Adapting to climate change: Information for the New Zealand food system

A project for the Ministry for Primary Industries
Sustainable Land Management and Climate Change Fund

Agreement Number SLMACC 405204

Final Project Report

By

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Workshop 1: Confirmation of project scope and identification of priority issues

Workshop 1 sector attendees:

AgResearch
Deer NZ
ESR
Farmlands
Fonterra
Massey University
Meat Industry Association of NZ
MPI
NIWA
Oceania Dairy Ltd
Seales Winslow limited
Zespri

Workshop 2: Presentation of initial findings and refinement of subjects for further investigation Workshop 2 sector attendees:

Tegel
AgResearch
DAIRYNZ
ESR
Fonterra
Massey University
MPI
NIWA
Seafood
Seales Winslow
Zespri

Workshop 3: One to one interactions between project team members and sector representatives, including:

Ngāi Tahu Seafood

Shellfish production and technology (SPATNZ)

New Zealand Avocados

New Zealand Apples and Pears

Foundation for Arable Research

Te Rūnanga o Ngāi Tahu

Seafood New Zealand

Aquaculture New Zealand

HortNZ

Meat Industry Association

Fonterra

Ahuwhenua Trust

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Contents

Executive summary

It is very difficult to say what the New Zealand primary industry and food system landscape will look like in 2050 and 2100. Global socio-economic trends may proceed along a highly globalised and sustainable pathway with subsequent low (or zero) greenhouse gas emissions and relatively mild climate changes; or they may proceed along a highly regionalised and resource-intensive pathway where greenhouse gas emissions are high and unabated and climate changes are at the top end of current projections. Or, it might be somewhere in between. Each one of these global pathways will have local, national and international consequences for the New Zealand primary industry and food system landscape.

It is acknowledged that timeframes out to 2100 are much longer than planning horizons usually considered by the individual entities within primary production sectors and the food system. Nevertheless, at a sector-wide level, an appropriate response is to be aware of the potential risks, particularly those associated with top end climate projections, and incorporate an assessment of these risks into any long-term planning and strategies.

This study has produced a series of climate change and food system risk matrices and fact sheets, based on a qualitative assessment of the literature and through workshop discussion and subsequent stakeholder review, for the following sectors: meat, arable, dairy, horticulture, wild foods, and seafood and aquaculture. Each risk matrix includes a number of possible sectoral impacts and the associated risk level in 2050 and 2100 based on a high atmospheric greenhouse gas concentration pathway. The matrices also include potential adaptation responses to the impacts, and the subsequent likely modification to the risk level associated with implementing the adaptations. For almost all impacts, adaptation will lead to a reduction in the risk. However, also for almost all impacts, the climate change related risks are not eliminated through adaptation.

Where practical, opportunities are also presented. At some level, they also assume adaptive measures will be taken. For example, the climate may become more favourable for growing both traditional and non-traditional plants, including pasture, avocadoes and kumara. Taking advantage of such opportunities also implies that industry is prepared to move to areas where the climate is more suitable and that other risks e.g. pests have been considered. Other opportunities may exist that include the harvesting of nuisance species e.g. undaria, that may bring other-benefits (ecological) to the primary sector.

To follow is an overview summary of the principal climate change impacts (based on very high pre-adaptation risk in 2100, corresponding to the high atmospheric greenhouse gas concentration pathway known as RCP8.5) for each sector, plus the potential adaptation responses that could reduce these risks. More detail on these and other potential impacts, risks and adaptations can be found in the sectoral risk matrices and fact sheets. Finally, gaps in knowledge and areas for future research are considered at the end of this report.

Sector	Principal impacts (RCP8.5)	Potential adaptations
Meat & Dairy	Increase in heavy rainfall events and flooding will favour contamination of feed or water for stock leading to greater pathogen load in faeces.	Strengthening of on-farm food safety management programmes.
	Increases in heavy rainfall and flooding will favour contamination leading to increased fungal infections in silage making and increase the risk of mycotoxins. Increases in dry matter content may also pose a risk in terms of level of contaminants.	Improvements to feed, handling and storage.

	Increase in humidity may result spread of facial eczema.	Change in cattle breed or use of genetically resistant animals. Monitoring pasture spore count during danger periods (minimum temperatures are above 12°C for two or three nights and humidity is high (usually January to May)) and either dosing animals with zinc or spraying pastures with a fungicide.
Arable	Increased temperatures and changes in rainfall may increase some crop diseases. The use of pesticides will likely increase. Amounts of pesticide in environment and applied to food items will therefore increase. Increases in heavy rainfall will increase flooding events contaminating land, spreading anti-biotic resistant organisms and increase the risk of fungal growth. Increased or new residues in food. Increased risk of foodborne disease. Changes to available suitable agricultural land, as sea levels rise, and low lying coastal areas become inundated with saline water.	Use of technologically-advanced foods (GMO). Use of new resistant commercial crop types and/or new species to avoid chemical treatment. Strengthening of food safety management programmes. Integrated management of water sources, soil, wildlife intrusion and manure application. Use of new salt-resistant commercial crop types and/or new species. Movement of some crops including their biocontrol systems away from coastal farmland. Change in land use. Some mitigation where economically viable.
Horticulture	Increased flooding could increase the spread of pathogens from animal faecal matter to plant systems. Increased temperatures and therefore inadequate winter chilling required for production. May increase the use of chemicals such as hydrogen cyanamide to compress budbreak and flowering. Increases in heavy rainfall will increase flooding events potentially contaminating land with fertilizer and chemical residues from neighbouring land used for livestock. Flooded land will affect moving in and	Strengthening of food safety management programmes. Integrated management of water sources, soil, wildlife intrusion and manure application. Movement of some plants further south, especially those requiring winter chilling. Strengthening of on-farm and food safety management programmes. Allocation of horticulture land to dedicated areas.

	around crops, e.g. for spraying, harvesting, machinery etc. Changes to available suitable agricultural land as sea levels rise and low lying coastal areas become inundated with saline water.	 Use of new salt-resistant commercial plant types and/or new species. Movement of some plants including their biocontrol systems away from coastal farmland. Change in land use. Some mitigation where economically viable.
Wild foods	Increases in heavy rainfall will increase flooding events contaminating estuaries and seawater food gathering sites. Increased risk of foodborne disease. Increase in ocean temperature will change the prevalence and range of marine pathogens. Increases in heavy rainfall will increase flooding events contaminating land, spreading anti-biotic resistant organisms and increase the risk of fungal growth. Increased risk of foodborne disease. Increase in ocean acidity (decreased pH) affects uptake of cadmium by shellfish. Increased seawater temperature results in increased range and frequency of algal toxin blooms.	Integrated management of water sources, soil, wildlife intrusion and manure application. Greater marine protection and enforcement at gathering sites. Increased warnings and education in areas at risk of contamination. Public health messages regarding food cleaning, handling (washing) and storage (refrigeration). Increased monitoring of harvested shellfish. Increased warnings and education in areas at risk of contamination. Integrated management of water sources, soil, wildlife intrusion and manure application. Public health messages regarding shellfish consumption/safety. Increased monitoring for potential blooms - expansion of current monitoring programme.
Seafood and Aquaculture	Increase in ocean acidity (decreased pH) affects uptake of cadmium by shellfish. Increased seawater temperature results in increased range and frequency of algal toxin blooms.	Public health messages re shellfish consumption. Increased monitoring for potential blooms - expansion of current monitoring programme. Harvesting controls. Selective breeding for shellfish more resilient to reduced aragonite

	Changes in ocean pH through acidification affects growth of feral and farmed shellfish (including pāua).	saturation associated with carbon dioxide emissions. Use of hatcheries to get past larval rearing crux.

Introduction

The primary industry sector in New Zealand comprises of agriculture, petroleum and minerals, forestry, agriculture forestry and fishing support services, forestry and logging and aquaculture and fishery. Each sector plays an important role in New Zealand's economy, accounting for $16.333 million dollars in primary production (for 2016) (MBIE, 2017).

In New Zealand, primary industry land use is often focused on particular regions, and climate is an important driver for location (for example see land use map at http://www.mfe.govt.nz/publications/environmental-reporting/enz07-dec07/html/chapter9-land/figure-9-3.html).

The success of these industries can be attributed to New Zealand's climate, soils, biosecurity system and a reliable supply of water. Normally land-use is determined by slope, soil type and water. Changes in temperature and carbon dioxide levels under climate change have the potential to affect land use, for example as shown by a study of shifts in the balance between C3 and C4 grasses (Dodd et al., 2009). Water availability will affect regional distribution of dairy farming, particularly where such farming is only possible due to irrigation.

This project addresses a specific topic in the 2016/17 Application Guidelines for the Sustainable Land Management and Climate Change Fund administered by the Ministry for Primary Industries (MPI):

"Theme 1: Impacts of climate change and adaptation"

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

Project 1.4

Impacts of climate change on the New Zealand food system. An assessment of the impacts of climate change on the New Zealand food system, assessing issues such as cold storage, food spoilage, food safety, changing food disease profiles and harvest times and impacts with a focus on the impact of increased temperature."

The project proposal was submitted by a collaborative group, including scientists from three partners from the New Zealand Food Safety Science and Research Centre (NZFSSRC). The collaborating institutions were the Institute of Environmental Science and Research (ESR), AgResearch, and Massey University, from the NZFSSRC, and the National Institute of Water and Atmospheric Research (NIWA).

Methodology (summarised from project proposal)

This SLMACC project will use recently-updated climate projection information based on downscaled output from global climate models analysed for the IPCC Fifth Assessment Report (AR5) for both terrestrial and coastal areas of New Zealand to assess in a qualitative manner changes requiring preparation and adaptation by the national food system. The potential impacts of climate change on the food system are wide-ranging, and include changes in production patterns and inputs, food safety and associated public health issues, and food preservation and spoilage prevention. The information provided by this project will enable the various food sectors to anticipate and adapt to climate change, to maintain production and manage changes in existing risks, and identify new opportunities arising from the changes.

Project scope: The wide range of potential impacts, issues and hazards will need to be agreed through discussions with industry, iwi and MPI. Thus, at the inception of the project, these stakeholders and end users will be asked to engage in more detailed discussions at a preliminary workshop in order to elicit and describe priority concerns from each sector. In particular, the emphasis given to primary production in the project scope will need to be clarified, as this topic has been addressed by other studies (especially those by the New Zealand Climate Change Centre).

Timeframe: Projected climate change over the next 50-100 years will be used, which is the timeframe over which significant changes will occur requiring attention by the food system.

Climate change projections: Updated climate projections based on IPCC AR5 global models, downscaled to a 5km grid, will be provided by NIWA. Climate variables include precipitation, temperature, relative humidity, wind strength and direction, solar radiation, and atmospheric pressure. Derived variables, such as the number of days above critical temperatures, precipitation or humidities may be produced, if relevant. For example, (Holland et al 2014) found the annual number of days exceeding 10 mm rainfall per day was associated with campylobacteriosis incidence risk.

For coastal marine climate changes, relevant to fisheries and aquaculture, projections from the NIWA Regional Climate Model will be used directly.

Food systems have been defined as the processes by which food is produced, processed, distributed, retailed, consumed and the associated waste products disposed of, as well as the associated inputs and outputs at each stage (Acres 2010).

For the purposes of this proposal, we expect to specifically address:

1. **Effects of climate change (especially temperature increase and changes in moisture/humidity) over the next 50-100 years, based on previous studies and expert-guided assessment, on:**

    - Primary production patterns (livestock, arable and horticulture, seafood, geographic distribution, seasonal cycles and harvest changes, harvesting of wild foods)
    - Food chain to retail (processing, transport, storage, potential for contamination of food)
    - Hazard behaviour (microbial – enteric bacterial pathogens, fungi, viruses) and associated human health risk
    - Hazard behaviour (chemical, including mycotoxins, agricultural chemicals, algal toxins, antimicrobials) and associated human health risk
    - Spoilage (microbial degradation)
    - Consumer behaviour (demographics, food preferences and consumption, preparation behaviours)
    - Regulatory monitoring and controls

2. **New Zealand future scenarios**

    The amount of climate change New Zealand will experience over the coming 50-100 years is uncertain. This is principally because global greenhouse gas emissions, the anthropogenic driver of climate change, over the same timeframe are as yet unknown. As a result, assessments of climate change impacts can only be done using a range of future scenarios. These scenarios not only include the likely climate changes, but also the global socioeconomic behaviour patterns and pathways that have led to relatively lower or higher global emissions. Recent work in the MBIE-funded “Climate Change Impacts and Implications to 2100” (CCII) project, which finished in September 2016 but has continued under the Deep South National Science Challenge, has assessed a small set of these future global socioeconomic scenarios and what they might mean for New Zealand. We will use this work to explore their implications for the food safety system globally and in our country.

3. **Adaptations and risk management to maintain food security, food safety, product quality and marketability, market access.**

   We need to prepare for climate change and adapt to its impacts to the food system. Adaptations may occur at all stages of the food chain, for example climate change may affect the geographic range and severity of parasite infection in ruminants resulting in more use of anthelmintic treatments thus increasing consumer exposure to residues. Intervention at the primary production level may include more stringent control of supply or changes to more resistant breeds, while intervention at the processing level may include more frequent meat sample testing.

The methodology for this project is presented as *three objectives*:

1. Review available data. This initial phase will comprise both literature review and an interactive workshop with representatives from MPI and the food system. The facilitated workshop will fulfil three important requirements for the project: (i) to assemble and engage with a network of food system representatives to help define the project scope, (ii) to provide sector specific background information and data on the New Zealand food system that is relevant to climate change, and (iii) to serve as an audience and communication channel for communication of outputs and direction of next steps.
2. Scenario analysis: Led by the climate change potential future scenarios under a variety of Representative Concentration Pathways (associated with socioeconomic factors), we assess impacts on the food system. These estimated impacts are presented to a second workshop (including the same audience), for discussion and review.
3. Recommended adaptation options: Practical and cost-effective options for climate change adaption are developed by the research team, and then presented at a final workshop.

Outputs:

1. Written report, organised by sector (as agreed with industry and MPI), containing recommended actions to address priority issues (prioritised by potential economic and public health impact).
2. Output workshop to provide an opportunity for industry and MPI representatives to discuss further the project recommendations.

Project timeline

Following contracting the project officially commenced on 17 February 2017, to conclude on 1 December 2017. Three workshops with industry and regulatory stakeholders were planned and incorporated into milestones.

The first workshop was intended to confirm the project scope and identify priority issues. This workshop was held at Massey University in Palmerston North on 22 February 2017.

The second workshop was intended to present initial findings, and agree subjects for further investigation, and was held at the same venue on 25 July 2017.

The first two workshops had shown that it was difficult to secure attendance by representatives of all food system sectors, and so the third workshop plans were amended to become a series of one-on-one meetings with individual sectors. This change was agreed by MPI. These meetings were held either face-to-face or by videoconference/teleconference or over e-mail discussions and were conducted over the period October to November 2017.

Scope of this report

The two workshops in February and July were very helpful in giving direction and scope to the project. From the minutes of the first workshop:

Primary production needs to be a focus for the project because:

- Primary production is where the major changes will occur, changes are already happening (greater variability in climate) so adaptations will be needed even if greenhouse gas emissions can be reduced
- We can't separate effects on primary production from post-primary food chain
- Post-primary parts of the food chain already manage issues relevant to climate change, and have the tools to do so as issues arise
- The research team will perform additional literature review and liaise with the current SLMACC synthesis project teams.

Priority for further investigation by the research team:

- Food safety issues (pathogens, AMR, chemical hazards) arising from changes in primary production practice as a result of climate change

Secondary priorities for investigation if resources allow:

- Farming changes (geographical distribution, product/animal changes and diversification)
- Energy use and alternative sources
- Land use changes (linked with energy and water use changes)

After the first workshop, to address the sector based outputs described in the project proposal, the project team developed a series of summary sheets, each containing a "risk matrix". The matrices included a table of hazard based risks, which were assigned a colour coded ranking of level of current risk (by region if appropriate), and future ranking for the year 2100, based on climate change projections. The matrices also included potential adaptations, and a comment about residual risk should an adaptation be implemented. The summary sheets (up to 3-4 pages) for each sector also included contextual information about climate change relevant to the sector.

Draft versions of the risk matrices and summary sheets were presented and discussed at Workshop 2. The format was generally positively received, and suggestions for improvements were made, in particular including projections fora shorter timeframe, to align with the timeframes for industry planning. A request was also made for information on a regional basis, particularly to support local and central government regional planning.

Further details on the design and discussion from Workshops 1 and 2 are given in Appendix A.

This report contains:

- An overview of climate change projections for New Zealand, and direction to information on a regional basis
- Literature review summary of the effects of climate change on the food system organised by sector, including New Zealand information where available, and selected overseas information
- Discussion of effects of climate change on cross cutting issues across sectors (antimicrobial resistance, biological control agents) and specific consideration of the food chain beyond the farm gate
- Feedback from sectors unable to attend workshops

- Discussion and suggested further studies
- Appendix A: Summary information from Workshops 1 and 2
- Appendix B: Six summary sheets including risk matrices for sectors: meat, arable, dairy, horticulture, wild foods, seafood and aquaculture. The summary sheets include case study information on Shiga-toxin producing *Escherichia coli*, Theileria Associated Bovine Anaemia (TABA)), where appropriate
- Appendix C: Literature information and workshop commentary on food system risks and adaptation options in table format and organised by sector (with references)

Climate change data, models and scenarios

The Intergovernmental Panel on Climate Change (IPCC) Fifth Assessment Report (AR5) Working Group Reports, Summary for Policy Makers and Synthesis Report were published in 2013 and 2014. The majority of the Working Group 1 assessment was based on output from the Fifth Coupled Model Intercomparison Project (CMIP-5) Global Climate Models (GCMs; IPCC 2013b). The number of GCM runs submitted to CMIP-5 (around 40, with varying run lengths) was much larger than for CMIP-3 (the models used for the previous IPCC AR4).

The climate change projection information used in this report is based on a selection of the CMIP-5 GCMs that have been dynamically and statistically downscaled for New Zealand (approximately 5km grid covering all of New Zealand). These projections are consistent with that published in MfE (2016). As described in the MFE (2016) report, climate projections for New Zealand are presented as scenarios based on alternative future pathways of atmospheric greenhouse gas concentrations (so called "representative concentration pathways" or RCPs). Furthermore, the climate projections for each RCP contain uncertainty associated with the global and regional climate models used. For the risk matrices presented in this report, we have focused on RCP8.5 (a high greenhouse gas concentration pathway) and have based the climate change information on the average of the global climate models assessed in MfE (2016).

NZ projected changes in climate

The global climate models (GCMs) used to make future climate change projections require information about future concentrations of greenhouse gases and aerosols. For the IPCC Fifth Assessment (IPCC, 2013), a new set of four forcing scenarios was developed, known as representative concentration pathways (RCPs) (van Vuuren et al 2011). These pathways are identified by their approximate total (accumulated) radiative forcing at 2100 relative to 1750:

- 2.6 W m^{-2} for RCP2.6
- 4.5 W m^{-2} for RCP4.5
- 6.0 W m^{-2} for RCP6.0
- 8.5 W m^{-2} for RCP8.5.

These RCPs include one mitigation pathway (RCP2.6. which requires removal of some of the CO_2 presently in the atmosphere), two stabilisation pathways (RCP4.5 and RCP6.0), and one pathway (essentially ‘business as usual’) with very high greenhouse gas concentrations by 2100 and beyond.

Figure 1 compares the SRES (emission scenarios used in previous IPCC Assessments) and RCP atmospheric carbon dioxide concentrations. CO_2 concentrations under RCP4.5 and RCP8.5 are very similar to those of the SRES scenarios B1 and A1FI, respectively.

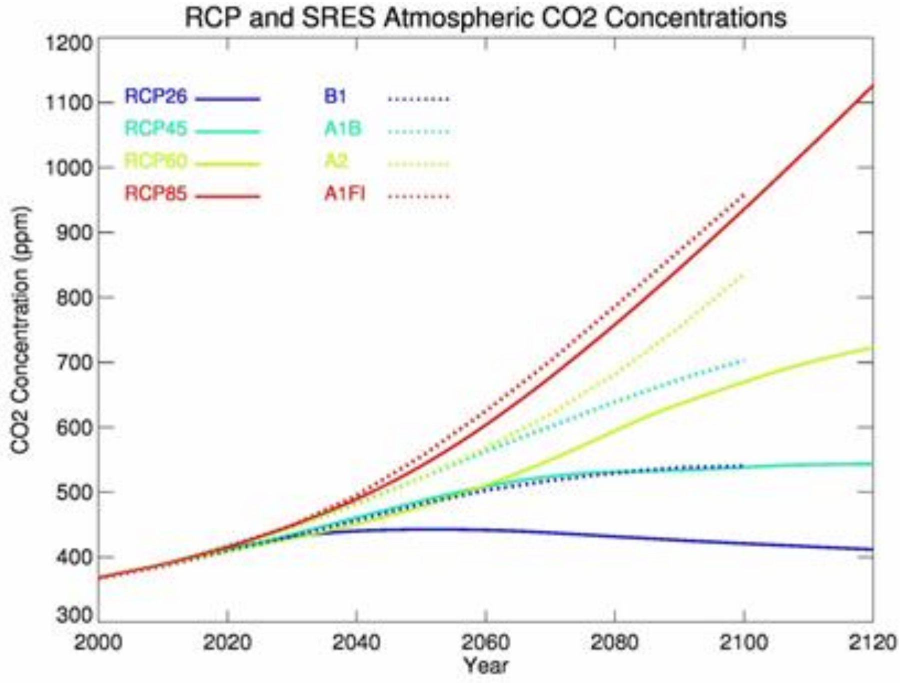


Figure 1: **Atmospheric carbon dioxide concentrations for the IPCC Fourth Assessment (dotted lines, SRES concentrations) and for the IPCC Fifth Assessment (solid lines, RCP concentrations) (MfE, 2016).**

The Ministry for the Environment (2016) report is a comprehensive up-to-date assessment of projected climate changes for New Zealand, based on downscaled GCM data produced for the IPCC Fifth Assessment (IPCC, 2013) and the four RCPs described above. The report contains multiple maps and figures showing projected climate changes for New Zealand (not shown here). The following summary table is reproduced from the climate projections report.

