptation in the sheep and beef sectors, from 27% to 300%. These are much higher impacts than we assume, however, the aim of this study is to estimate the value of the SLMACC research, and the assumption that the existing research will result in actual adaptation is rather tenuous. While our estimates therefore likely underestimate the impact of adaptation on future value, we recognise that the attribution of the change to the SLMACC research is difficult to substantiate.

We assume a cost of adaptation, which may arise carrying out some of the adaptations. Very little data was available regarding adaptation costs in NZ, and we therefore assume a one percent reduction in the output value over the period 2020 to 2040 to account for this.

Results

Because of the large number of assumptions involved in calculating these numbers, the results should really only be viewed as indicative of the potential scale of benefits involved. The CBA resulted in a NPV of $3.46 million over the period to 2040. This generates a benefit:cost ratio of 2.38 (indicating that for every dollar invested into the research, 2.38 are returned). This demonstrates very good value for money, especially considering the benefits of adaptation are very conservative.

Table A 5. Summary of indicative CBA for SLMACC adaptation research in the pastoral (dairy, beef/sheep) sector

PV Benefits ($m)	5.96
PV Costs (($m)	2.50
NPV (($m)	3.46
B:C ratio	2.38

Limitations

This analysis has a number of limitations, predominantly related to the assumptions made. The assumptions regarding the effect of climate change on the future value of the dairy, sheep and beef sectors, and the effect of adaptation, while in line with what little research is available, are rather crude. The most important assumption for this research however, is that any action on adaptation is as a result of the SLMACC research, which as already emphasised, is difficult to substantiate. Assessing the duration of the benefits that could be attributed to the research is also challenging.

Beyond these critical assumptions, a number of other limitations of the research exist. We do not consider any further implications on the wider economy, which would likely add to the benefits of the research.

We base the calculations on value to the sector, which is a function of output and price. In reality, price fluctuations will have an important effect on future value, and these may be

driven in part by climate changes in other parts of the world (see analysis by Saunders (2013) for possible trade effects).

It would also be possible to carry out a much more sophisticated analysis by region in NZ, but as the assumptions regarding the attribution to research are so coarse, this level of detail does not appear appropriate.

Because climate change impacts are not being experienced yet, we have made assumptions about future adaptation. However, in order for effective adaptation to occur and the associated benefits to be realised, a programme of extension and support and further research into adaptation delivery is likely to be necessary.

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Appendix F - Mind the gaps – adaptation workshop summary

INTRODUCTION

On May 17th, 2018, researchers from MWLR, NIWA, and Lincoln University co-hosted a workshop in Wellington on the topic of climate change adaptation and the primary industries in New Zealand with a specific focus on issues relating to the review of MPI's ten-year investment via the SLMACC program. Attendees included participants from central and local government, climate change research and primary industry sector groups and other end users. The workshop was held as part of a detailed review and assessment of the impact of adaptation research, being led by Dr Nicholas Cradock-Henry, MWLR. The following summarizes the discussion with participants on adaptation in the primary industries framed as current knowledge, research gaps and future priorities.

WORKSHOP FOCUS AND CONTEXT

Climate change adaptation is the process of preparing for actual or projected changes in climate averages and extremes. It relies on interpretations and values pertaining to key questions regarding ways hazards and vulnerability are determined; the nature of acceptable interventions; and the determinants of success. As a result, adaptation is both complex and political in nature. The process of identifying the most effective roles for various actors and the best policy instruments to use to reach certain goals is not only value-laden, but complex and uncertain.

Over the last ten years, MPI has invested over $8M into adaptation and cross-cutting research aimed at supporting the resilience of primary industries in New Zealand. As part of a larger review process, and to gain insight into the impact of this investment, participants were asked to consider the following questions:

1 **What do we know about adaptation to climate change for primary industries?** Based on your experience with the SLMACC program, are there any reports or activities that stand out? Why? What has the fund achieved over the last 10 years? What impact has SLMACC-funded research had on you or your organization and its activities?

2 **What do we <u>not</u> know?** What are the knowledge gaps, how do they vary between sectors and regions, and how do they relate to the need for 'impacts'-oriented research and decision- and action-oriented work?

3 **What do we <u>need</u> to know?** If you could recommend priorities for adaptation research what would they be and why? What recommendations do you have for MPI regarding the future of the fund? and What are the strengths of the SLMACC program (to retain) and weaknesses (to mitigate)?

To open the workshop, Dr. Stephen Flood (standing in for Dr. Nicholas Cradock-Henry, whose flight was delayed), Researcher at Manaaki Whenua Landcare Research, provided context for the discussion through a presentation on why climate change adaptation is an issue for primary industries, and the results of review to date. A summary of the presentation follows.