Table 1: **Main features of New Zealand climate change projections (references within this table refer to sections in the original report).**

Climate variable	Direction of change	Magnitude of change	Spatial and seasonal variation
Mean temperature	Progressive increase with concentration. Only for RCP2.6 does warming trend peak and then decline.	By 2040, from +0.7°C [RCP2.6] to +1.0°C [RCP8.5]. By 2090, +0.7°C to +3.0°C. By 2110, +0.7°C to +3.7°C.	Warming greatest at higher elevations. Warming greatest summer/autumn and least winter/spring.
Minimum and maximum temperatures	As mean temperature.	Maximum increases faster than minimum. Diurnal range increases by up to 2°C by 2090 (RCP8.5).	Higher elevation warming particularly marked for maximum temperature.

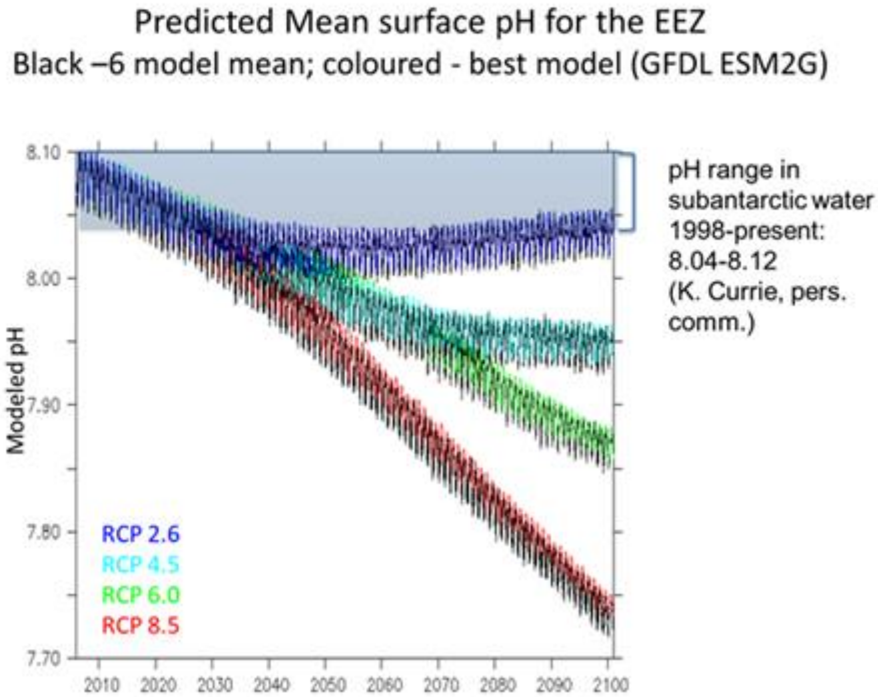
Daily temperature extremes: frosts	Decrease in cold nights (minimum temperature of 0°C or lower).	By 2040, a 30% [2.6] to 50% [8.5] decrease. By 2090, 30% [2.6] to 90% [8.5] decrease.	Percentage changes similar in different locations, but number of days of frost decrease (hot day increase) greatest in the coldest (hottest) regions.
Daily temperature extremes: hot days	Increase in hot days (maximum temperature of 25°C or higher).	By 2040, a 40% [2.6] to 100% [8.5] increase. By 2090, a 40% [2.6] to 300% [8.5] increase.	
Mean precipitation	Varies around the country and with season. Annual pattern of increases in west and south of New Zealand, and decreases in north and east.	Substantial variation around the country (see section 3.6.1, MfE 2016), increasing in magnitude with increasing emissions.	Winter decreases: Waikato, Gisborne, Hawke's Bay and Canterbury. Winter increases: Nelson, West Coast, Otago and Southland. Spring decreases: Auckland, Northland and Bay of Plenty.
Daily precipitation extremes: dry days	More dry days throughout North Island, and in inland South Island.	By 2090 [8.5], up to 10 or more dry days per year (~5% increase).	Increased dry days most marked in north and east of North Island, in winter and spring.
Daily precipitation extremes: very wet days	Increased extreme daily rainfalls, especially where mean rainfall increases.	More than 20% increase in 99th percentile of daily rainfall by 2090 [8.5] in South West of South Island. A few percentage decrease in north and east of North Island.	Increase in western regions, and in south of South Island. Decrease in extremes in parts of north and east of North Island.
Snow	Decrease.	Snow days per year reduce by 30 days or more by 2090 under RCP8.5.	Large decreases confined to high altitude or southern regions of the South Island.
Drought	Increase in severity and frequency.	By 2090 [8.5], up to 50mm or more increase per year, on average, in July–June PED.	Increases most marked in already dry areas.

Circulation	Varies with season.	Generally, the changes are only a few hectopascals, but the spatial pattern matters.	More northeast airflow in summer. Strengthened westerlies in winter.
Extreme wind speeds	Increase.	Up to 10% or more in parts of the country.	Most robust increases occur in southern half of North Island, and throughout the South Island.
Storms	Likely poleward shift of mid-latitude cyclones and possibly also a small reduction in frequency.	More analysis needed.	See section 3.7, MfE 2016.
Solar radiation	Varies around the country and with season.	Seasonal changes generally lie between -5% and +5%. (See section 3.9.1, MfE 2016.)	By 2090 [8.5], West Coast shows the largest changes: summer increase (~5%) and winter decrease (5%).
Relative humidity	Decrease.	Up to 5% or more by 2090 [8.5], especially in the South Island. (See section 3.9.1, MfE 2016.)	Largest decreases in South Island in spring and summer.

In addition to the information presented in Table 1, the following oceanic changes are projected for the whole New Zealand Exclusive Economic Zone (EEZ) region.

- Sea surface temperature (SST) and iron concentration are projected to increase (by around 2.5°C and 0.031 nM, respectively); while chlorophyll, nitrate, phosphate, and silicate are projected to decrease by, respectively, -0.043 mg m^{-3}, -0.49 µmol m^{-3}, -0.039 µmol m^{-3}, and -0.18 µmol m^{-3}. These changes are for the end of the century (compared with the period 1986-2005) and are based on RCP8.5 and the average from several global climate models (Law et al 2016).
- The rising atmospheric concentration of CO_2 is also causing 'ocean acidification', a collective term used to describe the changes in different components of the ocean carbonate system (Orr et al 2005). This change is most apparent as a decrease in pH. The projected pH for New Zealand waters is shown in Figure 2 for all RCPs. The sinusoidal pattern reflects the seasonal shift within each year of higher pH in summer (when phytoplankton growth removes CO_2) and lower pH in winter (when growth is low and mixing raises surface water CO_2). All projections indicate that the annual pH range falls below the current pH range by 2025, with only RCP2.6 projecting a return to this range by the end of the century (Cummings et al 2016).
- Global mean sea level rose by 0.19 ± 0.02 m from 1901 to 2010 (IPCC, 2013). Sea level rise around New Zealand is comparable to the global average, being approximately 0.17 ± 0.1 m for the 20th century (IPCC, 2014). Sea level is projected to rise by between 0.5m and 0.8m by the 2090s (2090 to 2099) relative to the 1980-1999. For longer-term considerations an allowance for further sea-level rise of 10 mm/year beyond 2100 is recommended (Ministry for the Environment, 2008).

Figure 2:



Predicted Mean Surface pH for the New Zealand region open ocean from a suite of six global climate models for four RCPs. The light blue bar indicates the range of pH measured to date in subantarctic water on the Munida time series (personal communication K. Currie and S. Mikaloff-Fletcher, NIWA).

Additional oceanic changes are also possible (for example, to the location and strength of ocean currents and sedimentation rates to river mouths and estuaries), however these have not been assessed in detail at present.

Regional information on climate change

The sector-based fact sheets produced for this project include some regional information about projected climate changes and impacts. For example, the north of the North Island is expected to become drier and warmer and therefore be susceptible to different impacts compared with the west and south of the South Island, where rainfall is expected to increase.

At one of the project workshops, it was suggested that regional fact sheets (including impacts across multiple sectors) would be useful. However, when the project team trialled the production of regional fact sheets they became excessively large and difficult to interpret.

Therefore, instead of the project team developing unwieldy regional fact sheets, it was agreed that users could more easily extract sector-specific regional information from the sector fact sheets and summarise this information for themselves. In addition, users are directed to the regional climate change pages on the Ministry for the Environment webpage:

http://www.mfe.govt.nz/climate-change/how-climate-change-affects-nz/how-might-climate-change-affect-my-region

Literature Review: Sector Specific Food System Risks and Adaptation Options

The literature relevant to this report is a mixture of scientific papers and discussion documents, usually prepared by government agencies. To locate this material, the following approach has been taken:

A literature search using the search engines "Web of Science", "Google Scholar", "Google", "Science Direct databases", and "Pubmed" using the search terms "climate change" together with either "food safety system" or "food system" and "New Zealand" and limited to the years 2010-2016 inclusive was completed. For some search engines, where the results of the search provided only a few documents, the search years were extended to the year 1990 and specific search terms were used i.e. "Primary production", "food transport", "food processing", "food storage", "food preparation", "processing plants", "animal stock", "plant farms", "coastal waters", "abattoir", "food production". A more general web search using the same search terms and both including and omitting "New Zealand" was carried out using Google and Google scholar to search for other relevant publications (e.g. Ministry documents), international articles and reports and the grey literature. Each abstract was read for its applicability to this review, and included where deemed relevant.

For the adaptation options, the literature review was extended, separated into each industry sector and examined for food safety and system risks arising from changes in primary production practice as a result of climate change.

Considerable work has already been completed examining the effect of climate change on New Zealand agriculture; much of this has been published on the MPI SLMACC web site.[1] Relevant MPI reports from this site have been integrated into this report. In particular, the extensive report by Clark et al., 2012 is an important resource for the primary sector.

For the purpose of this project, only reports considered relevant to the food system were reviewed; for example, this excludes reports on forestry, carbon markets, water infrastructure, and animal greenhouse gas emissions.

Climate change impacts projected for each sector, food safety issues and common adaptation measures from the international scientific literature, Workshop 1, and the ideas from the SLMACC team are summarised here. A summarised table on system risks, adaptation options and the relevant links to the literature can be found in Appendix C.

[1] https://mpi.govt.nz/funding-and-programmes/farming/sustainable-land-management-and-climate-change-research-programme/sustainable-land-management-and-climate-change-slmacc-research-reports/ accessed 23 January 2017

Dairy Sector

<u>Climate change may allow the establishment and spread of new exotic pests, sleeper pests, natural enemies, weeds and diseases resulting in disease outbreaks:</u>

- Mycotoxins, including aflatoxins, particularly in stored grains, nuts (including imports) will increase in range, type and amount due to increasing hot humid conditions. Harmful fungal metabolites under dry, hot conditions can also contaminate cereals and pulses during crop growth and post-harvest.
- When cows consume aflatoxin-contaminated feeds milk products can also serve as an indirect source of aflatoxins.
- Control responses may generate food safety problems due to the novelty of the pests in question as well as the unfamiliarity of farmers using the controls such as new pesticides or other measures.
- Pesticide, veterinary drug and antifungal residues in the environment may increase in response to changes in plant, animal diseases and pests.
- New or higher residues in food may occur, some from new approvals.
- Increased risk of antibiotic-resistant pathogens developing.
- Increases in animal diseases, e.g. tick associated bovine anaemia, leading to more reliance on veterinary medicines.

<u>Increased winter rainfall coupled with milder winter temperatures in some areas may require greater use of anthelminthics in young grazing cattle:</u>

Parasites life cycles are temperature and moisture sensitive and broadly speaking the development rates of eggs and early larval stages of helminths increase with increasing temperatures with desiccation as a limiting factor. Similarly, the development and distribution of the snail host of liver fluke is sensitive to moisture and temperature. Liver fluke has a more complex life cycle with specific water snails as an intermediate host. Fluke infection is more common on farms with slow moving water for the snails and a climate that suits the development requirements for both the snails and the flukes. Currently liver fluke infections commonly occur on the east and west coasts of the North Island and the west coast of the South Island. Thus, both with helminths and flukes climate change will affect the distribution, life cycles and the use of anthelminthics. The impact of this in terms of food safety/systems is an increase of antihelmintics residues in raw milk if with-holding times are not adhered to or if off-label use occurs.

<u>Increase temperatures and rainfall may result in the spread of facial eczema:</u>

Facial eczema (FE) is a major, endemic disease of NZ grazing livestock with serious welfare and production implications. In a related SLMACC project "*The effect of climate change on grazing livestock health in New Zealand*" workshop held October 24 2017, it was an identified priority disease. FE is caused by toxin (sproidesmin) produced by fungal spores from (*Pithomyces chartarum*) on pasture. The risk season generally runs from late December until May. Currently it is considered a North Island issue but it can also occur on the west coast and top of the South Island, and in Canterbury on irrigated dairy pastures. Ideal conditions for fungal growth are warmth and humidity, especially when night-time and grass minimum temperature is above 12 degrees C and rainfall is regular. Although called FE it is primarily a liver disease with facial and other skin changes due to secondary photosensitivity. There is no prevention or vaccine and zinc treatment, monitoring spore counts and pasture spraying/management are the cornerstones of control. Zinc protects the liver against the oxidative damage caused by sporidesmin and zinc oxide (ZnO) drenching or long-term dosing is the preferred protection. The most common method of delivering this to adult cattle is through oral dosing during high risk periods.

- There is no recognised concern to human health and globally systemic zinc toxicity is not a major health problem.
- There is some evidence to suggest that increased stress in animals (for poor health) can lead to increased food safety risks.

<u>Intermingling, crowding of food animals in response to natural disasters or climate:</u>

- Promotion of the transmission of pathogens between animals, resulting in greater pathogen load on hides and in faeces.

<u>Increased bacteria and biofilms in milk during transportation:</u>

- Bacteria within biofilms of dairy origin can increase with ambient temperatures.
- Biofilms may produce protiolytic enzymes.

<u>Climate change may require new sources of feed ingredients, storage and intake and conditions of compound feed storage:</u>

- Food safety issues, in particular mycotoxins.
- New raw materials and fewer varieties may increase food safety risks.

<u>Warmer and wetter conditions and flooding will favour contamination:</u>

- Contamination of pasture and silage by soil, manure and water. Parasites may also be a problem.

<u>Higher humidity:</u>

- May increase fungal infections in silage making and increase the risk of mycotoxins. Increases in dry matter contact may also pose a risk in terms of level of contaminants.

<u>Generic climate change:</u>

- May favour the introduction of exotic animal diseases through establishment of arthropod vectors e.g. Bluetongue virus in *Culicoides* midges. These may or may not have an effect on food safety.
- Evolution of current diseases, zoonotic diseases and foodborne infectious diseases will increase.
- Some parasites may continue to pose health issues where cycles would normally stop.

<u>Increased temperatures:</u>

- Increased temperatures can increase risk from pathogenic bacteria in raw milk.
- Higher microbial loads and parasites including ticks and helminths.
- Hot weather can reduce cows' immune systems due to heat stress and the cow can experience udder chapping, increasing pathogen entry for mastitis organisms.
- Increased animal stress, leading to reduced fertility in cattle: increased lameness.

Hot humid weather, and precipitation:

- Create muddy conditions where cows are more likely to feel tired and lay down, such that their udder will become coated with mud, increasing contact with environmental pathogens. Reduced grazing, can also occur resulting in a lowered immune system.
- West Coast may become too wet for dairying.

Hot weather and drier conditions in some parts of the country:

- Contamination of pasture and silage by emission, soil, manure and water. Parasites may also be a problem as well as increased risk of illness in cattle required use of veterinary medicines.
- Increased use of parasite and veterinary treatment leading to residues.
- Increased pathogens due to use of manure, waste water irrigation or runoff. Drier conditions could also lead to declining water quality could all lead to increases in the levels of pathogens and chemicals in food.

Summary of adaptation options for the dairy sector

Genetic characteristics of animals and feed crops can be used reduce the risk from existing and new diseases, reducing the requirements for treatment, and therefore potential residues in food. Moreover, the use of new resistant commercial crop types and/or new species can also reduce the risk of mycotoxin development in feed and subsequent illness and treatment needs in animals.

There may be new exotic diseases worth considering in terms of farm management preparedness, treatment and food safety. The likely diseases include subtropical pests, current seasonal immigrants and taxa already recognised as high risk. Establishment of such diseases may also require the use of treatments currently not approved.

Changes in farm design can help mitigate against some of the direct effects of climate change (e.g. heat stress).

There will be greater cooling requirements that will costs more in terms of energy. These can be alleviated by using more energy efficient cooling systems and sustainable energy sources.

In some cases, it may be useful to reduce herd size to decrease the risk of communicable diseases spreading during times of stress (i.e. extreme weather).

Some parts of the country will benefit from increased pasture production over the coming decades. They include increased photosynthesis allowing for more efficient use of available water and improve pasture growth rates, particularly with temperate pasture. The highest increases would be in the South Island. Drought is likely to affect summer yields of pasture such as in Hawke's Bay, Wairarapa, the eastern South Island and Central Otago. Experimental evidence points towards an increased legume component in pastures and increased use of subtropical grasses which could provide feed during times of water stress. However, those areas may also be of greater risk in terms of new exotic pests, sleeper pests, natural enemies, weeds and diseases.

During workshop 1 the dairy sector commented that they were experienced in dealing with many of the issues discussed, through its global food chains. Dairying occurs worldwide in extremes of heat and cold, there are existing tools and knowledge can be used from production through processing. Fonterra supplies in countries from -30 to 40+ °C.

Post processing mechanisms and systems are now in place – dairy is well placed to cope with climate change, especially temperature changes – as a wide range is already experienced across NZ and global markets.

Meat Sector

Increase in hot days (maximum temperature of 25°C or higher) could affect livestock production (e.g. heat stress, reproduction, feeding etc.):

- Changes to mitigate heat stress could affect food safety e.g. greater use of housing for shelter and other livestock may lead to crowding conditions.
- Higher parasite loads including ticks and helminths.

Increased temperatures resulting in heat stress:

- Higher parasite loads including ticks and helminths
- Hot weather can cause heat stress. In some animals, immune systems can reduce.
- Animal welfare may require indoor housing which has its own food safety issues (crowding etc.).

Establishment of new exotic pests, sleeper pest's natural enemies, weeds and diseases resulting in disease outbreaks:

- Increased microbial burden on carcasses and meat leading to foodborne illness.
- Increase in Salmonella in pigs
- Animals carrying more enteric pathogens in their guts or body surfaces. In particular, for pigs, the upper intestinal tract can act as a reservoir for particular strains of antibiotic-resistant bacteria.
- In poultry, research has indicated that retail products are more likely to carry higher total viable bacteria counts in summer.
- Pesticide and veterinary drug residues in the environment, crops will increase in response to changes in pests. New or higher residues in food may occur, some from new approvals.
- Climate change may affect the pesticide activity of some pesticides.
- Increased risk of antibiotic-resistant pathogens developing.
- Mycotoxins, including aflatoxins, particularly in stored grains and nuts will increase in range, type and amount due to increasing hot humid conditions. Harmful fungal metabolites under dry, hot conditions can also contaminate cereals and pulses during crop growth and post-harvest.
- When cows consume aflatoxin-contaminated feeds milk products can also serve as an indirect source of aflatoxins.
- Control responses may generate food safety problems due to the novelty of the pests in question as well as the unfamiliarity of farmers using the controls such as new pesticides or other measures.

Increased winter rainfall coupled with milder winter temperatures in some areas may require greater use of anti-helminthics as snail vectors multiply:

- Parasite resistant breeds, nutrition, pasture management, nematode-trapping fungi, antiparasitic vaccines and botanical dewormers.
- Promotion of integrated pest management and non-synthetic methods of pest control.
- Introduction of new bio control agents.

Increase temperatures and rainfall will may result spread of facial eczema:

- Increased use of zinc treatments for animals, however, there is no recognised concern to human health and globally systemic zinc toxicity is not a major health problem

Intermingling, crowding of food animals in response to natural disasters or climate:

- Food safety issues, in particular mycotoxins. New raw materials and fewer varieties may increase food safety risks.
- Promotion of the transmission of pathogens between animals, resulting in greater pathogen load in faeces.

Climate change may require new sources of feed ingredients, storage and intake and conditions of compound feed storage:

- Contamination of pasture and silage by emission, soil, manure and water. Parasites may also be a problem.

Generic climate change:

- Muddy conditions can be created where cows are more likely to feel tired and lay down, such that their udder will become coated with mud, increasing contact with environmental pathogens.
- Reduced grazing, can also occur resulting in a lowered immune system.

Hot humid weather, and precipitation:

- Parasites may be a problem as well as increased risk of illness in cattle required use of veterinary medicines.
- Contamination of pasture and silage by emission, soil, manure and water.
- Increased use of more genetically resistant animals.
- Farm design (trees) to provide paddock shade and reduce wind chill

Hot weather and drier conditions in some parts of the country:

- Increased use of parasite and veterinary treatment leading to residues.
- Pathogens may appear due to use of manure, irrigation or runoff. Contaminated irrigation water, the use of wastewater, increased demand for water and declining water quality could all lead to increases in the levels of pathogens and chemicals in food.
- Extreme drought can lead to boreholes contaminated with nitrates.
- Decreased survival of pathogens with increasing soil salinity or reduced water content.

Summary of adaptation options for the meat sector

Changing the breed or use of animals selected via genetics and using plants that are able to cope with projected changes in climate were common adaptation options. This would be particularly useful for projected increases in temperature that may lead to heat stress, reproductive issues, decreased feeding and increased parasite loading. This will also reduce the need to use veterinary medicines and subsequent residues or increased withholding periods.

Increases in pests could be reduced by using biocontrol agents and new approvals.

Improved on-farm systems that can cope with gradual and extreme changes in climate including housing for herds and changes in feedstock. For example, during Workshop 1, the poultry sector commented that micronutrients in feed are adjusted for temperature, when birds are heat stressed. In addition, housing will need to be adapted in regions where there will be extremes in heat e.g. able to cope with outside temperatures from -7°C to 40°C, using improved temperature control. Increased use of housing could also result in an increase of antibiotic use. Connected to these issues are the consumer perceptions associated with keeping animals indoors from an animal welfare perspective and a potential market shift towards more "organic" foods.

The microbial burden on carcasses may increase, leading to food chain rejection and/or outbreaks of disease. This issue was also raised during Workshop 1 by the meat and poultry sector. In particular, the potential for increased hide contamination due to increased rainfall and runoff, and extreme rainfall events, causing pasture based animals to have more contact with mud and faeces. For poultry, air chilling (uses more energy) vs current water chilling were issues. Therefore, improved detection and maintenance of efficient processing controls will be required. As well as increased microbial burden, the meat sector also commented during Workshop 1 that the types of microbial populations and disease profiles may affect the ability to meet food safety regulations for product in meat industry. This was echoed by the poultry sector adding that emerging organisms in poultry production animals could affect quantity / quality / as well as food safety. This may also be an issue with global import/export markets.

Increases in mycotoxins was an issue for feedstock with the potential for an increase in the human food chain. It is important to avoid where possible growing feedstock in warm and wet areas. Therefore, co-location of feed and stock may not be possible in some parts of NZ in the future. Mycotoxin controls include improved drying of grain at harvest, good crop husbandry, storage and transport. Fungicides should be avoided as they have been suggested to increase mycotoxin levels in some studies. It is possible to detoxify human and animal food using mostly chemicals. However, there are potential issues with consumer perceptions and newer methods are required (e.g. UV and heat treatment).

Arable Sector

Establishment of new exotic pests, sleeper pest’s natural enemies, weeds and diseases resulting in disease outbreaks:

- Use of new biocontrol agents and new approvals required leading to food residues.
- Pesticide and veterinary drug residues in the environment will increase in response to changes in pests. New or higher residues in food may occur. Pesticides may also degrade faster.
- Increased risk of antibiotic-resistant pathogens developing.

Changing of the microbial population of the macro-environment (soil, air and water):

- Biotic diseases attributable to (micro) organisms such as fungi, bacteria, viruses and insects may occur due and the population of pests or other vectors.

Changes to abiotic factors such as nutrient deficiencies, air pollutants and temperature/moisture extremes:

- Effects on plant health and productivity requiring increased use of pesticides and fertilisers or the use new approvals leading to food residues.
- Storage of feed and crops on farm may become an issue in relation to new pests and diseases (especially fungi, mycotoxins in grain).

Increases in heavy rainfall:

- Can increase pathogenic bacteria due to runoff, drainage. It can also transport bacteria to other land and water bodies that produce food.
- Possibility of splash dispersal and plant internalisation.

Changes to temperature and rainfall:

- Prevalence and geographical range of fungi producing mycotoxins are expected to increase. The dominant fungal species will be determined by meteorological conditions such that toxins produced are likely to be predicted by climate. Insects can also strongly influence the development of mycotoxins.
- Changes in food yields and food quality in terms of nutrition. Increased need for fertilisers. Increases in food sensitivity.
- Increased use of potentially contaminated alternative water sources.
- Severe water stress including projected drought in eastern or northern parts of the country.
- Changes in food yields and food quality in terms of nutrition. Increased need for fertilisers. Increases in food sensitivity.
- Increased use of potentially contaminated alternative water sources.

Changes to available suitable agricultural land, as sea levels rise, and low lying coastal areas will become inundated with saline water:

Coastal land that uses groundwater for irrigation may risk using more saline water as the water table rises with increases in sea-level that also results in increases between the interfaces of freshwater-saline water in underground aquifers.

Summary of adaptation options for the arable sector

Crops may become more susceptible to new and existing pests (including weeds) and diseases. Control of these may require increased use of traditional pesticide and veterinary drugs. In the case of new exotic pests, new approvals may be required. This may increase pesticide and veterinary drug residues, produce new residues in the environment leading to increased residues in food. Some studies also suggest that climate change could affect the activity of pesticides, including faster degradation due to higher temperatures. Increased use of pesticides and veterinary medicines may lead to resistance in pests and increase antibiotic-resistant pathogens. The use of biological controls has been suggested as an adaptation option, as well as the use of more genetically resistant crops and varieties, crop rotation methods and building resilience to climate within arable communities.

Changes to the climate will also affect the natural microbial population of soil, air and water such as fungi, bacteria, viruses and insects. Negative implications include poor nutrient content of plants, or increases in toxic elements (e.g. from the use of pesticides) and temperature and moisture extremes as well as heavy rainfall affecting plant growth. Storage on farm may become an issue and some farms may need to upgrade their storage facilities to deal with higher temperature (e.g. ventilation, infrastructure etc.). Genetic breeds that are able to withstand such changes are recommended. Increased heavy rainfall and flooding may also transport pathogenic bacteria, chemicals and waste into agricultural areas, contaminating crops and potentially spreading more antibiotic-resistant pathogens. Strengthening of food safety programmes and integrated management of water, soil and wildlife will help reduce those risks.

Horticulture Sector

Average increase in atmospheric CO_2 generating a 'fertilisation effect':

- Higher concentrations of CO_2 stimulate carbohydrate production and plant growth, but at the expense of protein and essential minerals in a number of widely consumed crops, including wheat, rice, and potatoes. This will have potentially negative implications in terms of human nutrition.
- Indirect effects on crop suitability, livestock and associated pests increasing the need for more new pesticides and fertilisers. Higher residues in food may occur. There is also an increased risk of antibiotic-resistant pathogens developing.
- Increased foodborne pathogen contamination of fresh produce by insect vectors.
- Negative implications in terms of human nutrition. Reduction in protein content and alteration of protein composition in certain plants, with the potential to alter allergenic (food) sensitivity.

Establishment of new exotic pests, sleeper pest's natural enemies, weeds and diseases resulting in disease outbreaks.

- Use of new biocontrol agents and new approvals increasing or introducing residues in food.
- Pesticide and veterinary drug residues in the environment will increase in response to changes in pests. New or higher residues in food may occur. Pesticides may also degrade faster. There is also an increased risk of antibiotic-resistant pathogens developing.

New biocontrol agents may be required:

- Increased need to use fertilisers leading to chemical residues in foods.
- Use of new resistant commercial crop types and/or new species.
- Southward movement of some crops including their biocontrol systems

Ability of soils to regulate water, supply and retain nutrients:

- Effects on plant health and productivity requiring increased use of pesticides and fertilisers or the use new approvals leading to food residues.

Changes to available suitable agricultural land, as sea levels rise, and low lying coastal areas will become inundated with saline water:

Coastal land that uses groundwater for irrigation may risk using more saline water as the water table rises with increases in sea-level that also results in increases between the interfaces of freshwater-saline water in underground aquifers.

Changes to temperature and rainfall:

- Changes in food yields and food quality in terms of nutrition.
- Increased use of potentially contaminated alternative water sources.
- Severe water stress including projected drought in eastern or northern parts of the country.
- Use of technologically advanced foods (GMO), functional foods and nanotechnology.
- Water security measures or movement to areas with more reliable rainfall/water supply.
- Drought-resistant plants. Water security measures or movement to areas with more reliable rainfall/water supply. Improvements to irrigation practises.
- Change to temperature, precipitation (patterns), and increased CO_2.

- Some food safety risks are associated with adaptation measures including development of GM crops.
- Mycotoxins are expected to increase. The dominant fungal species will be determined by meteorological conditions such that toxins produced are likely to be predicted by climate. Insects can also strongly influence the development of mycotoxins.
- There may be areas where yields increase due to expansion of suitable land. In other areas the opposite effect will occur due to decreases in water availability and increases in extreme weather.
- Increases in heavy rainfall will cause flooding, contaminating land, spreading anti-biotic resistant organisms and increase the risk of fungal growth.
- Lack of sufficient refrigerated capacity leading to food safety concerns.

Variation in the timing of the seasons, modification of the local environment such as soil:

- Degraded and drier soils, leading to reduced quality foods. Poor soils may result in increased use of fertilizers.

Changing of the microbial population of the macro-environment (soil, air and water):

- Biotic diseases attributable to (micro) organisms such as fungi, bacteria, viruses and insects may occur due and the population of pests or other vectors.

Summary of adaptation options for the horticultural sector

General increases in ambient temperature, CO_2 and precipitation will result in some positive and negative effects on agriculture in some parts of the country. Increased ambient temperatures will increase the risk of foodborne pathogen prevalence and growth, contamination of food and increase cooling requirements. Improved food cleaning, handling and storage can be used to moderate this risk. For cooling, the previous workshop suggested more sustainable energy supply with a greater focus on alternative forms of energy: biogas, solar, wind.

Water security will be a major issue for agriculture in areas projected to become drier, experience more drought conditions or become more saline due to sea level rise. This will increase pressure on alternative water sources that may become contaminated. The use of more drought resistant crops, improved efficiency irrigation, movement of some crops to wetter or more inland areas are appropriate adaptation methods. In areas where increases in rainfall are projected, or increases in more extreme rainfall, flooding can lead to contamination of soil, water and crops.

Reduced nutritional value of foods may occur requiring more fertilisers. Some adaptation measures include the use of GMO crops. Food allergies may increase due to changing crop types and/or practices. Good food processing practices are required.

New pest and diseases could increase and affect crop quality and productivity. Eco-sound farming practices, resistant crop types and new biocontrol agents will help to reduce the reliance on pesticide use.

During workshop 1 the horticulture sector raised a number of concerns, including wider ecological impacts of climate change such as effects on pollinators, shifts towards more C4 plants, reliance on rainfall for some fruit growing (requiring more irrigation in some areas) and the importance of frosts and winter chill for production which may reduce in more northern parts of the country.

Irrigation was determined as a food safety risk if alternative or contaminated water sources were used. The adaptation options proposed for agriculture are similar to those for arable with the additional increased risk of foodborne illness from leafy green vegetables by direct contamination. For all regulated foods, chronic low level exposure to low doses of chemical over long periods of time was highlighted as an issue requiring further attention.

Seafood and Aquaculture Sector

Reduction (ca. 6%, RCP8.5) in phytoplankton production in surface waters. Decline in particle flux (2.2 to 24.6% by 2100) affecting food availability for some commercial fish species:

- Increased imports of seafood from areas with minimal food safety practises, increasing risk of foodborne illness. Increased fish adulteration.

Increased pH of seawater:

- Potential threat to safety through acidification-induced increase in Cd accumulation in seafood (bivalves).

Rising ambient sea temperatures:

- Increased heavy metal and dioxin concentration in predatory fish e.g. methylation of mercury and subsequent uptake by fish.
- Accumulation of toxins by filter feeders, an increase in water temperatures promotes the growth of pathogenic organisms and subsequent consumption of contaminated foods can serious implications for health.
- Increase ambient sea surface temperatures have been correlated with increases in prevalence and concentration of *Vibrio* in seafood.

Projected increases in heavy rainfall changing sediment characteristics and reducing suitability of habitats for aquaculture species in intertidal areas of estuaries:

- Increases in contamination of shell fish through remobilisation of sediments, and terrestrial runoff of pathogens.

Increased sea surface temperature (SST) and ambient temperatures:

- Climate change is likely to affect food safety due to higher rates of microbial growth at increased temperatures, increasing importance of refrigeration in fisheries supply chains. Potential increased spoilage resulting in production of histamine from some species.
- Increased stressors resulting in reduced growth rates and increased recovery times from energy expenditure leading to reduced immunity and more diseases for farmed species. Use of veterinary medicines may increase leading to residues.
- Increasing incidence and intensity of harmful algal blooms (HAB) and toxins in shellfish, in part due to climate warming. This includes increased risk from ciguatera poisoning.
- Changes in the distribution and occurrence of pathogens found in fish such as microbes and parasites that are harmful for consumers. In particular, increases in the range and concentration of *Vibrio* species.
  Increased growth rates of parasites in fish hosts.
  Increased bioavailability and concentration of some contaminants (e.g. (methyl) mercury and persistent organic pollutants (POPs)) upwards through the food chain.

Summary of adaptation options for the seafood and aquaculture sector

Workshop 1 determined some risks to fisheries were related to sea level rise, increased pH, changes to ocean circulation, deep sea fishing and the need for changes in port infrastructure. The food safety risks identified relate to increased risk of algal blooms and shellfish diseases, changes in distribution of pathogens e.g. Vibrio due to temperature increase.

Climate change was the apparent reason that Sanford's mussel processing plant closed in Christchurch due to warming seawater temperatures affecting growth (Chief executive, Sanfords, Volker Kuntzsch, April 2015). Higher average sea surface temperatures will also increase the risk from heavy metals (hydrographic conditions, changes to metabolism and detoxification in organisms), pathogens (improved growth conditions), toxins (improved growth conditions) and anthropogenic contaminants (increased use and population increase) in seafood. There is also an increased risk from foodborne pathogens across the supply chain, particularly with chilling, storage, handling and transport. As food safety risks are expected to increase, adaptation options include improvements to food safety management, increased monitoring of harmful algal blooms and management of terrestrial sources of pollution. This includes elimination of point source sewage and indirect runoff. Chilling of food is considered a critical component in terms of the speed of cooling and the overall increase in cost of cooling is likely as ambient temperatures increase. In some cases, shifting of some fisheries to areas that are cooler or away from nutrient pollution sources could be an option, as well as shifts towards aquaculture for certain commercial species or life cycle stages. As per other sectors, for cooling, the previous workshop suggested more sustainable energy supply with a greater focus on alternative forms of energy: biogas, solar, wind.

Wildfood (non-commercial) sector

Establishment of new exotic pests and diseases resulting in disease outbreaks:

- Increased food borne illness.

Use of Mahinga Kai, particularly in many rural and coastal marae:

- For food and water-borne disease, a higher burden for Maori is expected, given the existing higher rates of enteric infection for Maori.
- Increased risk of outbreaks.

Increased pH of seawater:

- Potential threat to safety through acidification-induced increase in Cd accumulation in seafood (bivalves).

Rising ambient sea temperatures

- Increased incidence of harmful algal blooms (HAB), production of toxins including ciguatoxins, histamines toxins in shellfish.
- Increased heavy metal and dioxin concentration in predatory fish e.g. methylation of mercury and subsequent uptake by fish.
- Accumulation of toxins by filter feeders, an increase in water temperatures promotes the growth of pathogenic organisms and subsequent consumption of contaminated foods can serious implications for health.
- In general, climate change is likely to reduce food safety due to higher rates of microbial growth at increased temperatures and fisheries supply chains.

Changes in sea temperature affecting plankton and algae growth:

- Increase ambient sea surface temperatures have been correlated with increases in *Vibrio* in seafood.

Summary of adaptation options for the wildfood sector

Adaptation themes are similar to those from the seafood and aquaculture sector as the food safety risks are similar. As a number of food safety risks are projected to increase, the monitoring and dissemination of information to the public will be important in preventing outbreaks. This includes collection of wild food, through to chilling, storage, handling and preparation. The range and intensity of contamination may change across the country; such that new monitoring programs may be required. Opportunities arise from a projected increase use of wildfood to supplement changes to the NZ food system (e.g. increased food prices or decreased reliance of other food sources). Where safety concerns are met, this could increase opportunities for more locally sources sustainable food sources such as community gardens. Other opportunities include the growing of more exotic species such as kumara in the South Island and harvesting of pest species such as Undaria (wakame).

Overarching Food Safety Issues across sectors

Antimicrobial resistance (AMR)

Antimicrobial resistance (AMR) has been described as the "new climate change" (Stefanidou 2016). It is a global health issue that will affect everyone; and by 2050 it is estimated that 10 million deaths globally, will be attributable to AMR every year (O'Neill 2014). The development and spread of AMR is complex and multifaceted. However, the key driver is the use of antimicrobials to treat or prevent infection in humans, animals and to a lesser extent plants. Other factors may also come into play such as the use of other compounds, for example heavy metals, biocides and disinfectants may select for AMR (Horner et al 2012; Seiler and Berendonk 2012).

In the presence of antimicrobials, drug-resistant microbes will survive and multiply. Non-resistant bacteria may also acquire resistance through mutations in their genetic material or through the acquisition of genes encoding for AMR. These genes are often located on plasmids or other genetic mobile elements making them easily transmissible between bacteria. Antimicrobial resistant microorganisms and their determinants can be transferred to humans via food, through direct contact with animals, or through faeces contaminating the environment (e.g. water).

There is a global movement to prevent the spread of AMR and to handle our antimicrobials with care. Many countries have adopted surveillance programs and national action plans. In New Zealand, for animal use, the New Zealand Veterinary Association (NZVA) has made an aspirational statement that "*By 2030 New Zealand will not need antibiotics for the maintenance of animal health and wellness*". However, are the potential effects of climate change at odds with our goal to reduce antimicrobial use in animals? This was raised as an issue during the first workshop by Jeremy Hill (Fonterra Research and Development Centre). Previous research suggests that an increase in temperature results in an increase in the prevalence of certain diseases, both in animals and plants (Patz et al 2003; Wilkinson et al 2011; Wu et al 2016), which in turn would result in an increase in use of antimicrobials (as summarised below). During our second workshop it was raised whether climate change may impact on New Zealand's ability to be free-range. If temperatures are too warm outside animals may need to be moved inside, to temperature controlled environments. The presence of animals in closer quarters would result in an increase in the spread of disease. The poultry industry is currently moving towards less prophylactic use of antibiotics (e.g. a reduction in the use of bacitracin in-feed); however, a warmer climate may slow this change down.

Summary of potential climate change impacts, which may lead to increased AMU and therefore increased AMR residues:

1. Increase in hot days could increase stress in animals leading to an increase in disease risk (e.g. day-old chickens in truck transporters).
2. Increase in rainfall may create muddy conditions increasing contact with pathogens such as those that cause mastitis.
3. Warmer, wetter conditions could lead to more animal and plant bacterial infections.
4. Increase in hot days could lead to the increased use of temperature controlled sheds, where the presence of animals in closer quarters would result in an increase in the spread of disease.

Summary of potential climate change impacts, which may promote the transmission of AMR bacteria

1. Increase in rainfall could create muddy conditions, which may promote the transmission of AMR microorganisms between animals.
2. Increase in rainfall and flooding may result in transfer of AMR determinants from household or industry sewage to water sources used for irrigation.
3. General changes in climate may lead to the movement of beetles and other insects, which could act as a vehicle for the transfer of AMR microorganisms.

Biological control agents – Climate change related food safety and food system risks

Biocontrol agents themselves are rarely considered as food safety risks. This is due to the rigorous testing of each agent prior to approval. Only a number of biocontrols have resulted in predicted or unpredicted negative impacts, mostly in their use as weed control agents. Changes to climate may increase pressure to find alternatives to traditional pest and disease control, due to either ineffectiveness, consumer markets or resistance of the pest/disease. Biocontrols therefore may increase in usage. In terms of food safety systems, it is important that we consider interactions across multiple relevant abiotic environments and their interactions across food webs in relation to climate change.

Summary of climate related biocontrol risks to food safety systems:

1. Reduction in the biocontrol efficacy - *Climate change may shift interactions of invasive weeds, herbivorous insects, native plants, animal and plant diseases potentially affecting biological control efficacy and introduce non-target effects on native species.*
2. Changes in pest ecology affecting the type of biocontrol required – *climate change may alter plant life history, increase insect overwintering, damage and impact on seedling recruitment and synchrony between species within the system*
3. The biocontrol agent becomes a food source, competitor, or disease vector
4. Illegal importation of biocontrols – *previous breaches to biosecurity have led to release of biocontrol before necessary risk assessments to non-target species of animals and predator activity could be completed*

Introduction to biocontrol agents

Biocontrol or biological control agents are a method used to reduce populations of pests. Examples of pests include insects, mites, weeds and plant diseases. Natural pest predators include parasites, herbivores, fungi and other related natural mechanisms such as bacteriophages.

Biological control agents are rigorously assessed before they are approved for use. This includes host-range testing, pathogenicity, infectivity and risks to public health (EPA 2017; ERMA 2010; Hill et Hill et al 2011). Introducing biocontrol agents into the natural environment also requires an assessment of their fitness and behaviour under various conditions. This includes weed and invertebrate biocontrol testing and consideration of the impacts on native species and whether biocontrols are likely to cause significant displacement within their natural habitat. Climate change is one such condition that is projected to change the fitness and behaviour of both pest and biocontrol.

Biocontrols are increasingly being used as a form of pest control and as an alternative to chemical use. All pests and their biocontrols to some extent are sensitive to climate. Direct effects from climate change to biocontrols include those from extreme events and gradual changes to their efficacy as temperature and CO_2 increase and/or where water availability is likely to affect individual species response. These changes may be beneficial, neutral or harmful.

More southerly parts of New Zealand are expected to become suitable for alien invasive species that are adapted to warmer climates (Kriticos (2012). A general movement of pests (and their controls) away from the equator and towards the poles and also toward higher elevations, has been observed globally in some insect species (Mason et al 2015), although the distribution of those moving is uneven. For example, insect pests such as beetles, true flies, true bugs, butterflies, moths and thrips have consistently moved polewards in the Northern Hemisphere over the last 50 years, yet this pattern has not so far been observed in the order of insects such as bees, ants, and wasps or termites (Bebber et al 2014). In New Zealand, the lucerne weevil *Sitona discoideus* is currently controlled by the Moroccan parasitoid *Microctonus aethiopoides*. Projections of this agent suggest that it may become compromised as New Zealand's climate shifts towards that of South Australia, where the biocontrol agent currently fails to suppress the pest (Gerard et al 2010).

Climate change may also lead to changes in the synchrony between species within the system such as the time of emergence after winter, or flower availability for weed and seed biocontrol agents, increasing the number of generations per year of pests and/or of the agent, allowing reproduction of pest species through winter and having differential effects on species in systems where one has a day-length regulated life cycle (Gerard et al 2010). This could be favourable for natural enemies, however, it could also mean the disassociation between pests and their natural enemies (Gillespie et al 2017).

A key insect pest of tomatoes and corn in New Zealand, *Helicoverpa armigera* is controlled by two larval parasitoids. However, an increase in the number of generations of the pest even in the presence of these parasitoids can cause crop losses and disincentivise continuation of late cropping. Projections for increases in generation numbers due to climate change suggest that *H. armigera* will become more problematic for tomato and corn growers in eastern South Island since one of the biocontrols, *Cotesia kazak* is not effective in warmer areas overseas (Gillespie et al 2017).

Indirect non-target effects on ecosystems include when the biocontrol agent becomes a food source, competitor, or disease vector (Landcare Research 2017) and therefore poses a food safety system risk. Future warming could therefore increase the abundance of invasive species by releasing them from predation pressure. If the invasive species is a disease vector, these shifts could increase the impact of disease on human, animal, or plants (Gillespie et al 2017), although those risks are considered before approval. Failure of a biocontrol agent will lead to the examination of suitable alternatives or the return to more traditional options (e.g. chemical treatment), potentially posing food safety system risks from residues in food and the environment, resistance of pest species, as well as impacting on other (non-target) insect species in the environment.