SUMMARY PRESENTATION

The scientific evidence indicating that the climate is changing is irrefutable. The global temperature is currently increasing 0.2 degrees Celsius per decade. With this change comes alterations to many natural systems, such as higher sea levels, changing water cycles, and more extreme weather events such as flooding, drought, and cyclones. Primary industries are a significant economic driver for New Zealand, accounting for approximately 7% of GDP and provide the basis for regional and local economies, play an important social and cultural roles in the life of rural communities, and supporting industries. If we do not adapt our primary industries to withstand these disasters, their impacts on the economy, infrastructure, and society will be much greater.

Climate change adaptation can significantly reduce the negative risks of climate change if all sectors of society, such as business, government, the public, and NGOs, work together and commit to adaptation initiatives.

Over the last 10 years, the Ministry for Primary Industries (MPI) has invested upwards of $50M into climate change research through the Sustainable Land Management and Climate Change program. This investment has been focused on four main areas: forestry and carbon sinks; GHG mitigation; technology transfer; and adaptation and cross-cutting issues. The fund has allocated funding through a competitive process almost annually since 2007. MPI has contracted review teams to assess the impact of this work, the return on investment and outcomes for New Zealand. The adaptation review is led by a team of researchers from MWLR, NIWA, and Lincoln University.

The overall aim of the review is to determine what we know, do not know and need to know about climate change adaptation for New Zealand primary industries. To answer these questions a number of methods have been used including a systematic review of the published literature; an assessment of SLMACC projects and reports; program specific evaluation of adaptation-related criteria; cost-benefit analysis of selected projects, and survey of stakeholders and researchers. Results will be written up and shared in a variety of formats and through different mediums.

A systematic review of the published literature was used to establish a baseline for the review. A search of several databases found only a small number (n=22) of published peer-reviewed papers that were focused on adaptation and the primary industries in NZ. Much of this literature was also focused on the impacts of climate change (e.g. increased pasture productivity due to elevated levels of $C0_2$ in the atmosphere), with very little work on the implications, adaptation and decision making, or behaviour change and documenting actions aimed at reducing vulnerability.

A typology for assessing the research was presented, drawing on recent work by several of the reviewers (Lawrence et al. 2016). One way to organise the research is through consideration of its orientation or focus along a spectrum from Impacts, through to Implications, Decisions, and Actions. Impacts-oriented research is concerned with the direct and indirect impacts of climate change, such as higher temperatures, decreased precipitation or changes in variability and extremes. The focus is on understanding how, where, and what the impacts of climate change will be for primary industries in particular. Work that is focused on the Implications of climate change is concerned with managing the negative (and

positive) effects of climate change at farm, industry and regional levels. It is guided by a need to better understand what is at risk, why and in what ways? The third category considers decision-making for adaptation. It is focused on enhancing capability and capacity to make informed risk decisions, to better understand the types of decisions that need to be made in order to mitigate the effects of climate, at what scale, and over what time frames. Finally, Acting (or Actions) is work that seeks to better understand and enable change at the individual and collective scale, to catalyse action towards adaptation planning. These four categories are not mutually exclusive, rather they have overlapping characteristics. Ideally, as research moves across this spectrum (from left to right) it involves more stakeholders and end-users in research design, planning and implementation to ensure the science is useful, useable and used. For example, Impacts-oriented research typically involves only scientists, however the addition of social-scientists, policy-, decision-makers, and communities are vital to ensuring uptake and application to real world problems.

The review of 33 SLMACC programs reveals a number of trends in adaptation research. A majority of the science investment to date has been directed towards better understanding the impacts of climate change for the primary industries. Approximately 2/3 of funding between 2007 – 2017 has gone to projects focusing on changing atmospheric conditions and its direct impacts for pasture productivity and soil moisture for example. The remaining funding has been distributed between work on implications and decision-making, with little to no work on better understanding of adaptation actions. There are also marked differences in sectoral investment, for example the pastoral industries have received over 80% of funding, with only limited investment for example, in high-value horticulture and viticulture.

Overall, the SLMACC program has been a success. It has funded diverse projects across different sectors, and has supported both biophysical and social research. Much of what we do know about adaptation in the primary industries is due to the fund. In addition to contributing to the adaptation knowledge base, the fund has played an important role in developing adaptation research capability and capacity throughout the science ecosystem. It has provided an important pathway for early-career researchers, for example, to bid for funding, gain experience managing and leading projects and develop independent research careers. New knowledge networks, and international collaborations have also been supported and developed through SLMACC-funded projects.

There are a number of barriers to seeing the full benefits of this investment being realised however. First, adaptation research in general is still funded at significantly lower levels than mitigation. Second, the focus of the adaptation research to date has been on impacts – which, while vital, is only part of the story. It is necessary to also consider the extent to which some changes are already locked in, and therefore to focus on enabling flexible and adaptive responses. This will require greater emphasis on understanding decision-making contexts, drivers, and barriers to action including cognitive, normative and financial barriers.