Illegal importation of biocontrols pose an additional risk. Earlier work by the Parliamentary Commissioner for the Environment (PCE) has highlighted the implications from the illegal importation of biological control agents. In their example, the illegal importation of calicivirus led to a breach in New Zealand's biosecurity before the necessary research on risks to non-target species of animals and predator activity in high priority conservation areas could be completed (PCE 1998). Another breach occurred in Auckland, where *Macrolophus pygmaeus*, a biological control for vegetable crop pests commercially available overseas was illegally introduced (ERMA 2010). The potential for illegal releases of new organisms under changing climate conditions could increase as pest pressures on farming systems increase and the high costs and wait times of obtaining approval under the HSNO Act become prohibitory. Unfortunately, biosecurity failure becomes expensive and difficult, requiring eradication or long-term and often quite ineffective management strategies (Goldson et al 2016).

As climate changes, with appropriate adaptation, biocontrol resilience is possible. This would include taking advantage of New Zealand's fragmented landscape that provides many micro-habitats. For example, fragmented land can act as refuges to conserve biocontrol systems operating in a region during for example extreme weather events (Gerard et al 2010).

Biocontrols as an adaptation option

<u>Aquaculture</u>

Work done in several parts of the world show a number of technologies are available for minimizing the use of antimicrobial agents in aquaculture (Bondad-Reantaso et al 2012). Good aquaculture management will also ensure reductions in disease problems.

Other technologies that are developing in the aquaculture sector include immunostimulants that have the potential to improve disease resistance against a wide range of pathogens (Bondad-Reantaso 2012). Pre- and pro-biotics are another technology used as both feed supplement and disease control. Regulatory approval for use of probiotics as feed supplements has been documented in some regions. In New Zealand, probiotic feeds were used in laboratory feeding trials of abalone and significant growth improvements were observed (Hadi 2012).

Arable and agriculture

Greenhouse weeds are projected to become an issue especially in the warmer and more northerly areas of New Zealand. In addition to the control of weeds, the spread of C4 grasses also pose an issue (McGlone et al 2010) and workshop 1. Only a minor number of biocontrol agents used against weeds have resulted in the attack on non-target plants, mostly as a result of transitory, 'spill-over' attacks. Of the 26 fungal pathogens that have been released for biocontrol worldwide none have caused unexpected non-target damage (Landcare Research 2017. For mycotoxins, Reddy and others (2009) reported a reduction in AFB1, an aflotoxin considered to be carcinogenic to humans (IARC 2012; Kew 2013) by using plant extracts and bio-control agents in stored rice. An important consideration for food safety should include food safety risks associated with allergic properties of the agent, risks from their toxic metabolites, genetic recombination, displacement of natural strains and the effect on biodiversity (Butt 2000).

Dairy and Meat

For mycotoxins, biological controls include inoculation of atoxigenic strains so that they become the dominant population in the field (Bondad-Reantaso et al 2012). Studies so far have had some success. In New Zealand work suggests that biocontrol could successfully reduce facial eczema risk and toxic liver damage in other animals such as lamb, if problems associated with the production of inoculum and survival of the atoxigenic strains could be overcome (Towers 2006). There are also opportunities to use genetic modification to eliminate toxin production in aggressively growing strains and to extend the work to other toxin producing fungi. In areas where mycotoxin production may increase and lead to potential contamination of toxins from feeds to milk, mycotoxin-binding feed supplements could provide a useful solution. For bacteriophages, it is assumed most will respond in line with its associated bacterial host. In the future, bacteriophage use in meat carcass processing may increase. Recent studies found bacteria and phages are more resistant and infectious, respectively, at the temperature at which they previously coevolved, confirming that local adaptation to abiotic conditions can play a crucial role in determining parasite infectivity and host resistance (Gorter et al 2016). This may not be an issue in temperature controlled environments but should be considered in meat processing (including smoking of meats), small goods and packaged meat and cheese.

Food safety/system risks associated with livestock processing

The majority of the literature related to this subject describes climate impacts on the livestock themselves rather than any processing involved.

Environmental change

- Aquaculture (seawater environment) threats include the spread of ciguatoxin-potential areas as the sea warms. A number of other aquatic toxins could reach NZ.
- An increase in risks from marine bacteria, for example *Vibrio* species (see risk matrix for seafood) are projected.
- It is suggested persistent organic pollutants (POPs) concentrations could also increase, (Lloret et al 2015).
- Parasites in seafood may pose a future issue, refer to MPI reports (e.g. Literature review of ecological effects of aquaculture (MPI, 2013)).

Processing plants and infrastructure

Climate change impacts on water, processing and transport networks, energy supply, processing facilities and infrastructure can be found in Clark et al (2012):

- Increased erosion and sedimentation rates, along with more flooding, will have significant effects on infrastructure such as bridges and flood protection works. This brings additional maintenance and operation costs and can significantly affect to supply chain.
- Flooding and storm surges will affect ports, processing facilities and transport nodes, particularly in low-lying coastal regions. Higher temperatures might buckle railway lines and melt road tarmac. Slips and erosion could hamper transport and processing infrastructure. There is a medium to high likelihood of these impacts in the next 20 to 30 years. Different sectors are vulnerable to different impacts: dairy, for instance, relies heavily on road and rail freight; while the arable sector is concentrated in areas susceptible to more water stress, which can damage pumping and pipe infrastructure. Dairy, meat and horticulture are also vulnerable to power outages, which require contingency planning.
- The above issues may pose system risks in related to transportation, food spoilage and crop disease.

Adaptation – (see also Clark et al 2012)

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

Processing to consumption

- Increased microbial loads on livestock and plants due to increases in ambient temperature
- Increased microbial loads on livestock and plants due to contamination (water or feed sources)
- Increased gross contamination of animal hides due to heavy rainfall events increasing risk of transfer onto carcasses during hide removal. The gross contamination will be environmental and faecal material.

Based on data examining the concentration of *Salmonella* through the processing cycle of poultry, there are some areas that are at potential risk from climate change in terms of food safety (Figure 3).

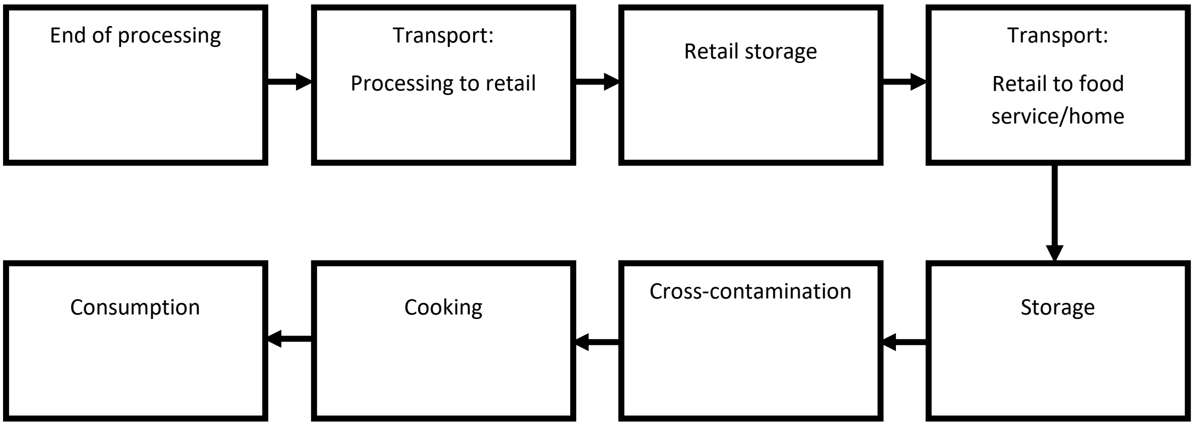


Figure 3: Modules modelled to determine the risk of salmonellosis from the consumption of poultry - end of processing to the time of consumption (FSANZ 2005).

Transport to retail

Salmonella numbers will increase when storage conditions favour growth. The minimal growth temperature is 7°C, although growth is greatly reduced at <15°C.[2] In a model used in the FSANZ 2005 report, it is assumed that transport from the processing plant to retail is well controlled and the temperature of the product remains below the minimum growth temperature. The growth of *Salmonella* was modelled based on generation times calculated in the FAO/WHO (2002) risk assessment (c.f. FSANZ 2005).

Quality of live animals exported (presumably for high economic gain) has the potential to be greatly affected by changing climatic conditions:

'*Warm and humid conditions cause heat stress, which affects behaviour and metabolic variations on livestock or even mortality. Heat stress impacts on livestock can be categorized into feed nutrient utilization, feed intake, animal production, reproduction, health, and mortality. Climate change may induce livestock diseases (e.g. outbreaks of severe diseases or new diseases), affecting animals that are not usually exposed to those diseases*' (Rojas-Downing et al 2017).

[2] http://www.foodsafety.govt.nz/elibrary/industry/non-typhoid-salmonellae.pdf accessed 30 Nov 2017

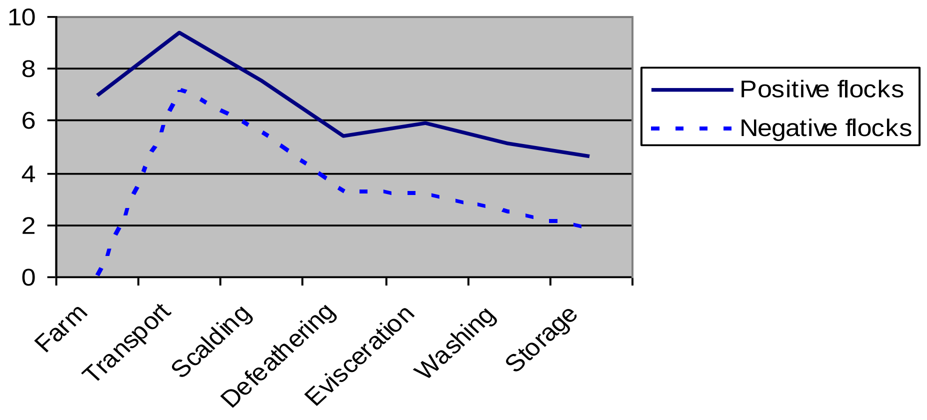


Figure 4: Changes in Campylobacter contamination (levels) modelled on poultry carcasses (Hartnett et al 2002).

In the FAO/WHO risk assessment for *Campylobacte*r, negative as well as positive poultry flocks were modelled (Figure 4) (FAO/WHO, 2002). In that model, negative flocks became contaminated after transportation and remained contaminated throughout processing. Transport crates and equipment used during processing were largely responsible for the contamination, and increased temperatures may increase the spread and growth of bacteria in faecal material on these surfaces. Increased ambient temperatures may increase food safety and system risk in the future without adequate controls.

The use of biocides and other chemicals

Biocides include products such as disinfectants, preservatives, pest control and anti-fouling products that are used to destroy and control viruses, bacteria, algae, moulds and pests. Literature related to biocide use and other chemicals from a climate change and food safety and systems perspective was not found.

Safer insecticides and repellents and alternative preventative approaches such as biological pest control or biocides and a focus on targeted research and policy changes were suggested in Boxall et al (2009) and Harrus and Baneth (2005) in response to higher temperatures, new pathogens, vectors or hosts. Climate change is anticipated to fuel an increase in the use of pesticides and biocides if farming practices intensify as a result of increased food shortages or food security issues.

Feedback from industry unable to attend workshops

The project team were aware that not all relevant industry representatives were able to attend the workshops, particularly in the case for Maori, smaller umbrella groups within horticulture and seafood and aquaculture sectors. Some representation is assumed through the wider organisations (e.g. Fonterra). In order to collate as much feedback as possible as well as reach out to a wider range of stakeholders, the team and MPI agreed to refer the draft risk matrices and factsheets to a number of other organisations for feedback. Summaries are provided below.

Arable – Foundation for Arable Research

We contacted the CEO and Director of Business and Relationships at FAR to ask for comments on the risk matrix and fact sheets for the arable sector. The main comments have been summarised.

There are some positives to increasing temperature in terms of crop growing, however there could be issues with:

- Unknown unknowns
- Incursions of new pests
- More aggressive weeds that are not normally requiring control – herbicides may be required to remove them before harvest introducing food safety concerns from residues. Timing of application of chemical/herbicide treatments could help

Storage on farm was also perceived as a potential future issue in relation to:

- Farms needing to upgrade their storage facilities to deal with higher temperatures e.g. ventilation, infrastructure
- Storage accounting for new pests and diseases (esp. fungi, mycotoxins in grains)

Both these issues are covered in the literature review.

Chemical controls:

- New pests/diseases may encourage the use of off-label treatments where no other option is available. Some insecticides are slowly being withdrawn. Resistance to chemical treatments is a real threat.

This was incorporated into the risk matrix and Appendix B.

Biocontrols:

- Climate change will affect soil conditions and this could impact on some biocontrols (seed treatments, endophyte loss, and bacterial treatments)
- The literature review on biocontrols was extended to examine issues with seed treatments, endophyte loss and bacterial treatments. There was generally a lack of literature in these areas. They have therefore been included in the recommended future studies section.

Adaptation:

Integrated pest management, selective breeding and nominal insecticide use (to prevent non-target impacts) is standard practise for arable farmers. Prevention of resistance to chemicals is a good reason to encourage this type of management.

Horticulture – NZ Avocadoes

We received comments from the Project Manager, Biosecurity Manager and R&D Manager at NZ avocadoes on the risk matrix and fact sheets for the horticulture sector. The following comments were made:

- A warmer climate is likely to be advantageous, however, an increase in major weather events is concerning.
- Temperature increases could possibly change flowering patterns.
- Temperature increases may also change harvest time due to the fruit maturing early.
- There is already awareness from the impact of pests associated with warmer climates and the possible use of new/more pesticides and the consequences of that (e.g. contamination from flooding and leaching, residues in food).

Adaptation:

The NZ avocado industry has systems in place for residues so any new chemicals (e.g. fertilisers, pesticides, fungicides) are tested.

Horticulture – New Zealand Apple and Pears

The following comments were received from the Technical Manager at NZ Apples and Pears on the risk matrix for the horticulture sector:

- Most horticultural crops already have or are moving to nutrient budgets that optimise nutrient and water use. In the case of water that may be contaminated there are technologies available to remove/filter contaminants. However, these come with added cost.
- Many crops are already grown in low quality soils, and water budgets and moisture probes optimise water use, therefore industry experienced in dealing with drought conditions.
- The industry is aware of the issues associated with increases in heavy rainfall. Growers have problems accessing land post-flooding/waterlogged ground for tasks including spraying, harvesting/use of machinery.
- Existing pests, diseases & weeds will move as climate changes. Growers anticipate more vigilance at borders as well as new pesticides to combat new organisms, others may not be needed/used. New biocontrol agents will be needed for new organisms.
- Increasing urban sprawl may become more of an issue in the future in terms of storm water runoff.
- There will be a need for more efficient/responsive/agile plant breeding. Genetic modification could be part of this solution.

Dairy, meat and horticulture – East Coast farms

The risk matrices and fact sheets were distributed to dairy, sheep/beef farm managers in East Coast regions for comments, they included:

The inclusion of maps was requested into the outputs rather than a descriptive term.

- The industry had many examples of extreme events that had damaged infrastructure (e.g. woolsheds, yards, fences in river valleys). Those extreme events had made mustering and handling animals difficult, mostly related to animal production, health and welfare such as delivering anthelmintic, trace elements and vaccines rather than food safety/security issues per se.

- A specific request was made regarding the use of this report, the matrices and fact sheets to become living documents rather than reports. This was related to setting priorities and timelines and the farm, regional and policy level.

Seafood and Aquaculture - Shellfish Production and Technology New Zealand Ltd (SPATNZ)

The following comments were received from the Programme Manager at SPATNZ on the risk matrix for the horticulture sector:

- Clarification is required with regards to shellfish species that may bio-accumulate cadmium as pH decreases (ocean acidification).
- The bioavailability of cadmium should also be included with respect to increases in cadmium as ocean pH decreases.

Adaptation:

- Use of post-harvest depuration techniques.
- Improved land management practices to reduce loadings.
- Farm relocations from warmer sites to cooler sites.
- Improved husbandry, feeds and proactive health management tools such as pre-biotics, probiotics etc.
- Changes to the aragonite saturation state is associated with increases in CO_2 and larvae are sensitive to those changes. The use of hatcheries can assist in larvae development during these sensitive stages of growth.
- Selective breeding for shellfish more resilient to reduced aragonite saturation associated with carbon dioxide emissions.

Seafood and Aquaculture – Ngāi Tahu Seafood

We received comments from a marine biologist at Ngai Tahu seafood on the risk matrix and fact sheets for the seafood and aquaculture sector. The following comments were made:

- Biotoxin accumulation is a potential issue for rock lobster in relation to toxic algae and toxic algal blooms. Monitoring is essential for quality assurance and future management of growing areas.
- Warming ocean temperatures (polar shift) could facilitate/assist the arrival and spread of invasive organisms into cooler regions. The impact of this on aquaculture and wild stocks could have significant impacts on the aquaculture/ seafood industry i.e. habitat change through invasive seaweed outcompeting our native species and subsequent impact on ecosystem function and energy transfer.
- Higher temperatures will impact on future salmon farming production and sustainability. Temperatures over 16 degrees can negatively impact on Chinook Salmon i.e. current farming sites may not be viable under future climate predictions, this will be very important for future planning of new aquaculture sites and species selection.

Seafood and Aquaculture – Aquaculture NZ

Comments received from the technical director of Aquaculture NZ included:

- Adaptation to increased run-off should consider the origin of contamination rather than industry needing to adapt to downstream changes. This may involve changes to land-use policy and operational rules.

- It is important to differentiate between shellfish grown in different parts of the water column that may be exposed to different levels of heavy metals of interest.
- Aquaculture locations in Marlborough Sounds and Golden Bay may also be affected by future changes to run-off (not just east coast sites).

Wildfoods – Ngai Tahu

Comments on the wild foods matrix were received by Environmental Advisor for Te Rūnanga o Ngāi Tahu:

- Climate change may increase community reliance on readily available/fast food in the absence of locally sourced wild foods. Perceptions of food safety may also prevent collection in the absence of available information.
- Climate change may result in a shift in harvesting seasons in conflict with traditional calendars/maramataka e.g. fish spawning, trees flowering may throw communities off course.

Adaptation:

- Outreach to communities was considered an important aspect of providing opportunities to present information and allow feedback (two-way communication) of food safety risks.
- Shared landscapes such as rivers and lakes would benefit from riparian planting to decrease sunlight that promote bloom events.
- Regular flushing at tidal gates may help reduce pathogen loads from terrestrial sources

Opportunities:

- Harvesting and growing of new exotic species such as kawakawa and kumara. There may be co-benefits such as removal of unwanted pests as a food source e.g. Undaria (wakame).
- Education programs in wānanga form at maraes in rural communities
- Workshops for young adults that are hands on allow for one to one interaction and utilising local leadership bodies.

MPI Synthesis Reports

Dr Nick Craddock-Henry (Landcare) was consulted regarding synthesis reports which are being prepared from previous SLMACC projects under specified themes. He reviewed the synthesis reports in progress, but commented that there was no relevant information on food safety or food systems (pers. comm.). A potential issue was for the dairy industry and the use/dependence on PKE (palm kernel expeller). PKE use is increasing, partly because of economic drivers, but also as an adaptation to climate change. There is some limited evidence to suggest that PKE affects milk quality.

Discussion and Conclusions

Individual sub-sectors will be affected by both generic and specific climate-related food system risks. For example, in the agricultural sector, changes in temperature can affect growing patterns in different ways such as dependencies on frost for fruit bearing and changes to the season for flowering. Common risks across all sectors include those from extreme events that are capable of damaging crops and significant infrastructure. Wind and flooding were the most common extreme event issues throughout the literature, followed by increases in temperature. Increased risk of food spoilage, and increasing need for refrigeration were food system-wide issues. The potential for increased usage of pesticides in response to existing or exotic pests and increased use of biocides in response to pesticide resilience and food spoilage were also noted by industry. These issues are interconnected. Flooding for example can also lead to increased residues in run-off that have the potential to contaminate other crops and degrade soil quality.

Many adaptation options also include ways to mitigate or reduce greenhouse gas emissions. For example, changes to refrigeration technology will increase cooling efficiency under high-ambient temperatures whilst switching refrigerant gases (e.g. hydrocarbon refrigerant) to more efficient alternatives that also have lower global warming potential.

Biosecurity plays a key role in the prevention of a number of food safety and system related risks identified in this review. For land-based sectors, new pests (weeds, insects and fungi in particular) pose an increased risk that may require the use of new, currently unapproved or off-label treatments. The most sustainable adaptation options avoid the use of chemical treatments and instead foster good management practices and biocontrols. However, the effectiveness of biocontrols was identified as being at risk from changes in climate and will require careful monitoring and further research as to their efficacy in the future.

There are some elements of biosecurity that are difficult or impossible to manage, and will require effective responses. For example, wind-blown pests and diseases, plants and animals carried by ocean currents and illegal and accidental imports such as dumping of ballast in NZ water all carry biosecurity risks.

Marine pests in particular pose an issue and their numbers and establishment have increased in recent years (MfE and StatsNZ 2016).

Climate change may shift the growth of traditional crops and animals

The physical impacts of climate change will lead to direct changes to land-use in New Zealand. Some sectors such as pastoral and some cropping varieties may benefit, depending on the location and climate scenario. However, under the higher RCP scenarios, land use change will require adaptions to warmer, and drier or wetter environments.

Oceanic changes are likely to affect aquaculture industry such as salmon and shellfish, as sea temperatures increase, pH decreases and sea level rises. Currently, the New Zealand salmon industry benefits from a lack of endemic pests and diseases, thus is free from known disease and environmental events that have occurred in salmon farming areas elsewhere in the world. New Zealand is therefore the only source of salmon that is not routinely treated with therapeutics. However, projected changes to the coastal environment include increases in surface water temperature, eutrophication, increases in sedimentation and turbidity, and extreme events which pose a risk to infrastructures (Callaway et al 2012; Rouse et al 2013). In addition, diseases, parasites and pathogens, including invasive species may increase, exacerbating temperature and ocean pH related stressors (Clark et al 2008; Floerl et al 2013; Hollowed et al 2013; Minchin 2007).

Climate change may also shift the growth of invasive species. An example of an invasive species incursion associated with climate change is that of Bluetongue virus, a serious disease of ruminants. The virus is vector borne and it is recognised that changes in European climate have led to its spread into Northern Europe over the period last 15 years. Warming has allowed the virus to over-winter, adding the expansion of the main vector *Culicoides imicola* northward and facilitating transmission by indigenous European *Culicoides* species

(Bishop et al 2006; Purse et al 2005). This disease is exotic to New Zealand; only New Zealand and Antarctica are free of *Culicoides* midges. MPI has active monitoring stations for the midge and conducts serological surveillance of sentinel herds. There is no known food safety issue with Bluetongue virus as there are for example with Shiga toxin-producing *Escherichia coli*. However, there is significant morbidity and mortality for framed ruminant species, potentially affecting food production.