Other barriers – which are not necessarily exclusive to primary industries – include uncertainty and the challenges to decision making when the future is not clear; resources and psychosocial factors such as scepticism around the drivers of climate change, trust in science, and confidence in governance and institutional arrangements.

Participants then discussed the questions, framed in the context of the impact of SLMACC research to date, and potential for further investment to ensure successful

climate change adaptation in NZ primary industries. A summary of their responses follows:

SUMMARY OF DISCUSSION 1: WHAT DO WE KNOW?

Question: Based on your experience and professional insight, what has been the impact of SLMACC-funded adaptation research and its benefits and outcomes for you, your industry and/or New Zealand?

Climate change is increasingly part of long-term thinking, and is being incorporated into strategic planning.

- No direct adaptation associated with CC, but awareness of long-term trends has become part of thinking/planning.

SLMACC investment has been a valuable catalyst for CRI's to leverage strategic science investment (SSIF) and core-funding.

- NIWA often co-funds SLMACC through core funding
- Most SSIF funded work is core research building core capacity (e.g. RCM development) → These capacities are utilised by researchers in SLMACC projects.

SLMACC investment has played an important role in enhancing research capability and capacity.

- Internally at CRIs through co-funding, ECR researchers, and through opportunities to develop international partnerships and collaborations.
- Build-up of research teams.
- SLMACC has advanced our knowledge of CC impacts and our modelling capability.

Sector-specific information has been useful, useable and used – and in demand/enhanced awareness/increased understanding

- Clark and Nottage (2012) seminal report
- Adaptation for 1° industries pub'd 2012 – series of reports looking at different parts of the picture (Clark and Nottage)
- Another impact of SLMACC will be for the IPCC sixth assessment report NZ+Aus chapter → great source of published informatio for the assessment.
- Interest from govt (PCE)on more impacts (supply side information, demand)
- Climate change adaptation workshops for farmers. 2012 – 2013? (Kenny?)

There are still gaps in our understanding, and research that hasn't been effectively utilised.

- Impacts of climate change on biosecurity/biodiversity
- List of SLMACC research:
  - To check that users (e.g. industry) have seen the reports.

Other research

- Deep South

- OLW
- Implications of CC drought + flood risks for the agri sector in NZ. Farnaz Pouzard, PhD student at VUW w/Ilan Noy

SUMMARY OF DISCUSSION 2: WHAT DO WE NOT KNOW?

Question: What adaptation knowledge gaps remain (given SLMACC and other work?) Where are they (which sector) and where do they lie on the spectrum (from 'Impact' to 'Action')? Do the needs vary from sector to sector? How?

There is a need to move beyond knowing about the impacts of climate change, towards better understanding its decision-implications, and actions that can reduce vulnerability.

- Research shift: Impacts → Implications
- Need to move from impacts to implications and implementation.
- Social science research ☺
- How do groups/people interpret/understand the impact of stuff.
- *Applied actions
  - Solid understanding of work in this space.
- Most of SLMACC research has been 'impact" orientated
  - This is natural as it reflects the evolution of science capability in this space.
- Actions orientated research is challenging as most actions are not with respect to long term.

Effective engagement for adaptation action.

The "how" engagement:

- More research into tools for effective engagement with stakeholders and their differing needs.
- Integration engagement.

Difficulty in bringing people together to discuss

- Louise Gibson Fed Farm
- Best extension practice to get uptake on the ground.
- What does it mean to be a farmer and what critical decisions does it relate to.

Leveraging post-disaster 'windows of opportunity'.

- Concentrate on communicating shortly after events (e.g. late frosts).

Vulnerability hotspots.

- Which regions need attention, when?

Breadth and depth of information required to support robust adaptation.

T-shaped research - Disciplinary boundaries become increasingly unclear when grappling with "wicked problems," which present a complex set of policy, cultural, technological, and scientific dimensions. "T-shaped" research, i.e. depth and breadth of knowledge, from multiple perspectives is needed to play a critical role in complex adaptation problem-solving.

Sectors have different needs:

- Temperature (av.)
- Drought/flood
- Extremes of temp.

Implications

- Sector needs are quite different
  - Depends upon their sensitivity to climate
  - Depends on how much they need to do long term planning.
- Climate scenarios e.g. projecting for different regions

GHG implications of particular adaptations for livestock industry.

- GHG emissions reduction will be increasingly important to the livestock sector.

Assessing adaptation turning points, tipping points, and thresholds.

- How much can each sector take of each of these things in each region?
- Differs by ← composition of stakeholders
- → Environment in the context of ….
  - Policy/Governance
  - Regulation
  - Markets etc.