Adaptation options may include research and commercialisation of new species as has occurred previously in the seafood sector (e.g. Pacific oysters). If the plant and animal products at the farm cannot be changed, the alternative is to move stocks to more suitable areas. Re-location of aquaculture sites may be one of the most effective ways to reduce those impacts (MPI, 2017).

For fish farms this would require sites with deep, cooler water and sufficient current flow that provide adequate flushing to prevent build-up of sedimentation on the sea-bed and reducing water quality impacts. This option was also raised as an issue in the seafood sector, and future planning of new aquaculture sites and species selection were raised as priority issues.

Change in climate will co-occur with many other current environmental issues such as pollution from land-based activities. Nutrient over enrichment and altered hydrologic conditions can result in marine and freshwater algal blooms some of which can be toxic to animals and humans. Rising temperatures and greater hydrologic variability will increase growth rates and alter critical nutrient thresholds for harmful algal blooms. Therefore, nutrient input controls may need to be more aggressively pursued because their optimal algal growth rates at relatively high water temperature plays a key role in their expansion and persistence (Gobler et al 2017; Michalak et al 2013).

In terms of adaptation farmers also need to manage the risk of pollution within their farm management systems. In many cases limiting the combined effects from nutrient input (nitrogen; N and phosphorus; P) will reduce the risk from harmful algal blooms in both fresh and marine water as well as reduce pollutants downstream. These issues are already being addressed, but may require increased attention under climate change.

The increased range of insect and other vectors will require increased use or newer insecticides and repellents that are safe for the environment, and for the development of alternative preventative approaches such as biological pest control, e.g., the use of entomopathogenic fungi, nematodes, wasps and birds in the control of ticks and other vectors (Gubler 1998; Samish and Rehacek 1999).

Opportunities

Dairy and Meat

Some parts of the country will benefit from increased pasture production over the coming decades, thus assisting meat and dairy livestock production. Higher carbon dioxide concentrations may increase photosynthesis allowing for more efficient use of available water and improved pasture growth rates, particularly with temperate pasture. The highest increases would be in the South Island. This issue is addressed in detail by Clark et al., 2012.

Drought is likely to affect summer yields of pasture such as in Hawke's Bay, Wairarapa, the eastern South Island and Central Otago. Experimental evidence points towards an increased legume component in pastures and increased use of subtropical grasses which could provide feed during times of water stress. However, those areas may also be of greater risk in terms of new exotic pests, sleeper pests, natural enemies, weeds and diseases.

Arable, Dairy and Wildfoods

The climate may become more favourable for growing both traditional and non-traditional plants, including pasture, avocadoes and kumara. Industry may need to move to areas where the climate is more suitable whilst considering other risks e.g. pests. Other opportunities may exist that include the harvesting of nuisance species e.g. undaria, that may bring other-benefits (ecological) to the primary and mahinga kai.

Aquaculture and Seafood

Aquaculture may provide an opportunity grow seafood away from negative changes to the marine environment (e.g. reduced aragonite saturation state, increases in sea surface temperature). However, some industries may benefit in the long-term by relocating to more suitable environments.

All sectors can benefit from improved energy, water and nutrient efficiencies, reducing their greenhouse gas emissions and shifting to cleaner forms of energy generation.

Cross-fertilisation

Finding synergy, linking outputs and learning from this project will inform the related SLMACC project "The effect of climate change on grazing livestock health in New Zealand" in which Andrew Tait and Jackie Benschop from this project are named investigators.

Future Studies

- Systems and livelihoods – most of the work on agricultural impacts of climate change has focused on crops or direct impacts on livestock yet there is very little literature on the impacts of climate change on farming systems and infrastructure.
- Post-farm related risks – climate impacts on post-farm issues and in particular those associated with processing and transportation in specific industries.
- Interactions between climate change and other drivers for farming systems such as population growth, export demand, globalisation, urbanisation, changing socio-economic expectations, cultural preferences.
- The future use of water - water policies and integrated planning, and technologies for advanced water treatment and re-use. The inclusion of local problems and socio-economic aspects must be considered.
- Farmer responses to climate change, farmer stress and sustainable farming practices.
- Viticulture – Sector specific study examining the effect of climate change on food systems for the viticulture industry.
- Wool - Sector specific study examining the effect of climate change on food systems for the wool industry (with regards to potential residues in wool).
- Apiculture - Sector specific study examining the effect of climate change on food systems for the apiculture industry with a focus on hive health, potential new toxins in honey from exotic plants, disease risks (parasites + bacteria + fungi).
- Potential food safety risks related to community based agri-sector, including community gardens, orchards and permaculture.
- Life cycle analysis of key sectors to identify areas with the potential to mitigate climate change
- Exotic pest incursions associated with climate change that may affect food production systems e.g. Bluetongue Virus.
- Further consideration of potential adaptations for each of the food sectors and international overview of those implemented overseas in countries to New Zealand.
- Regional studies addressing changes in land use, growing conditions and resource availability across all sectors (liaising with Regional Council activity on this topic).

Appendix A – Workshops

The workshops were developed using the co-innovation model (Figure 5).

Co-innovation is a systemic approach to facilitating practice change and, more broadly, innovation when addressing complex challenges both on-farm and in-market. Taking a systemic approach means consideration of the problem within the wider system by:

- including multiple participants from on-farm and off-farm
- taking the time to understand the problem from many different views and developing a shared systemic view
- brokering the bringing together of elements of solutions
- interactively learning to create knowledge to develop and refine solutions
- using practical experimentation that challenges current practices and supports change
- interactively working through cycles of planning-doing-monitoring-reflecting.

Figure 5: A schematic of the New Zealand Food Safety Science and Research centre's co-innovation model

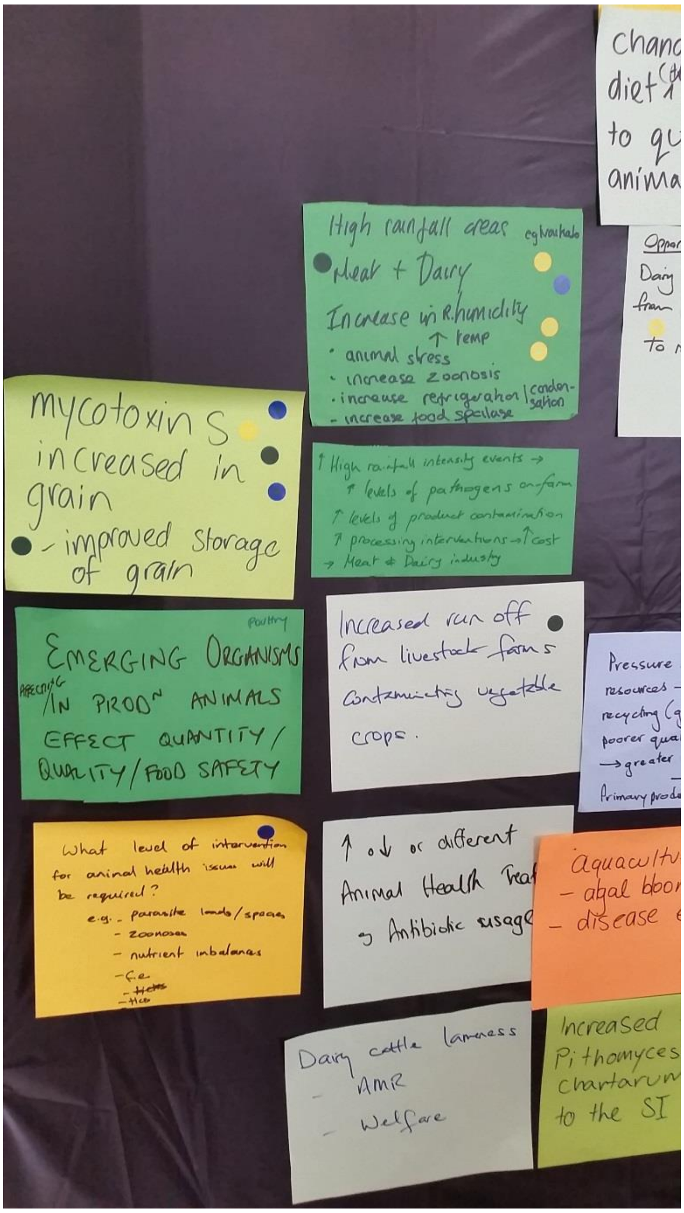


Figure 6: Photograph from Workshop 1 showing themed issues and dotmocracy votes by participants.

Synthesis of data from the workshops

Workshop 1: at Massey University, 22 February 2017. The focus was to bring together industry, government and research representatives to scope out the priorities and concerns regarding climate change and the New Zealand food system. Helen Percy (AgResearch) facilitated this meeting. Prior to the meeting a detailed facilitation run-sheet was developed in consultation with the project team. Two presentations outlining the project (RL) and CC in NZ (AT) started the workshop, then Helen outlined the process for gathering information from the participants. This was split into the following sessions:

1. Impact of CC on your industry. Participants formed sector specific groups and brainstorming questions, creation of wall notes, clustering of ideas, grouping into themes and voting by dotmocracy were used to identify key issues for industry (Figure 6).
2. Scenario analysis. AT introduced these. Participants formed cross-sector groups and considered how the scenario (e.g. Unspecific Pacific) would impact the food industry. Ideas were gathered on flip chart paper and groups fed back to the workshop.

3. A case study of the effect of CC on intensified livestock farming off-pasture was presented for a round table discussion.
4. A round up session including capturing further ideas and inviting participants to feedback on the day's workshop.

The participants of the first workshop on "Adapting to Climate Change: Information for the New Zealand Food System", reached a number of general recommendations. The main recommendation was that primary production needed to be a focus for the project as:

- Primary production is where the major changes will occur, changes are already happening (greater variability in climate) so adaptations will be needed even if greenhouse gas emissions can be reduced
- We can't separate effects on primary production from post-primary food chain
- Post-primary parts of the food chain already manage issues relevant to climate change, and have the tools to do so as issues arise

As a result, the research team performed additional literature review and liaised with the current SLMACC synthesis project teams.

Workshop 1 also noted that changes associated with global climate change would be implicitly linked to changes in NZ through:

- The food product itself may change: changes in the food we grow and how we preserve it are likely as a result of trading changes.
- Food demand globally will affect NZ in terms of increased pressure to produce more food (population increase and decrease in some current food producing countries?).
- Primary production is likely to shift further away from the equator.
- Trading changes may alter import patterns, raising biosecurity issues.

Priority research areas that were identified as requiring further investigation by the research team included:

- Food safety issues (pathogens, AMR, chemical hazards) arising from changes in primary production practice as a result of climate change.

Specifically:

- Prevalence and distribution of pathogens
- Increases in antimicrobial use to control animal diseases will make antimicrobial resistance (AMR) a more important issue.
- High intensity rainfall events will lead to increased transmission of pathogens on-farm, surface/groundwater movement of pathogens, product contamination and need for processing interventions and therefore higher costs.
- High rainfall areas e.g. Waikato for meat and dairy and increases in humidity and temperature could result in animal stress and increased shedding of zoonotic pathogens.
- Need for increased refrigeration and likely increased condensation.
- Increased food spoilage.
- Increased mycotoxin production due to higher temperatures will be an issue for human health as well as animal feed.

From workshop 1 the production systems that impact on food safety and preservation identified were:

- increase in temperature and humidity leading to increase in animal stress, animal diseases and increased prevalence of zoonotic pathogens
- increase in mycotoxins in grains and feeds
- increase in use of biocides and antibiotics and potentially AMR
- changes in food contamination and need for biocides
- challenges meeting trade and food safety criteria

Secondary priorities for investigation if resources allow:

- Farming changes (geographical distribution, product/animal changes and diversification)
- Energy use and alternative sources
- Land use changes (linked with energy and water use changes)

Following workshop 1, the project team devised a series of risk matrices for each sector. The risk matrix represents a sector specific overview of the climate change impacts to food safety and systems, their risk now, in the future under a high emission scenario (both at 2050 and 2100), and following suggested adaptation options. The risks are defined as low = green, medium = yellow, high = orange, extremely high = red. Information used to develop the risk matrices was sourced from scientific publications and industry feedback from Workshop 1 and based on the high emission scenario [RCP8.5]. The purpose of the risk matrix is to provide a summary of potential impacts for discussion with representatives from the NZ food sectors, research providers and government agencies.

Workshop 2: at Massey University, 25th July 2017. This workshop focused on the project team's outputs to date. Andrew Tait revisited CC projections and Rob Lake presented a summary of Workshop 1 findings of the relevance of CC for each sector. An overview of the risk matrices and the fact sheets was presented and project members presented some specific examples of risk matrices (e.g. meat, and antimicrobial resistance). Feedback was sought during the presentations and by round table discussions.

During workshop 2, the sector specific risk matrices were presented to the sector representatives followed by a general discussion. The main discussion points, suggested outputs and their integration into this report are summarised in Table 2 below:

Table 2: Main discussion points raised during Workshop 2 and summary of project team's response

Comments from Workshop 2	Response
Information on changes in ultra-violet radiation	These are included in the risk matrix and factsheets (Appendix B)
Information on changes to relative humidity	These are included in the risk matrix and factsheets (Appendix B)
A summary of related SLMACC synthesis projects	This is included at the end of the section "Feedback from Industry".
A regional summary across all sectors	This is included as a separate section "Regional information on climate change".
Information on food safety system risks associated with climate change and biocontrols.	This is integrated into the literature review section "Discussion of other relevant issues: Biological control agents".

Increased use of controlled atmosphere environments – for both animals (housing for dairy herds) and plants (greenhouses).	These are included in the risk matrix and factsheets (Appendix B)
Information on food safety system risks associated with climate change and issues beyond the farm gate (livestock processing, biocides and chemicals, transportation etc.).	This is integrated into the literature review section "Discussion of other relevant issues: Issues beyond the farm gate".

Workshop 3: was proposed to take place before the end of November 2017. However, experience from the first two workshops revealed that it was very difficult to assemble representatives from all relevant sectors at the same meeting, and there were some sectors which had not been present at either workshop despite invitations. With agreement from MPI, the project team planned to conduct small sector specific meetings and discussion, with 2-3 representatives from each sector, being: meat, arable, dairy, horticulture, seafood, and Maori agribusiness. The load of these meetings was spread across the project teams, with 2-3 from the team attending each meeting. The timeline of the meetings was the same as originally intended for the third workshop i.e. meetings to occur before end of November 2017.

These meetings (to 30 November 2017) have included:

Annette Bolton met with staff from the Foundation for Arable Research in September 2017 to discuss our project and received some useful feedback and raised awareness about the project.

Industry feedback was received from Ngāi Tahu Seafood, Shellfish production and technology (SPATNZ), New Zealand Avocados, New Zealand apples and pears, Foundation for Arable Research, Te Rūnanga o Ngāi Tahu.

Risk matrices and factsheets have also been discussed and/or sent to the following industry representatives:

Seafood New Zealand

Aquaculture New Zealand

HortNZ

Meat Industry Association (who have placed the risk matrix and factsheet on their website and sent them to meat processors for comment)

Fonterra

Ahuwhenua Trust

Appendix B – Risk Matrices and Factsheets

Factsheet 1: Projected Climate-related Impacts on Food Safety/Systems in the Dairy Sector

RISK MATRIX

The risk matrix represents a sector specific overview of the climate change impacts to food safety and systems, their risk now, in the future under a high emission scenario, and following suggested adaptation options. The risks are defined as low = green, medium = yellow, high = orange, high = red. Information used to develop the risk matrices was sourced from scientific publications and industry feedback from Workshop 1 and based on the high emission scenario. The purpose of the risk matrix is to provide a summary of potential impacts for discussion with representatives from the NZ food sectors, research providers and government agencies.

Issues have been categorised as follows:

Category 1: Existing hazards affected by climate change

- Those arising from infectious agents
- Those arising from naturally occurring chemicals and biotoxins

Category 2: From risk management to address climate change issues

- Chemical interventions (pesticides, antibiotics etc.)
- Other changes in production processes

We have based our indications of climate change expected over the next 100 years on the highest representative concentration pathway (RCP) 8.5, because this enables us to more clearly assess future change.

Additional commentary is provided below the table.

CLIMATE CHANGE AND FUTURE IMPACTS

Extreme events are likely to increase and include:

- Frequency, duration and intensity of hot spells, mostly in the north of the NI and Eastern SI, however, towards the end of the 21st Century this could affect all of the NI and Eastern SI.
- Frequency of heavy precipitation events and the potential for associated flooding will affect all of NZ.
- Intensity of ex-tropical cyclone events.
- Incidence of extremely high sea levels during storm surges.
- Longer dry spells in some areas (especially in the north of the North Island and east of both islands), and the areas affected by drought each year, are likely to increase.

- Cold spells and frosts will decrease in frequency, duration and intensity (Solomon et al 2007).

Changes to the average climate will include:

- Increases in warmer and wetter weather in Western NZ and Southern SI.
- Most areas of New Zealand will experience increased average crop and pasture yields associated with increased CO_2 generating a 'fertilization effect', and anticipated mean temperature rises of 1–3°C. This will compensate for negative yield impacts of climate change with the exception of area expected to increase in frequent drought.
- Average annual rainfall in New Zealand will generally increase in the south and west and generally decrease in the north and east of the country, with seasonal variations.
- The winter season is projected to have the greatest rainfall changes (an exacerbation of the annual changes), as westerly winds (particularly across the South Island) are likely to strengthen. Together with warmer temperatures, this is likely to have a significant effect on winter cropping and pasture production.
- Average relative humidity is likely to increase for most areas of New Zealand.
- All regions will be susceptible to yield losses, but impacts on global food availability would be small owing to compensatory institutional factors, such as enhanced global markets.
- By the end of the 21st century, mean growing season temperatures are highly likely to equal current extremes in temperate areas (including New Zealand) and to exceed them in the tropics and subtropics, resulting in major impacts on global food production (Battisti and Naylor 2009).
- By 2100, the models suggest increases of up to 10 per cent ultra-violet radiation on the West Coast in summer, and smaller increases elsewhere with notable exception of the coastal Canterbury where sunshine is predicted to decrease.
- The reduced summer sunshine levels in coastal Canterbury are consistent with increased rainfall there in that season.
- The winter changes are almost the reverse of the summer ones: about a 5 per cent decrease in radiation in western parts of the North Island, and 10 per cent or more in western and southern South Island.
- Eastern North Island is projected to have an increase in winter sunshine levels.

FOOD SAFETY SYSTEM ISSUES

The impacts of global climate change on food systems will be widespread and complex

- Individual pathogens will likely differ widely in epidemiological responses, but the net impact of climate change will lead to a large increase in the burden of infectious diseases (Costello et al 2009).

- For plant-derived foods including stock feed, mycotoxins are considered the key issue for food safety under climate change (Tirado et al 2010).
- Rising incidence of disease will lead to overuse or misuse of pesticides and veterinary medicines (Miraglia et al 2009; Solomon et al 2007; Tirado et al 2010).

Specifically for the New Zealand Dairy Sector:

Increase in hot days (maximum temperature of 25°C or higher)

- Increased heat stress could affect dairy/milk production (reduced feed intake, fertility rates, lameness [claw horn]) through increased levels of mastitis infection/increased somatic cell counts together with higher parasite loads including ticks and helminths.
- Increased heat stress could mean more sub-clinically affected animals exhibit signs of TABA
- Heat stress may result in more shedding of STEC (see case study).
- Changes to mitigate heat stress such as housing for shelter may increase food safety risks e.g. hide contamination, crowding conditions that enhance transmission of other infectious diseases, hygienic dressing more difficult.
- Increased demand for water and declining water quality could all lead to increases in the levels of pathogens and chemicals in food.
- Extreme drought can lead to boreholes contaminated with nitrates.
- Combined with increased rainfall tick abundance, competency and activity is favoured.
- Extreme drought will desiccate ticks.

Increased temperature and rainfall

- Combined with increased rainfall tick abundance, competency and activity is favoured.

Increased winter rainfall coupled with milder winter temperatures

- Contamination of pasture, drinking water and silage by emission, soil, manure and water leading to increased contamination of livestock.
- Increased pesticide and veterinary drug residues in the environment, leading to new or higher residues in food, some from new approvals.
- Changes in pesticide activity of some pesticides.
- Control responses may generate food safety problems due to the novelty of the pests in question as well as the unfamiliarity of farmers using the appropriate controls.
- Increase spread of facial eczema resulting in increased use of zinc treatments.
- Muddy conditions can be created where cows are more fatigued and prone to lay down, with associated udder contamination, increasing contact with environmental pathogens.
- Reduced grazing, can also occur resulting in a lowered immune system

Increased rainfall and humidity

- Increased rainfall and humidity will also lead to more animal stress that increased shedding of pathogenic bacteria. This will also result in higher pathogen loads transferred to waterways.

Increased rainfall with milder winter temperatures

- Rainfall and muddy conditions can be created where cows are more fatigued and pastures are damaged. Resultant reduced grazing leads to more hide contamination, nutritional stress thus more sub-clinically affected animals' exhibit signs of TABA.
- An extension of the tick distribution and abundance may lead to extension of unstable TABA zones resulting in increased use of acaricides and other ACVMs (e.g. Buparvaquone, erythtomycin) with subsequent residue issues.
- Extended tick distribution may lead to extension of the stable endemic area.

Emergence of new exotic pests, weeds and diseases resulting in outbreaks:

- Increased intestinal/hide microbial burden associated with animal, especially in summer, leading to increased pathogen levels in raw milk.
- Increased risk of antibiotic-resistant pathogens developing.
- Mycotoxins, including aflatoxins will increase in range, type and amount.
- When cows consume aflatoxin-contaminated feeds and milk products can also serve as an indirect source of aflatoxins.

Meeting stringent climate change targets

- Refrigerant management ranked as the No. 1 global solution in terms of estimated atmospheric CO_2-equivalent reductions between 2020 and 2050. About 20% of the global-warming impact of refrigeration plants is due to refrigerant leakage.
- Reduced dairy consumption – ethical food choices
- Land use changes

At the farm level

- Better use of seasonal climate forecasting (Jarvis et al 2011).
- Greater deployment of water conservation technologies
- Diversification of on-farm activities (Hansen et al 2007).
- Cooling of animals during milking. Infrastructural changes to the milking platform and farm landscape to reduce heat stress.
- Improved farm design, provide shelter through trees or housing systems
- Development and adoption of different varieties and species more suited to emerging climatic conditions.
- Improved management of pests and diseases.

- Promotion of integrated pest management and non-synthetic methods of pest control.
- Adjustments in cropping and management practices i.e. once a day milking, good husbandry, biosecurity and pasture management (Easterling et al 2007; Jarvis et al 2011).
- Shift in production to areas more suitable e.g. further south to avoid new pests and diseases or to areas with more reliable rainfall/water supply.
- Reduction of mingling during transport and lairage of calves.
- Changes in management of calf shed – e.g. number of animals, bedding turn-over.
- Decontamination of hides at lairage.
- Post dressing interventions: hot water acidified sodium chloride wash.
- Routine testing of supplemental feed to check for presence of aflatoxins and use of additives to prevent absorption, where necessary

At post-harvest/off-farm level

- Improving energy efficiency.
- Promotion of alternative refrigeration technologies and refrigerants such as fluorinated gases (MfE, 2017; EECA 2017)
- Switching to cleaner and renewable fuels.
- Improved processing and food safety technologies.
- Strengthening food safety systems, including hazard intervention and control.
- Improving non-energy resource efficiency, such as through recycling and reuse.
- CH_4 from wastewater treatment could potentially be recaptured for energy generation, minimize food waste.
- Enhanced transport truck hygiene measures.
- Vaccine development (similarities with human malaria).
- Identification and selection of genetically resistant animals.

CASE-STUDY #1: STEC (Shiga toxin-producing Escherichia coli)
STEC are bacteria primarily transmitted via the faecal-oral route. Ruminants, predominantly cattle, are important reservoirs. STEC has no known animal health or production effects and is considered normal gut flora. Due to the public health risk, STEC are a red meat trade concern and declared adulterants of beef and bobby veal in the USA. STEC are also a domestic public health risk, causing haemorrhagic diarrhoea and kidney failure, particularly in children. New Zealand has a high and increasing incidence of human cases of STEC compared to other countries, with 9.6 cases per 100,000 people reported in 2016. A 2011/2012 New Zealand case-control study of 113 cases and 506 controls identified the presence of cattle in the local area, contact with animal manure and contact with recreational waters, as significant risk factors for human STEC infection.

A nationwide 2014 cross-sectional study of 1508 young calves on 102 randomly selected dairy farms reported 20% of calves and 75% of farms had infection detected of STEC. Risk factors included region, with Northland most affected, and increased shed humidity and number of calves per shed.

CASE-STUDY #2: THEILERIOSIS

Theileriosis is a tick-borne protozoal disease of cattle in New Zealand that in naïve cattle can cause anaemia, jaundice and death. Theileria-associated bovine anaemia (TABA) is associated with the abundance, activity and competence of the brown cattle tick *Haemaphysalis longicornis* which thrives in warm, moist conditions.

TABA is more likely to be seen at time of stress, therefore the largest burden is seen in the dairy industry e.g. in cows when transitioning and at peak lactation, and in bulls during concentrated periods of mating. Beyond a concern of residues for treatment/support of affected animals there are no known public health effects of this infection in cattle and there are no current trade issues.

TABA is a recent introduction to New Zealand and at the time was concerned exotic. The first three notifications occurred in the spring of 2012 in Northland and Waikato. By March 2014 there were approximately 500 case herds (80% dairy). To date (September 2017) an estimated 65% of North Island versus 2% of South Island farms are infected. The infection is considered endemic (every animal becomes infected) from north Waikato north thus TABA is in equilibrium and serious clinical disease is unlikely except in calves. More concerning are current unstable areas of the mid north island and coastal east and west of the lower north islands, also the top of the South Island. There is no equilibrium and new disease cases occur both in adults and calves.

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Factsheet 2: Projected Climate-related Impacts on Food Safety/Systems in the Meat Sector

RISK MATRIX

The risk matrix represents a sector specific overview of the climate change impacts to food safety and systems, their risk now, in the future under a high emission scenario, and following suggested adaptation options. The risks are defined as low = green, medium = yellow, high = orange, high = red. Information used to develop the risk matrices was sourced from scientific publications and industry feedback from Workshop 1 and based on the high emission scenario. The purpose of the risk matrix is to provide a summary of potential impacts for discussion with representatives from the NZ food sectors, research providers and government agencies.

Issues have been categorised as follows:

Category 1: Existing hazards affected by climate change

- Those arising from infectious agents
- Those arising from naturally occurring chemicals and biotoxins

Category 2: From risk management to address climate change issues

- Chemical interventions (pesticides, antibiotics etc.)
- Other changes in production processes

We have based our indications of climate change expected over the next 100 years on the highest representative concentration pathway (RCP) 8.5, because this enables us to more clearly assess future change.

Additional commentary is provided below the table.

CLIMATE CHANGE AND FUTURE IMPACTS

Extreme events are likely to increase and include:

- Frequency, duration and intensity of hot spells,
- Frequency of heavy precipitation events and the potential for associated flooding,
- Incidence of extremely high sea levels during storm surges,
- Longer dry spells in some areas (especially in the north of the North Island and east of both islands), and the area affected by drought each year, are likely to increase.
- Cold spells and frosts will decrease in frequency, duration and intensity (Solomon et al 2007).

Changes to the average climate will include:

- Most areas of New Zealand will experience increased average crop and pasture yields associated with anticipated mean temperature rises of 1–3°C,
- Average annual rainfall in New Zealand will generally increase in the south and west and generally decrease in the north and east of the country, with seasonal variations.
- The winter season is projected to have the greatest rainfall changes (an exacerbation of the annual changes), as westerly winds (particularly across the South Island) are likely to strengthen. Together with warmer temperatures, this is likely to have a significant effect on winter cropping and pasture production.
- Average relative humidity is likely to increase for most areas of New Zealand.
- By the end of the 21st century, mean growing season temperatures are highly likely to equal current extremes in temperate areas (including New Zealand) and to exceed them in the tropics and subtropics, resulting in major impacts on global food production (Battisti and Naylor 2009).
- By 2100, the models suggest increases of up to 10 per cent ultra-violet radiation on the West Coast in summer, and smaller increases elsewhere with notable exception of the coastal Canterbury where sunshine is predicted to decrease.
- The reduced summer sunshine levels in coastal Canterbury are consistent with increased rainfall there in that season.
- The winter changes are almost the reverse of the summer ones: about a 5 per cent decrease in radiation in western parts of the North Island, and 10 per cent or more in western and southern South Island.
- Eastern North Island is projected to have an increase in winter sunshine levels.

FOOD SAFETY SYSTEM ISSUES

The impacts of global climate change on food systems will be widespread and complex

- Scientific consensus says that individual pathogens will differ widely in epidemiological responses, the net impact of climate change will lead to a large increase in the burden of infectious diseases (Costello et al 2009).
- For plant-derived foods including stock feed, mycotoxins are considered the key issue for food safety under climate change (Tirado et al 2010).
- Rising incidence of disease will lead to overuse or misuse of pesticides and veterinary medicines, particularly in fisheries (Miraglia et al 2009; Solomon et al 2007; Tirado et al 2010).

Specifically, for NZ's Meat Sector:

Increase in hot days (maximum temperature of 25°C or higher)

- Changes to mitigate heat stress such as housing for shelter may increase food safety risks e.g. hide contamination, crowding conditions, hygienic dressing more difficult.
- Heat stress may result in more shedding of STEC (see case study).
- Increased demand for water and declining water quality could all lead to increases in the levels of pathogens and chemicals in food.
- Extreme drought can lead to boreholes contaminated with nitrates.

Increased rainfall and humidity

- Increased rainfall and humidity will also lead to more animal stress that increased shedding of pathogenic bacteria. This will also result in higher pathogen loads transferred to waterways.

Increased winter rainfall coupled with milder winter temperatures

- Contamination of pasture, drinking water and silage by emission, soil, manure and water leading to increased contamination of livestock
- Increased pesticide and veterinary drug residues in the environment, leading to new or higher residues in food, some from new approvals.
- Changes in pesticide activity of some pesticides.
- Control responses may generate food safety problems due to the novelty of the pests in question as well as the unfamiliarity of farmers using the controls
- Increase spread of facial eczema resulting in increased use of zinc treatments.
- Muddy conditions can be created where cows are more likely to feel tired and lay down, such that their udder will become coated with mud, increasing contact with environmental pathogens.
- Reduced grazing, can also occur resulting in a lowered immune system
- Rainfall and muddy conditions are stressful and also may result in more hide contamination.

Emergence of new exotic pests, weeds and diseases resulting in outbreaks:

- Increased microbial burden on carcasses and meat leading to foodborne illness.
- Animals carrying more enteric pathogens in their guts or body surfaces e.g. research has indicated that retail products are more likely to carry higher total viable bacteria counts in summer.
- Increased risk of antibiotic-resistant pathogens developing.
- Mycotoxins, including aflatoxins will increase in range, type and amount.
- When cows consume aflatoxin-contaminated feeds and milk products can also serve as an indirect source of aflatoxins.

Local efforts to reduce greenhouse gas emissions

- Refrigerant management ranked as the No. 1 global solution in terms of estimated atmospheric CO_2-equivalent reductions between 2020 and 2050.

About 20% of the global-warming impact of refrigeration plants is due to refrigerant leakage.

- Reduced meat and dairy consumption – ethical food choices
- Land use changes

ADAPTATION OPTIONS

At the farm level

- Better use of seasonal climate forecasting (Jarvis et al 2011).
- Greater deployment of water conservation technologies
- Diversification of on-farm activities (Hansen et al 2007).
- Improved farm design, provide shelter through trees or housing systems
- Development and adoption of different varieties and species more suited to emerging climatic conditions,
- Improved management of pests and diseases,
- Promotion of integrated pest management and non-synthetic methods of pest control
- Adjustments in cropping and management practices (Easterling et al 2007; Jarvis et al 2011).
- Shift in production to areas more suitable e.g. further south to avoid new pests and diseases or to areas with more reliable rainfall/water supply
- Reduction of mingling during transport and lairage of calves.
- Changes in management of calf shed – e.g. number of animals, bedding turn-over.
- Decontamination of hides at lairage.
- Post dressing interventions: hot water acidified sodium chloride wash.
- Routine testing of supplemental feed to check for presence of aflatoxins and use of additives to prevent absorption, where necessary

At post-harvest/off-farm level

- Improving energy efficiency,
- Promotion of alternative refrigeration technologies and refrigerants such as fluorinated gases (MfE, 2017; EECA business 2017)
- Switching to cleaner and renewable fuels,
- Improved processing and food safety technologies,
- Strengthening food safety systems, including hazard intervention and control
- Improving non energy resource efficiency, such as through recycling and reuse.
- CH_4 from wastewater treatment could potentially be recaptured for energy generation, minimize food waste
- Enhanced transport truck hygiene measures.

CASE-STUDY: STEC (Shiga toxin-producing Escherichia coli)

STEC are bacteria primarily transmitted via the faecal-oral route. Ruminants, predominantly cattle, are important reservoirs. STEC has no known animal health or production effects and is considered normal gut flora. Due to the public health risk, STEC are a red meat trade concern and declared adulterants of beef and bobby veal in the USA. STEC are also a domestic public health risk, causing haemorrhagic diarrhoea and kidney failure, particularly in children. New Zealand has a high and increasing incidence of human cases of STEC compared to other countries, with 9.6 cases per 100,000 people reported in 2016. A 2011/2012 New Zealand case-control study of 113 cases and 506 controls identified the presence of cattle in the local area, contact with animal manure and contact with recreational waters, as significant risk factors for human STEC infection.

A nationwide 2014 cross-sectional study of 1508 young calves on 102 randomly selected dairy farms reported 20% of calves and 75% of farms had infection detected of STEC. Risk factors included region, with Northland most affected, and increased shed humidity and number of calves per shed.

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Factsheet 3: Projected Climate-related Impacts on Food Safety/Systems in the Arable Sector

RISK MATRIX

The risk matrix represents a sector specific overview of the climate change impacts to food safety and systems, their risk now, in the future under a high emission scenario, and following suggested adaptation options. The risks are defined as low = green, medium = yellow, high = orange, high = red. Information used to develop the risk matrices was sourced from scientific publications and industry feedback from Workshop 1 and based on the high emission scenario. The purpose of the risk matrix is to provide a summary of potential impacts for discussion with representatives from the NZ food sectors, research providers and government agencies.

Issues have been categorised as follows:

Category 1: Existing hazards affected by climate change

- Those arising from infectious agents
- Those arising from naturally occurring chemicals and biotoxins

Category 2: From risk management to address climate change issues

- Chemical interventions (pesticides, antibiotics etc.)
- Other changes in production processes

We have based our indications of climate change expected over the next 100 years on the highest representative concentration pathway (RCP) 8.5, because this enables us to more clearly assess future change.

Additional commentary is provided below the table.

CLIMATE CHANGE AND FUTURE IMPACTS

Extreme events are likely to increase and include:

- Frequency, duration and intensity of hot spells, mostly in the north of the NI and Eastern SI, however, towards the end of the Century this could affect All of the NI and Eastern SN
- Frequency of heavy precipitation events and the potential for associated flooding will affect all off NZ,
- Incidence of extremely high sea levels during storm surges,
- Longer dry spells in some areas (especially in the north of the North Island and east of both islands), and the areas affected by drought each year, are likely to increase.

- Cold spells and frosts will decrease in frequency, duration and intensity (Solomon et al 2007).

Changes to the average climate will include:

- Increases in warmer and wetter weather in Western NZ and Southern SI
- Most areas of New Zealand will experience increased average crop and pasture yields associated with increased CO_2 generating a 'fertilisation effect', and anticipated mean temperature rises of 1–3°C. This will compensate for negative yield impacts of climate change with the exception of area expected to increase in frequent drought.
- Average annual rainfall in New Zealand will generally increase in the south and west and generally decrease in the north and east of the country, with seasonal variations.
- The winter season is projected to have the greatest rainfall changes (an exacerbation of the annual changes), as westerly winds (particularly across the South Island) are likely to strengthen. Together with warmer temperatures, this is likely to have a significant effect on winter cropping and pasture production.
- Average relative humidity is likely to increase for most areas of New Zealand.
- All regions will be susceptible to yield losses, but impacts on global food availability would be small owing to compensatory institutional factors, such as enhanced global markets.
- By the end of the 21st century, mean growing season temperatures are highly likely to equal current extremes in temperate areas (including New Zealand) and to exceed them in the tropics and subtropics, resulting in major impacts on global food production (Battisti and Naylor 2009).
- Northern regions of New Zealand show greater risk of negative silage maize yield impacts than southern regions, where climatic suitability for maize is potentially improved.
- With projected warmer temperatures, some regions in New Zealand currently too cool may become suitable and some regions where crops are currently grown successfully may become less suitable over time.
- By 2100, the models suggest increases of up to 10 per cent ultra-violet radiation on the West Coast in summer, and smaller increases elsewhere with notable exception of the coastal Canterbury where sunshine is predicted to decrease.
- The reduced summer sunshine levels in coastal Canterbury are consistent with increased rainfall there in that season.
- The winter changes are almost the reverse of the summer ones: about a 5 per cent decrease in radiation in western parts of the North Island, and 10 per cent or more in western and southern South Island.
- Eastern North Island is projected to have an increase in winter sunshine levels.

FOOD SAFETY SYSTEM ISSUES

The impacts of global climate change on food systems will be widespread and complex –

- Scientific consensus says that individual pathogens will differ widely in epidemiological responses, the net impact of climate change will lead to a large increase in the burden of infectious diseases (Costello et al 2009)
- For plant-derived foods including stock feed, mycotoxins are considered the key issue for food safety under climate change (Miraglia et al 2009).
- Rising incidence of disease will lead to overuse or misuse of pesticides and veterinary medicines, particularly in fisheries (Gerard et al 2010; Kean et al 2015; Lennon et al 2015; Miraglia et al 2009; Shalaby et al 2013; Solomon et al 2007).
- Many adaptation solutions include the use of GMO – how these are regulated and accepted by society may impact food systems.

Increase in hot days (maximum temperature of 25°C or higher)

- Increased demand for water and declining water quality could all lead to increases in the levels of pathogens and chemicals in food.
- Extreme drought may promote use of contaminated water supplies (algal toxins, chemicals and pathogens). Water stress also increases the need for fertiliser.
- Increases in hot/dry days will favour the growth of some fungal metabolites on crops.

Increased winter rainfall coupled with milder winter temperatures

- Contamination of pasture and silage by emission, soil, manure and water
- Increased pesticide and veterinary drug residues in the environment, leading to new or higher residues in food, some from new approvals.
- Changes in pesticide activity of some pesticides.
- Control responses may generate food safety problems due to the novelty of the pests in question as well as the unfamiliarity of farmers using the controls

Increased average temperature

- Increase in pathogen loads
- Increase in insect vectors
- Increased energy requirements
- Changes in soil nutrients and bioavailability of elements in soils

Increased temperature/CO_2

- Change to nutrient content of foods, potential for allergenic foods
- Change in crop suitability

Sea level rise

- Changes in land use and availability of land

Establishment of new exotic pests, weeds and diseases resulting in outbreaks

- Increased risk of antibiotic-resistant pathogens developing.
- Mycotoxins, including aflatoxins will increase in range, type and amount.

Meeting stringent climate change targets

- Refrigerant management ranked as the No. 1 global solution in terms of estimated atmospheric CO_2-equivalent reductions between 2020 and 2050. About 20% of the global-warming impact of refrigeration plants is due to refrigerant leakage.
- Reduced meat and dairy consumption – ethical food choices, increased demand for arable crops?
- Land use changes

ADAPTATION OPTIONS

At the farm level

- better use of seasonal climate forecasting (Jarvis et al 2011),
- greater deployment of water conservation technologies,
- diversification of on-farm activities (Hansen et al 2007),
- development and adoption of different varieties and species more suited to emerging climatic conditions,
- improved management of pests and diseases,
- Promotion of integrated pest management and non-synthetic methods of pest control
- adjustments in cropping and management practices (Easterling et al 2007; Jarvis et al 2011),
- Shift in land use or crop varieties that are more suitable for new conditions
- At a national scale, considering logistic and economic constraints, expansion of cropping areas to regions with improved climatic suitability is an adaptation option to minimise negative impacts on silage maize yields. At a local scale, adaptation of agronomic practices, such as the use of earlier sowing dates and long-cycle genotypes for maize, may minimise negative impacts on silage maize yields.

At post-harvest/off-farm level

- improving energy efficiency,
- switching to cleaner and renewable fuels,
- improved processing technologies,
- strengthening food safety systems, including hazard intervention and control
- improving non-energy resource efficiency, such as through recycling and reuse,
- CH_4 from wastewater treatment could potentially be recaptured for energy generation, minimize food waste

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Factsheet 4: Projected Climate-related Impacts on Food Safety/Systems in the Horticulture Sector

RISK MATRIX

The risk matrix represents a sector specific overview of the climate change impacts to food safety and systems, their risk now, in the future under a high emission scenario, and following suggested adaptation options. The risks are defined as low = green, medium = yellow, high = orange, high = red. Information used to develop the risk matrices was sourced from scientific publications and industry feedback from Workshop 1 and based on the high emission scenario. The purpose of the risk matrix is to provide a summary of potential impacts for discussion with representatives from the NZ food sectors, research providers and government agencies.

Issues have been categorised as follows:

Category 1: Existing hazards affected by climate change

- Those arising from infectious agents
- Those arising from naturally occurring chemicals and biotoxins

Category 2: From risk management to address climate change issues

- Chemical interventions (pesticides, antibiotics etc.)
- Other changes in production processes

We have based our indications of climate change expected over the next 100 years on the highest representative concentration pathway (RCP) 8.5, because this enables us to more clearly assess future change.

Additional commentary is provided below the table.

CLIMATE CHANGE AND FUTURE IMPACTS

Extreme events are likely to increase and include:

- Frequency, duration and intensity of hot spells;
- Frequency of heavy precipitation events and the potential for associated flooding;
- Incidence of extremely high sea levels during storm surges;
- Longer dry spells in some areas (especially in the north of the North Island and east of both islands), and the area affected by drought each year, are likely to increase;
- Cold spells and frosts will decrease in frequency, duration and intensity (Solomon et al 2007).

Changes to the average climate will include:

- Most areas of New Zealand will experience increased average crop and pasture yields associated with anticipated mean temperature rises of 1–3°C;
- Average annual rainfall in New Zealand will generally increase in the south and west and generally decrease in the north and east of the country, with seasonal variations.
- The winter season is projected to have the greatest rainfall changes (an exacerbation of the annual changes), as westerly winds (particularly across the South Island) are likely to strengthen. Together with warmer temperatures, this is likely to have a significant effect on winter cropping and pasture production.
- Average relative humidity is likely to increase for most areas of New Zealand.
- By the end of the 21st century, mean growing season temperatures are highly likely to equal current extremes in temperate areas (including New Zealand) and to exceed them in the tropics and subtropics, resulting in major impacts on global food production (Battisti and Naylor 2009).
- By 2100, the models suggest increases of up to 10 per cent ultra-violet radiation on the West Coast in summer, and smaller increases elsewhere with notable exception of the coastal Canterbury where sunshine is predicted to decrease.
- The reduced summer sunshine levels in coastal Canterbury are consistent with increased rainfall there in that season.
- The winter changes are almost the reverse of the summer ones: about a 5 per cent decrease in radiation in western parts of the North Island, and 10 per cent or more in western and southern South Island.
- Eastern North Island is projected to have an increase in winter sunshine levels.

FOOD SAFETY SYSTEM ISSUES

The impacts of global climate change on food systems will be widespread and complex

- Scientific consensus says that individual pathogens will differ widely in epidemiological responses, the net impact of climate change will lead to a large increase in the burden of infectious diseases (Costello et al 2009).
- For plant-derived foods including stock feed, mycotoxins are considered the key issue for food safety under climate change (Tirado et al 2010).
- Rising incidence of disease will lead to overuse or misuse of pesticides and veterinary medicines, particularly in fisheries (Miraglia et al 2009; Solomon et al 2007; Tirado et al 2010).