Need to understand the whole of the system's structure

- Need for systems-based assessments, including natural ecosystems → interactions/feedbacks

New knowledge synthesis and understanding adaptation knowledge networks is required.

- Need for lit reviews/summary sheets/SLMACC book
- Knowing who is funding what and how it all fits together - integration.

New tools, processes and practices are urgently required.

- Need for more tools, like the UKCIP Adaptation Wizard

Gaps associated with impacts and implications of policy decisions associated with climate change.

- E.g. ETS, Billion Trees
- or associated with other policies
  - e.g. water quality ≠ nutrient limits

Multiple stresses

- Increases CC and other stresses
- AR5

Impacts, implications of current decisions

- Other policy areas
- Other aspects
  - Water availability

Translate science into practical on-farm actions.

Adaptation actions - assess how they fit into existing farm systems or how farm systems will need to change and how this will affect profitability, environment and social/cultural aspects.

- Literature review summarising everything, an IPCC type report for the primary sector
- Update of Clark & Nottage 2012

SUMMARY OF DISCUSSION 3: WHAT DO WE NEED TO KNOW?

Question: If you could recommend priorities for adaptation research what would they be and why? What recommendations do you have for MPI regarding the future of the fund? What are the strengths of the SLMACC program (to retain) and weaknesses (to mitigate)?

Regional, and sector specific vulnerability assessments across NZ

- Most effective mechanisms to apply adaptation pathways approach to enable effective engagement
- Need social science to understand whole systems at a reginal level
  - All stakeholders
  - Market implications, cultural/social heritage etc.
- Research needed that moves from impact to the needs of
  - specific industries
  - so that it is relevant and meaningful
- Seems to be a specific need to understand needs of: VITICULTURE
- Geographical/regional mapping of what climate change impacts will be where.
- Need to move on from knowledge base – need it but need to move on
  - Specific to industry (viticulture, kiwi etc.)
  - Understand needs of regions and crops

- Need specific adaptation strategies.

Whole of systems joined up consideration over a range of factors

- Climate change, water quality, biodiversity, soils, economics, and social impacts.
  - Triple/Quad bottom line approaches to assessment of options
  - Environment/social/cultural/economic

Understand decision making processes for people when faced with need to adapt.

- e.g. maintain existing land use or shift to new land use, what are the barriers to action?

How to incentivise adaptation?

- What drives behaviour change for farmers?

Understand / research land use suitability for all areas of NZ

- Link between Adaptation Pathways SMACC and Deep South/OLW project

Understanding which regions and sectors are most resistant to change and why

- Are there 'quick wins' – sectors/regions that are receptive to change?
  - e.g. drought prone areas – looking for solutions?

Need for more sensitivity analyses.

- Start at the decision end, rather than at the impacts end
- Consider the current vulnerabilities and how to minimise these (plus consider future hazards/risks)
- Use the wealth of knowledge on impacts of CC to help shape the discussions on future vulnerability (but don't start with the CC impacts and expect people to make change).

Understand the opportunities associated with climate change.

- Focus on positives and opportunities
  - e.g. fewer frosts, longer growing seasons, new crops
- Demonstration farms should be used to show potential for changing management options/crop types etc.

Understanding the adaptive capacity for primary sector

- Adaptation options /roots where they are going to have the most impact, who are they useful to, where does there need to be more research/options for adaptation?
- Cost/benefit vs cost of not adapting.

Climate resilient PIs (interdisciplinary researchers?)

- More socialising of the SLMACC outputs
  - Key messages

- Including a discussion on CC in other conversations.
  - e.g. during workshops etc. on topic like animal genetics, erosion control, nutrient management, irrigations schemes etc.

Turning the science into a useable form

- For (a) rural professionals to provide advice to sector landowners (b) for land users to make decisions.

SUMMARY OF DISCUSSION 4: HOW CAN WE CONTINUE TO SUPPORT THE DEVELOPMENT OF CLIMATE-RESILIENT PRIMARY INDUSTRIES?

Question: How might we continue to support adaptation in the NZ primary sectors? What could this look like and how best to progress this and other conversations about adaptation?

Strengths – what to keep?

- Essential for SLMACC to continue to at at least the same funding level.
  - One of the few places this research is being done.
- Need to continue the fund to begin to move on from the impacts research to implications and applications.
- Keep doing good impact modelling, particularly systems models
  - Support the climate change, impact modelling community in NZ.

Weaknesses – what needs to be changed?

- The small pot of money for specific projects does not result in big picture systems modelling.

CLOSING STATEMENT

In a closing statement, the participants of the climate change adaptation workshop agreed that adaptation is not just one step, but a continuing process that must be reviewed and changed with the changing climate.