Specifically for NZ's Horticulture Sector:

ADAPTATION OPTIONS

At the farm level

- Greater deployment of water conservation technologies

- Improved management of pests and diseases,
- Shift in production to areas more suitable
    - the importance of frosts and winter chill for production which may reduce in more northern parts of the country
    - movement of crops to wetter areas
- Shift towards more C4 plants
- Treatment of water used for irrigation
- Use of new resistant commercial crop types and/or new species
- New biocontrol agents may be required
- Water security measures or movement to areas with more reliable rainfall/water supply
- Natural plant growth promoters

At post-harvest/off-farm level

- Improvements to food cleaning, handling and storage

CASE-STUDY: *Escherichia coli* on leafy greens and tomatoes

Heavy precipitation events, as a result of climate change, may result in contamination of some food plants such as leafy greens and tomatoes (Park et al 2015; Kniel et al 2017). Contamination may occur by splashing of faecal matter, by runoff from neighbouring fields where livestock graze, or irrigation with contaminated water (Mootian et al 2009). Amended soils containing manure have also been shown to cause contamination events. Increased temperatures and drought conditions as a result of climate change may lead to an increased use of amendments for poor soils.

After a contamination event additional growth of *E. coli* may occur as a result of increased temperatures and high humidity. For example, field trials in Atlanta examined the transmission and growth of *E. coli* on tomatoes from a one-off irrigation event using water contaminated with faecal matter (Kniel et al 2017). Spikes of *E. coli* levels were observed following the contamination event suggesting that there was additional growth. *E. coli* may be internalised within the plant and in this case cleaning and sanitisers are unlikely to be effective adaptation options (Erickson 2012); therefore, the prevention of contamination events using adaptation options around water security measures and land management practices (e.g. around the application of fertiliser) will be essential.

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Factsheet 5: Projected Climate-related Impacts on Food Safety Systems in the Seafood and Aquaculture Sector

RISK MATRIX

The risk matrix represents a sector specific overview of the climate change impacts to food safety and systems, their risk now, in the future under a high emission scenario, and following suggested adaptation options. The risks are defined as low = green, medium = yellow, high = orange, high = red. Information used to develop the risk matrices was sourced from scientific publications and industry feedback from Workshop 1 and based on the high emission scenario. The purpose of the risk matrix is to provide a summary of potential impacts for discussion with representatives from the NZ food sectors, research providers and government agencies.

Issues have been categorised as follows:

Category 1: Existing hazards affected by climate change

- Those arising from infectious agents
- Those arising from naturally occurring chemicals and biotoxins

Category 2: From risk management to address climate change issues

- Chemical interventions (pesticides, antibiotics etc.)
- Other changes in production processes

We have based our indications of climate change expected over the next 100 years on the highest representative concentration pathway (RCP) 8.5, because this enables us to more clearly assess future change.

Additional commentary is provided below the table.

CLIMATE CHANGE AND FUTURE IMPACTS

The following oceanic changes are projected for the whole New Zealand Exclusive Economic Zone (EEZ) region.

Sea surface temperature (SST) and iron concentration are projected to increase (by around 2.5°C and 0.031 nM, respectively); while chlorophyll, nitrate, phosphate, and silicate are projected to decrease by, respectively, -0.043 mg Chl m-3, -0.49 µmol m-3, -0.039 µmol m-3, and -0.18 µmol m-3. These changes are for the end of the century (compared with the period 1986-2005) and are based on RCP8.5 and the average from several global climate models (Law et al., 2016). By 2100, models suggest increases of up to 10 % ultra-violet radiation on the West Coast in summer, and smaller increases elsewhere with notable exception of the coastal Canterbury where sunshine is predicted to decrease. The reduced summer sunshine levels in coastal Canterbury are consistent with increased rainfall there in that season. The winter changes are almost the reverse of the summer ones: about a 5 per cent decrease in radiation in western parts of the North Island, and 10 per cent or more in western and southern South Island. Eastern North Island is projected to have an increase in winter sunshine levels.

The rising atmospheric concentration of CO_2 is also causing 'ocean acidification', a collective term used to describe the changes in different components of the ocean carbonate system (Orr et al., 2005). This change is most apparent as a decrease in pH. All projections indicate that the annual pH range falls below the current pH range by 2025, with only RCP2.6 projecting a return to this range by the end of the century (Cummings, 2016).

Global mean sea level rose by 0.19 ± 0.02 m from 1901 to 2010 (IPCC, 2013). Sea level rise around New Zealand is comparable to the global average, being approximately 0.17 ± 0.1 m for the 20th century (IPCC, 2014). Sea level is projected to rise by between 0.5m and 0.8m by the 2090s (2090 to 2099) relative to the 1980-1999. For longer-term considerations, an allowance for further sea-level rise of 10 mm/year beyond 2100 is recommended (Ministry for the Environment, 2008).

Additional oceanic changes are also possible (for example, to the location and strength of ocean currents and sedimentation rates to river mouths and estuaries), however these have not been assessed in detail at present.

FOOD SAFETY SYSTEM ISSUES

Impact on fisheries:

Phytoplankton from the base of marine food webs and support ecosystems and fisheries. Primary phytoplankton production in surface waters is projected to decline by an average 6% from the present day under RCP8.5, with Subtropical waters, which have low primary production, experiencing the largest decline (Law et al., 2016).

A proportion of the organic matter produced by phytoplankton in the surface of the ocean sinks down through the water column. This particle flux from surface to sea-bed is an important factor that determines energy flow through marine ecosystems, and also the amount of carbon sequestered in the deep ocean. Consequently, determining the impact of climate change on particle flux into the ocean interior is important for predicting future carbon uptake by the ocean, and the impacts of climate change on marine ecosystems and fish stocks. Particle flux from the surface to the seabed is projected to decrease by 9-12% by 2100, which indicates that carbon sequestration will decline in the open ocean around New Zealand. Changes in particle flux will alter the food available for fish.

Impact on aquaculture:

The 'Australasia' chapter of IPCC (2014) concludes that climate change could lead to substantial changes in production and profit of aquaculture species such as salmon, mussels and oysters. Ecosystem models also project changes to habitat and fisheries production.

Climate change may adversely affect pāua (*Haliotis iris*). Experimental work on the impacts of acidification in New Zealand waters on juvenile pāua showed that while survival was not affected, growth was significantly reduced, and dissolution of the shell surface was evident (Cunningham 2013). Similar effects were found for growth and shell surfaces of flat oysters (*Tiostrea chilensis*) (Cummings et al., 2013, 2015). Rock lobster (*Jasus edwardsii*) may also be adversely affected by the effects of climate change, including ocean acidification (Cornwall and Eddy, 2015).

Changes to carbon markets may threaten some supply chains. For example, a life cycle analysis of Australian rock lobsters identified that airfreight to markets had 50% of global warming potential, a measure of the environmental footprint (van Putten et al 2015) that could threaten the supply chain.

Projected increases in heavy rainfall (with likely related increases in river flooding events) could result in changes in sediment characteristics that reduce suitability of habitats for aquaculture species in intertidal areas of estuaries. This typically results in muddier habitats and reductions in the abundance of sea grass meadows and intertidal shellfish beds (Cummings, 2016).

Warming ocean temperatures (Polar shift) could facilitate/assist arrival and spread of invasive organisms into cooler regions and how this could impact aquaculture and wild stocks i.e. habitat change through invasive seaweed outcompeting our native species and how this could impact ecosystem function and energy transfer.

The effects of higher temperatures on salmon farming may affect future production and sustainability of the industry, as temperatures over 16 degrees can negative impacts on Chinook Salmon i.e. current farming sites may not be viable under future climate predictions, this will be very important for future planning of new aquaculture sites and species selection.

SUPPLEMENTARY INFORMATION FOR RISK MATRIX:

Infectious agents:

Increased ocean temperature:

- Most important hazard is *Vibrio* spp., research is in progress at Plant and Food Research. Seawater temperatures above 19 degrees have been suggested as trigger for increased risk and monitoring (Cruz et al., 2015). As well as a food safety issue, *Vibrio* can cause wound infections.
- Post-harvest processing options for such hazards include low temperature pasteurisation, freezing, high hydrostatic pressure and irradiation.
- Refrigeration will be an increasingly important component of the food chain, for both maintaining quality and preventing pathogen growth.

Increased runoff from rainfall:

- Increase in rainfall predicted for western regions of New Zealand, and in south of South Island. Decrease in rainfall and extremes in north and east of North Island.
- This is likely to affect marine environments for aquaculture and feral populations of shellfish. Effects could include increased viral contamination of filter feeders, and increased sediment runoff affecting growth.
- May affect mussel farms in Foveaux Strait. However, most aquaculture in on east coast which is likely to experience reductions in rainfall.
- Adaptation through aquaculture farm location.

Chemicals and biotoxins

Cadmium

- Ocean acidification has been shown to increase cadmium accumulation by bivalve molluscs (blue mussels, blood and hard clams) (Shi et al., 2016). Cadmium affects kidney toxicity, cancer. If this effect also occurs in species harvested in New Zealand, increased absorption may need to be monitored.

- In New Zealand cadmium dietary intake estimates are within WHO guidelines[3], and oysters (along with bread and potatoes) are major contributors (2009 Total Diet Survey).

Algal blooms

- A study of harmful marine algal bloom growth rate and duration over the last 40 years concluded that increasing ocean temperature is an important factor facilitating the intensification of these from 40°N to 60°N in the North Atlantic, although the link was less strong in more northern regions (Gobler et al., 2017). The risk for New Zealand is uncertain, but any such increases may affect feral and farmed shellfish. Risk to human health from consumption will affect harvesting through closures, and restrictions on mussel spat movement affecting production (MacKenzie et al., 2014).

Chemical interventions

- Temperature changes may also increase animal stress, requiring greater disease management.

Other production processes

- There is no conclusive evidence of climate change impact on fish abundance in New Zealand waters (Reisinger, 2014).
- In a comparison of 147 countries, New Zealand marine fisheries assessed as amongst the least vulnerable to climate change. Vulnerability to climate change was defined as the product of three variables, namely: (1) exposure to climate change impacts; (2) sensitivity of an economy/community/country to changes in productive capacity associated with climate change impacts; and (3) adaptive capacity, or the ability to modify or adjust fisheries and livelihoods in order to cope with the negative impacts of climate change and pursue any emerging opportunities (Blasiak et al., 2017).

[3] https://www.mpi.govt.nz/protection-and-response/environment-and-natural-resources/land-and-soil/cadmium/ accessed 21 November 2017

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Factsheet 6: Projected Climate-related Impacts on Food Safety Systems in the Mahinga Kai/Wildfood Sector

RISK MATRIX

The risk matrix represents a sector specific overview of the climate change impacts to food safety and systems, their risk now, in the future under a high emission scenario, and following suggested adaptation options. The risks are defined as low = green, medium = yellow, high = orange, high = red. Information used to develop the risk matrices was sourced from scientific publications and industry feedback from Workshop 1 and based on the high emission scenario. The purpose of the risk matrix is to provide a summary of potential impacts for discussion with representatives from the NZ food sectors, research providers and government agencies.

Issues have been categorised as follows:

Category 1: Existing hazards affected by climate change

- Those arising from infectious agents
- Those arising from naturally occurring chemicals and biotoxins

Category 2: From risk management to address climate change issues

- Chemical interventions (pesticides, antibiotics etc.)
- Other changes in production processes

We have based our indications of climate change expected over the next 100 years on the highest representative concentration pathway (RCP) 8.5, because this enables us to more clearly assess future change.

Additional commentary is provided below the table.

CLIMATE CHANGE AND FUTURE IMPACTS

Harvesting of wild foods can provide an additional food source and collection and sharing of wild food has cultural and spiritual value for Maori. Commonly collected or hunted wild foods include seafood that also form part of recreational activities (i.e. fishing, tourism). Other wild foods include whitebait, watercress and seaweed although there are a many native plants and animals that are eaten or used for medicinal purposes.
Climate change could lead to food security issues and an increase in the reliance of wild food.
Wild foods are susceptible to the same effects of climate change as commercially grown plants and animals.

Extreme events are likely to increase and include:

- Frequency, duration and intensity of hot spells, mostly in the north of the NI and Eastern SI, however, towards the end of the Century this could affect All of the NI and Eastern SN
- Frequency of heavy precipitation events and the potential for associated flooding will affect all off NZ,
- Incidence of extremely high sea levels during storm surges,
- Longer dry spells in some areas (especially in the north of the North Island and east of both islands), and the areas affected by drought each year, are likely to increase.

Changes to the average climate will include:

- Increases in warmer and wetter weather in Western NZ and Southern SI
- Average annual rainfall in New Zealand will generally increase in the south and west and generally decrease in the north and east of the country, with seasonal variations.
- The winter season is projected to have the greatest rainfall changes (an exacerbation of the annual changes), as westerly winds (particularly across the South Island) are likely to strengthen.
- Average relative humidity is likely to increase for most areas of New Zealand.
- By the end of the 21st century, mean growing season temperatures are highly likely to equal current extremes in temperate areas (including New Zealand) and to exceed them in the tropics and subtropics, resulting in major impacts on global food production (Battisti and Naylor 2009).
- With projected warmer temperatures, some regions in New Zealand currently too cool may become suitable and some regions where crops are currently grown successfully may become less suitable over time.
- Ocean temperatures will increase and ocean pH decrease.
- By 2100, the models suggest increases of up to 10 per cent ultra-violet radiation on the West Coast in summer, and smaller increases elsewhere with notable exception of the coastal Canterbury where sunshine is predicted to decrease.
- The reduced summer sunshine levels in coastal Canterbury are consistent with increased rainfall there in that season.
- The winter changes are almost the reverse of the summer ones: about a 5 per cent decrease in radiation in western parts of the North Island, and 10 per cent or more in western and southern South Island.
- Eastern North Island is projected to have an increase in winter sunshine levels.

FOOD SYSTEM ISSUES

Increased ocean temperate and acidification

- An increase in ocean temperature will affect the range and prevalence of marine pathogens and toxins. One of the most important pathogens is *Vibrio* spp. Seawater temperatures above 19 degrees have been suggested as trigger point for increased risk and monitoring (Cruz et al., 2015). There is also the potential for foodborne and wound infections during gathering.
- Increased ocean temperature, deluge and drought may also lead to an increase risk of toxic algal blooms. Some shellfish can accumulate toxins and above certain levels if they are eaten can poison humans.
- There is some evidence to suggest that climate change will increase heavy metal and dioxin concentrations in some foods e.g. methylation of mercury will increase levels in predatory fish (Paranjape and Hall 2017; Thomson and Rose 2011). Cadmium is also projected to increase in foods. Increased absorption may approach regulatory limits. Watercress can absorb contaminants from waterways. Molluscs are a minor contributor to overall dietary exposure - adaptation may not be necessary.
- Increased ocean temperatures and acidification will affect primary production impacting on many fish species as well as fish metabolic changes affecting behaviour and survivability.
- Ocean acidification will also affect the size and growth of harvested shellfish. Rock lobster may also be adversely affected by the effects of climate change, including acidification. Changes in sedimentation may result in muddier habitats and reductions in the abundance of seagrass meadows and intertidal shellfish beds.

Increase in hot days (maximum temperature of 25°C or higher)

- Increased animal stress. Reduction in immunity. Higher parasite loads including ticks and helminths. Potential transmission of zoonotic diseases.

Increased average temperature and changes in precipitation

- Increase in pathogen loads
- Increase in insect vectors. Possible uptake of chemicals used in vector control.
- Increased energy requirements needed for refrigeration leading to food safety concerns.
- Changes in soil nutrients and bioavailability of elements in soils.

Increased number of days with heavy rainfall

- Increased run-off from rainfall - Affects river and marine environments for fishing, gathering of plants and feral populations of shellfish, particularly important for viral contamination. Sediments also affect growth.
- Flooding events may lead to contaminated land and an increased risk of fungal growth. An increased risk of foodborne disease may result.

Establishment of new exotic pests, weeds and diseases resulting in outbreaks

- Increased risk of antibiotic-resistant pathogens developing.
- Mycotoxins, including aflatoxins will increase in range, type and amount.
- Harmful algal blooms may increase in range and type in both fresh and marine waters. There is a risk to human health from consumption of food containing toxins from HAB. This will affect harvesting through closures and restrictions (MacKenzie et al., 2014).

Indirect effects

Shift in harvesting season will affect traditional calendars/maramataka.
A reduction in safe or available mahinga kai or the perception of increased wild food risks, may lead to increase reliance on readily available, less healthy foods

Adaptation options:

- Post-harvest processing options will need to account for increased risks of pathogens.
- Refrigeration will be an increasingly important component of the food chain, for both maintaining quality and preventing pathogen growth. Improved energy efficient cooling is encouraged. Public health messages regarding food cleaning, handling (washing) and storage (refrigeration) would be beneficial.
- Although there are few if no adaptation options for increased ocean temperature and acidification (apart from mitigation of greenhouse gases), studies suggest New Zealand marine fisheries are amongst the least vulnerable to climate change (Blasiak et al., 2017).
- Gatherers need to be informed of safe levels of consumption/areas unsafe for harvesting. MPI assesses the safety of commercial and wild foods, however more effort is required to work in outreach, at community level and to utilise local leadership for education programmes.
- Increased monitoring of harvested shellfish may be required. Public health messages regarding shellfish consumption/safety.

- In terms of zoonotic disease risks – surveillance, laboratory capability, training and education required and communication of potential human health impacts.

Opportunities

Opportunities include harvesting of exotic or less known native species as a source of kai, harvesting unwanted organisms such as Undaria, and growing of crops not currently available such as kumara.

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Appendix C – Detailed food system issues arising from changes in primary production practice as a result of climate change and adaptation measures for each sector

Table C1: Food safety issues arising from changes in primary production practice as a result of climate change and adaptation measures for the dairy sector.

SECTOR: DAIRY					
Climate Change Impact(s) on dairy sector	**Food System Risks Identified**	**Implications for Industry**	**Proposed Adaptation Measures**	**Reference**	**Study Location**
Climate change may allow the establishment and spread of new exotic pests, sleeper pests, natural enemies, weeds and diseases resulting in disease outbreaks.	Mycotoxins, including aflatoxins, particularly in stored grains, nuts (including imports) will increase in range, type and amount due to increasing hot humid conditions. Harmful fungal metabolites under dry, hot conditions can also contaminate cereals and pulses during crop growth and post-harvest. When cows consume aflatoxin-contaminated feeds milk products can also serve as an indirect source of aflatoxins.	Feed used for cows may cause health effects such as mycosis or mycotoxicosis. There could be residues of mycotoxins in milk.	Use of new resistant commercial crop types and/or new species. Improvements required to store feed. Routine testing of supplemental feed to check for presence of aflatoxins and use of additives to prevent absorption, where necessary.	(Bennett and Klich 2003; Kean et al 2015), Comment at Workshop 1	NZ
		Cost, insufficient application (over or under-use)	Shift in production to areas further south to avoid new pests and diseases.	SLMACC PROJECT IDEA	NZ

	Control responses may generate food safety problems due to the novelty of the pests in question as well as the unfamiliarity of farmers using the controls such as new pesticides or other measures.	Unknown human health effects of new pesticides or veterinary medicines. Withholding periods affected. Pesticide residues may be higher than approved levels.	Use crops to break pest cycles.	(Clark et al 2012)	NZ
	Pesticide, veterinary drug and antifungal residues in the environment will increase in response to changes in plant, animal diseases and pests.	Residues	Introduction of new bio control agents. Some mitigation techniques will require further studies. For example, enterohaemorrhagic E. coli has been positively associated with increased temperature and antibiotic treatment in dairy cows. Negative associations were found when cows were more days in milk, has a higher hygiene score and cow contact.	(Gerard et al 2010; Gerard et al 2012; Stenkamp-Strahm et al 2017)	NZ, USA
	New or higher residues in food may occur, some from new approvals.	Residues	Pesticide safety training programs for farmers with stringent enforcement of pesticide laws.	SLMACC PROJECT IDEA	NZ

	Increased risk of antibiotic-resistant pathogens developing.	Need for newer treatments. Unknown human health effects of new pesticides or veterinary medicines. Withholding periods affected. Pesticide residues may be higher than approved levels.	Promotion of integrated pest management and non-synthetic methods of pest control.	SLMACC PROJECT IDEA, Clark et al (2010)	NZ
	Increases in zoonotic diseases leading to more reliance on veterinary medicines.	Need for newer treatments. Unknown human health effects of new pesticides or veterinary medicines. Withholding periods affected. Pesticide residues may be higher than approved levels.	Use of technologically-advanced foods (GMO), functional foods and nanotechnology in preference to the use of pesticides. Change in cattle breed or use of genetically resistant animals	(Clark et al 2012; Dennis et al 2014; Vermeulen et al 2012)	Global, NZ
			Sharing knowledge of agronomic and food science technology.	(Fedoroff et al 2010)	Global
			Strengthening of food safety systems	SLMACC PROJECT IDEA	NZ

Increased winter rainfall coupled with milder winter temperatures in some areas may require greater use of anti-helminthic as snail vectors multiply.	Antihelmintics residues in raw milk	An increase in the dosage or frequency of use of anti-helminthic agents with attendant implications for residue levels. Increasing usage may lead to resistance in helminths.	Parasite resistant breeds, nutrition, pasture management, nematode-trapping fungi, antiparasitic vaccines and botanical dewormers.	(Lennon 2015; Shalaby 2013)	Ireland, Global
Increase temperatures and rainfall will may result spread of facial eczema	Increased use of zinc treatments. There is no recognised concern to human health associated with these treatments.	Lowered production, skin irritation and peeling and sometimes death of animal. The use of zinc treatment and pasture management will not fully eliminate the impacts of facial eczema.	Movement of animals to areas with lower temperatures and humidity driven by temperature and water effects on pasture species.	Workshop 1 outcome; (Plum et al 2010)	NZ
	There is some evidence to suggest that increased stress in animals (for poor health) can lead to increased food safety risks.		Change in cattle breed or use of genetically resistant animals	Clark et al (2010,) Dennis et al (2012), Rostagno (2009)	NZ
			Monitoring pasture spore count during danger periods (minimum temperatures are above 12°C for two or three nights and humidity is high (usually January to May) and either dosing animals with zinc or spraying pastures with a fungicide.	Dairy NZ (https://www.dairynz.co.nz/animal/cow-health/facial-eczema/)	NZ

Intermingling, crowding of food animals in response to natural disasters or climate	Promotion of the transmission of pathogens between animals, resulting in greater pathogen load in faeces.	Increase use of parasite and veterinary treatment leading to residues.	Improved farm design (trees) to provide shelter, paddock shade and reduce wind chill. Housing control systems, new feeding systems/crops. Could also mean better control of effluent.	(Wheeler 2015), Workshop 1 outcome	Global
			Small reduction in stock	SLMACC PROJECT IDEA	NZ
Increased bacteria and biofilms in milk during transportation	Bacteria within biofilms of dairy origin can increase with ambient temperatures. Biofilms may produce protiolytic enzymes.	Milk spoilage. Increased pathogens in raw milk. Protiolytic enzymes can remain active after pasteurisation.	Maintain quality and temperature of raw milk. Adequate cleaning and sanitation of milk tankers.	(Teh 2013)	NZ
Climate change may require new sources of feed ingredients, storage and intake and conditions of compound feed storage	Food safety issues, in particular mycotoxins. New raw materials and fewer varieties may increase food safety risks	Mycosis and mycotoxicosis in cows. Prevention of mycotoxin formation is essential since there are few ways to completely overcome problems once mycotoxins are present.	Intensification of food safety management including all sector (farm to fork) co-ordination, surveillance and monitoring, risk assessment, predicative modelling. Routine testing of supplemental feed to check for presence of aflatoxins and use of additives to prevent absorption, where necessary.	(Tirado et al 2010; van der Spiegel et al 2012)	The Netherlands, Global

Warmer and wetter conditions and flooding will favour contamination	Contamination of pasture and silage by emission, soil, manure and water. Parasites may also be a problem.	Need for newer treatments. Unknown human health effects of new pesticides or veterinary medicines. Withholding periods affected. Pesticide residues may be higher than approved levels.			
			Improvements to food cleaning, handling and storage	(Britton et al 2010)	NZ
Higher humidity	May increase fungal infections in silage making and increase the risk of mycotoxins. Increases in dry matter contact may also pose a risk in terms of level of contaminants.		Strengthening of food safety management programmes	van der Spiegel, (2012)	The Netherlands
Generic climate change	May introduce unknown animal diseases. Evolution of current diseases, zoonotic diseases and foodborne infectious diseases will increase. Some parasites may continue to pose health issues where cycle's wold normally stop.	Need for newer treatments. Unknown human health effects of new pesticides or veterinary medicines. Withholding periods affected. Pesticide residues may be higher than approved levels.	Increased use of more genetically resistant animals. Strengthening of food safety management programmes	Clark et al (2010), van der Spiegel, (2012), Wheeler et al (2015), Ziska et al (2016),	The Netherlands, Global, Global, NZ, The Netherlands

Increased temperatures	Increased temperatures can increase risk from pathogenic bacteria in raw milk. Higher microbial loads and parasites including ticks.	Food safety risks associated with raw milk and some bacteria (e.g. lactic acid bacteria).	Cooling during milking. Refrigeration to cool drinking water. Improved energy efficient cooling. Use of sustainable energy sources.	van der Spiegel, (2012), Clark et al (2010), Comment at Workshop 1	The Netherlands, NZ
	Higher parasite loads including ticks and helminths	Increased need for parasite treatment or prevention leading to potential for residue problems	Increased use of more genetically resistant animals.	van der Spiegel, (2012) Clark et al (2010)	The Netherlands, NZ
	Increased risk of mastitis infection and raise somatic cell count. Hot weather can reduce cows' immune systems due to heat stress and the cow can experience udder chapping, increasing pathogen entry.		Infrastructural changes to the milking platform and farm landscape to reduce heat and cold stress	Clark et al (2010)	NZ
	Increased animal stress, leading to reduced fertility in cattle: increased lameness		Improved farm design (trees) to provide shelter, paddock shade and reduce wind chill. Housing control systems, new feeding systems/crops. Could also mean better control of effluent.	(Drake 2008) Workshop 1 outcome	USA
Hot humid weather, and precipitation	Create muddy conditions where cows are more likely to feel tired and lay down, such that their udder will become coated with mud, increasing contact with environmental pathogens. Reduced grazing, can also occur resulting in a lowered immune system.		Increased use of more genetically resistant animals.	Drake, (2008)	USA

	West Coast may become too wet for dairying.		Farm design (trees) to provide paddock shade and reduce wind chill	Clark et al (2010	NZ
Hot weather and drier conditions in some parts of the country	Contamination of pasture and silage by emission, soil, manure and water. Parasites may also be a problem as well as increased risk of illness in cattle required use of veterinary medicines.	Heat stress.	Movement of dairying (to the South) driven by temperature and water effects on pasture species.	(Shalaby 2013)	Global
	Increased use of parasite and veterinary treatment leading to residues.	Increased use of irrigation	Breeding Zebus or their crosses instead of Jersey or Friesian cattle. Opportunities to change to smaller ruminants (e.g. sheep milk) and their products.	Comment at Workshop 1	NZ
	Increased pathogens due to use of manure, waste water irrigation or runoff. Drier conditions could also lead to declining water quality could all lead to increases in the levels of pathogens and chemicals in food.	Increased use of irrigation	Parasite resistant breeds, nutrition, pasture management, nematode-trapping fungi, antiparasitic vaccines and botanical dewormers.	(Edwards et al 2010; Lake et al 2010; Shalaby 2013)	Global, UK, Australia

Table C2: Food System issues arising from changes in primary production practice as a result of climate change and adaptation measures for the meat sector (sheep, beef, poultry, and pigs).

SECTOR: MEAT					
Climate Change Impact(s) on meat sector	**Food System Risks Identified**	**Implications for Industry**	**Proposed Adaptation Measures**	**Reference**	**Study Location**
Increase in hot days (maximum temperature of 25°C or higher) could affect livestock production (e.g. heat stress, reproduction, feeding etc.)	Changes to mitigate heat stress could affect Food System e.g. greater use of housing for shelter and other livestock may lead to crowding conditions.	Decrease in livestock production and reproduction issues	Use of more genetically resistant animals. Refrigeration to cool drinking water. Improved energy efficient cooling. Use of sustainable energy sources.	(Clark et al 2012; Renwick et al 2013; van der Spiegel et al 2012), Comment at Workshop 1	NZ, The Netherlands, NZ
	Higher parasite loads including ticks and helminths.	Increased need for parasite treatment or prevention leading to potential for residue problems.	Improved farm design (trees) to provide shelter, paddock shade and reduce wind chill. Housing control systems, new feeding systems/crops. Could also mean better control of effluent.	(Drake 2008) and Comment at Workshop 1	USA
Increased temperatures resulting in heat stress.	Higher parasite loads including ticks and helminths	Increased need for parasite treatment or prevention leading to potential for residue problems	Use of more genetically resistant animals.	van der Spiegel, (2012) Clark et al (2010)	The Netherlands, NZ
	Hot weather can cause heat stress. In some animal's immune systems can reduce.	Increased risk of illness and need for treatment	Infrastructural changes to the farm landscape to reduce heat and cold stress	Clark et al (2010)	NZ

	Animal welfare may require indoor housing which has its own food safety issues (crowding etc.).	Indoor environments will cost more in terms of infrastructure and energy requirements (e.g. cooling)	Farm design (trees) to provide paddock shade and reduce wind chill. Refrigeration to cool drinking water. Improved energy efficient cooling. Use of sustainable energy sources.	Drake, (2008) Clark et al (2010), Comment at Workshop 1	USA, NZ
Establishment of new exotic pests, sleeper pest's natural enemies, weeds and diseases resulting in disease outbreaks.	Increased microbial burden on carcasses and meat leading to foodborne illness.	Rejected from the food chain	Improved meat processing techniques	Comment at Workshop 1	NZ
	Increases in Salmonella in pigs	Rejected from the food chain	Improved meat processing techniques	Comment at Workshop 1	NZ
	Animals carrying more enteric pathogens in their guts or body surfaces. In particular, for pigs, the upper intestinal tract can act as a reservoir for particular strains of antibiotic-resistant bacteria.	Rejected from the food chain.	Improved meat processing techniques	Comment at Workshop 1	NZ
	In poultry, research has indicated that retail products are more likely to carry higher total viable bacteria counts in summer.	Rejected from the food chain. Potential seasonal issues in poultry.	Improved meat processing techniques	Comment at Workshop 1 (Gregory 2010)	Australia
	Pesticide and veterinary drug residues in the environment, crops will increase in response to changes in pests. New or higher residues in food may occur. Climate change may affect the pesticide activity of some pesticides. There is also an increased risk of antibiotic-resistant pathogens developing.	Increased or new residues in food.	Use of new bio control agents and new approvals (prevention)	(Gerard et al 2010; Kean et al 2015; Miraglia et al 2009)	NZ, NZ, Europe

	Mycotoxins, including aflatoxins, particularly in stored grains and nuts will increase in range, type and amount due to increasing hot humid conditions. Harmful fungal metabolites under dry, hot conditions can also contaminate cereals and pulses during crop growth and post-harvest. When cows consume aflatoxin-contaminated feeds milk products can also serve as an indirect source of aflatoxins.	Feed used for animals may cause health effects such as mycosis or mycotoxicosis.	Use of new resistant commercial crop types and/or new species. Avoid growing feedstock in warm and wet areas. Use of mycotoxin controls including improved drying of grain at harvest, good crop husbandry, storage and transport.	Kean et al (2015)	NZ
	Use of new bio controls	Cost, insufficient application (over or under-use)	Shift in production to areas further south to avoid new pests and diseases.	Comment at Workshop 1	NZ
	Control responses may generate food safety problems due to the novelty of the pests in question as well as the unfamiliarity of farmers using the controls such as new pesticides or other measures.	Unknown human health effects of new pesticides or veterinary medicines. Withholding periods affected. Pesticide residues may be higher than approved levels.	Use crops to break pest cycles.	Clark et al (2010)	NZ
	Pesticide, veterinary drug and antifungal residues in the environment will increase in response to changes in plant, and animal diseases and pests.	Pesticide, veterinary drugs and antifungal residues in meat	Introduction of new bio control agents.	Gerard et al (2010)	NZ
	New or higher residues in food may occur, some from new approvals.	Residues from new approvals in meat	Pesticide safety training programs for farmers with stringent enforcement of pesticide laws.	Comment at Workshop 1	NZ

	Increased risk of antibiotic-resistant pathogens developing.	Need for newer treatments. Unknown human health effects of new pesticides or veterinary medicines. Withholding periods affected. Pesticide residues may be higher than approved levels.	Promotion of integrated pest management and non-synthetic methods of pest control.	Comment at Workshop 1, Clark et al (2010)	NZ
			Use of technologically-advanced foods (GMO), functional foods and nanotechnology in preference to the use of pesticides	(Vermeulen et al 2012)	Global
			Sharing knowledge of agronomic and food science technology.	(Fedoroff et al 2010)	Global
			Strengthening of food safety systems	Comment at Workshop 1	NZ
	Antihelmintic residues in meat?	An increase in the dosage or frequency of use of anti-helminthic agents with attendant implications for residue levels. Increasing usage may lead to resistance in helminths.	Parasite resistant breeds, nutrition, pasture management, nematode-trapping fungi, antiparasitic vaccines and botanical dewormers.	Lennon, J. (2015) Shalaby (2013)	Ireland, Global
Increased winter rainfall coupled with milder winter temperatures in some areas may require greater use of anti-helminthics as snail vectors multiply.	Increased use of zinc treatments	Lowered production, skin irritation and peeling and sometimes death. The use of zinc treatment and pasture management will not fully eliminate the impacts of facial eczema.	Movement of animals to areas with lower temperatures and humidity.	Comment at Workshop 1	NZ

			Change in cattle breed or use of genetically resistant animals	Clark et al (2010) and Dennis et al (2012)	NZ
Increase temperatures and rainfall will may result spread of facial eczema			Monitoring pasture spore count during danger periods (minimum temperatures are above 12°C for two or three nights and humidity is high (usually January to May) and either dosing animals with zinc or spraying pastures with a fungicide.	Dairy NZ (https://www.dairynz.co.nz/animal/cow-health/facial-eczema/)	NZ
	Promotion of the transmission of pathogens between animals, resulting in greater pathogen load in faeces.	Increase use of parasite and veterinary treatment leading to residues.	Improved farm design (trees) to provide shelter, paddock shade and reduce wind chill	(Wheeler 2015)	Global
Intermingling, crowding of food animals in response to natural disasters or climate		Disease outbreaks	Small reduction in stock	Comment at Workshop 1	NZ
	Food safety issues, in particular mycotoxins. New raw materials and fewer varieties may increase food safety risks	Mycosis and mycotoxicosis in cows. Prevention of mycotoxin formation is essential since there are few ways to completely overcome problems once mycotoxins are present.	Intensification of food safety management including all sector (farm to fork) co-ordination, surveillance and monitoring, risk assessment, predicative modelling. Routine testing of supplemental feed to check for presence of aflatoxins and use of additives to prevent absorption, where necessary.	van der Spiegel, (2012) Tirado et al. (2010)	The Netherlands, Global

Climate change may require new sources of feed ingredients, storage and intake and conditions of compound feed storage	Contamination of pasture and silage by emission, soil, manure and water. Parasites may also be a problem.	Need for newer treatments. Unknown human health effects of new pesticides or veterinary medicines. Withholding periods affected. Pesticide residues may be higher than approved levels.	Strengthening of food safety management programmes.	van der Spiegel, (2012)	The Netherlands
Warmer and wetter conditions and flooding will favour contamination	Contamination of feed or water stock				
	May increase fungal infections in silage making and increase the risk of mycotoxins. Increases in dry matter content may also pose a risk in terms of level of contaminants.		Improvements to food cleaning, handling and storage	Britton et al (2010)	NZ
Higher humidity	May introduce unknown animal diseases. Evolution of current diseases, zoonotic diseases and foodborne infectious diseases will increase. Some parasites may continue to pose health issues where cycles would normally stop.	Need for newer treatments. Unknown human health effects of new pesticides or veterinary medicines. Withholding periods affected. Pesticide residues may be higher than approved levels.	Increased use of more genetically resistant animals.	van der Spiegel, (2012) Clark et al (2010)	The Netherlands, NZ
Generic climate change			Strengthening of food safety management programmes	van der Spiegel, (2012)	The Netherlands
	Create muddy conditions where cows are more likely to feel tired and lay down, such that their udder will become coated with mud, increasing contact with environmental pathogens. Reduced grazing, can also occur resulting in a lowered immune system.		Increased use of more genetically resistant animals.	Drake, (2008)	USA

Hot humid weather, and precipitation	Parasites may be a problem as well as increased risk of illness in cattle required use of veterinary medicines.	Increase use of parasite and veterinary treatment leading to residues.	Increased use of more genetically resistant animals.	Drake, (2008)	USA
	Contamination of pasture and silage by emission, soil, manure and water.	Heat stress.	Farm design (trees) to provide paddock shade and reduce wind chill	Clark et al (2010	NZ
Hot weather and drier conditions in some parts of the country	Increased use of parasite and veterinary treatment leading to residues.	Increase use of parasite and veterinary treatment leading to residues.	Increased use of more genetically resistant animals.	Drake, (2008)	USA
	Pathogens may appear due to use of manure, irrigation or runoff. Contaminated irrigation water, the use of wastewater, increased demand for water and declining water quality could all lead to increases in the levels of pathogens and chemicals in food.	Increased use of irrigation may lead to contamination of the environment (soils, water).	Parasite resistant breeds, nutrition, pasture management, nematode-trapping fungi, anti-parasitic vaccines and botanical dewormers.	Edwards, et al (2010), Lake et al (2010), Shalaby et al (2013)	Australia, UK, Global
	Extreme drought can lead to boreholes contaminated with nitrates.	Increases in severe water shortages (drought conditions) leading to culling of animals.	Drought-resistant forage plants	Gregory, (2010), Kean et al (2015).	Global, NZ
	Decreased survival of pathogens with increasing soil salinity or reduced water content.	Increases in severe water shortages (drought conditions) leading to culling of animals.	Water security measures or movement to areas with more reliable rainfall/water supply	(Hellberg and Chu 2016)	Global

Table C3: Food System issues arising from changes in primary production practice as a result of climate change and adaptation measures for arable

SECTOR: ARABLE					
Climate Change Impact(s) on Primary Industries	**Food System Risks Identified**	**Implications for Industry**	**Proposed Adaptation Measures**	**Reference**	**Study Location**
Establishment of new exotic pests, sleeper pest's natural enemies, weeds and diseases resulting in disease outbreaks.	Use of new biocontrol agents and new approvals required leading to food residues.	Rejected from the food chain.	Southward movement of crops including their biocontrol systems	Kean et al (2015), FAO, (2015) and Gerard, (2010)	NZ, Global and NZ (respectively by author)
	Pesticide and veterinary drug residues in the environment will increase in response to changes in pests. Off-label use of treatment may occur where no other option is available. Pesticides may also degrade faster. There is also an increased risk of antibiotic-resistant pathogens developing.	Increased or new residues in food. Resistance to chemical treatment.	New biocontrol agents may be required	Gerard, (2010), Feedback from Foundation for arable research	NZ
	More aggressive weeds that do not normally require control.	Use of herbicides before harvest may introduce food safety concerns from residues.	Timing of application of chemical/herbicide treatment may be useful.	Feedback from Foundation for arable research	NZ
Changing of the microbial population of the macro-environment (soil, air and water).	Biotic diseases attributable to (micro) organisms such as fungi, bacteria, viruses and insects may occur due and the population of pests or other vectors.	Rejected from the food chain. Increased or new residues in food.	New biocontrol agents may be required	Wheeler et al., (2015)	Global
	Climate change will affect soil conditions	Impact on some biocontrols (seed treatments, endophyte	Integrated pest management is standard practise. Selective breeding, nominal pesticide use	Feedback from Foundation for arable research	NZ

		loss and bacterial treatments).	(to prevent non-target impacts) will help to minimise resistance of pests and diseases.		
Changes to abiotic factors such as nutrient deficiencies, air pollutants and temperature/moisture extremes.	Effects on plant health and productivity requiring increased use of pesticides and fertilisers or the use new approvals leading to food residues.	Rejected from the food chain. Increased or new residues in food.	Genetic variability in existing food crops including those that are able to increase their nitrogen intake in order to reduce eutrophication and greenhouse gas emissions.	Wheeler et al (2015), Fedoroff et al. (2010	Global
Increases in heavy rainfall	Can increase pathogenic bacteria due to runoff, drainage. It can also transport bacteria to other land and water bodies that produce food.	Increased or new residues in food.	Integrated management of water sources, soil, wildlife intrusion and manure application.	(Hellberg and Chu 2016)	Global
	Possibility of splash dispersal and plant internalisation.	Increased risk of foodborne disease.	Strengthening of food safety management programmes	van der Spiegel, (2012)	The Netherlands
Changes to temperature and rainfall	Mycotoxins are expected to increase. The dominant fungal species will be determined by meteorological conditions such that toxins produced are likely to be predicted by climate. Insects can also strongly influence the development of mycotoxins.	Increased or new residues in food.	Use of new resistant commercial crop types and/or new species.	Miraglia et al (2009)	Europe
	Changes in food yields and food quality in terms of nutrition. Increased need for fertilisers. Increases in food sensitivity.	Decreased ability to supply and retain nutrients. Increased need for fertilisers. Change to production may be required to avoid contamination of food allergens.	Use of technologically advanced foods (GMO), functional foods and nanotechnology.	Fitzgerald et al, Ziska et al (2016), Edwards et al (2010).	NZ, USA, Australia

	Increased use of potentially contaminated alternative water sources.	Increased contaminants in food.	Water security measures or movement to areas with more reliable rainfall/water supply.	Hellberg et al (2016)	Global
	Severe water stress including projected drought in eastern or northern parts of the country.	Decreased production. Poor quality food. Drier, drought conditions may lead to more viruses. Increased costs associated with losses or increased need for irrigation.	Drought-resistant plants. Water security measures or movement to areas with more reliable rainfall/water supply. Improvements to irrigation practises.	Ziska, et al, (2016), Gregory, (2010), Kean et al (2015), van Munster et al 2017	USA, Global, NZ

Table C4: Food System issues arising from changes in primary production practice as a result of climate change and adaptation measures for agriculture.

SECTOR: AGRICULTURE					
Climate Change Impact(s) on Primary Industries	**Food System Risks Identified**	**Implications for Industry**	**Proposed Adaptation Measures**	**Reference**	**Study Location**
Average increase in atmospheric CO_2 generating a 'fertilisation effect'.	Higher concentrations of CO_2 stimulate carbohydrate production and plant growth, but at the expense of protein and essential minerals in a number of widely consumed crops, including wheat, rice, and potatoes. This will have potentially negative implications in terms of human nutrition.	Decreased ability to supply and retain nutrients in extensively managed systems.	Ecologically sound farming practices that encompasses local educational, technical, and research capacity, food processing capability, storage capacity, and other aspects of agribusiness. Rural transportation and water and communications infrastructure.	(Fedoroff et al 2010; Orwin et al 2015)	NZ, Global
	Indirect effects on crop suitability, livestock and associated pests increasing the need for more new pesticides and fertilisers. Higher residues in food may occur. There is also an increased risk of antibiotic-resistant pathogens developing.	Increased use of pesticides and fertilisers required.	New biocontrol agents may be required	Ziska, et al, (2016), Gerard (2010)	USA, NZ
	Increased foodborne pathogen contamination of fresh produce by insect vectors.	Rejected from the food chain.	Improvements to food cleaning, handling and storage.	(Ziska et al 2016)	USA
	Negative implications in terms of human nutrition. Reduction in protein content and alteration of protein composition in	Decreased ability to supply and retain nutrients in extensively managed systems. Increases in food	Use of technologically-advanced foods (GMO), functional foods and nanotechnology.	(Edwards et al 2010; Ziska et al 2016)	USA, Australia

	certain plants, with the potential to alter allergenic (food) sensitivity.	sensitivity may require change its production practices to prevent allergen cross-contamination.			
Establishment of new exotic pests, sleeper pest's natural enemies, weeds and diseases resulting in disease outbreaks.	Use of new biocontrol agents and new approvals increasing or introducing residues in food.	Increased cost. Rejection from the food chain. Increased consumer demand for chemical or bio-free foods.	Use of new resistant commercial crop types and/or new species. Southward movement of some crops including their biocontrol systems	Kean et al (2015) and Gerard, (2010)	Global and NZ (respectively by author)
	Pesticide and veterinary drug residues in the environment will increase in response to changes in pests. New or higher residues in food may occur. Pesticides may also degrade faster. There is also an increased risk of antibiotic-resistant pathogens developing.	Increased or new residues in food.	New biocontrol agents may be required.	Wheeler et al., (2015), Gerard (2010)	Global, NZ
Generic climate change impacts on agriculture	Increased need to use fertilisers leading to chemical residues in foods.	In NZ, negative yield impacts in some crops.	Use of new resistant commercial crop types and/or new species. Southward movement of some crops including their biocontrol systems	(Gerard et al 2010; Kean et al 2015; Kenny 2001; Orwin et al 2015)	NZ, Global

Ability of soils to regulate water, supply and retain nutrients	Effects on plant health and productivity requiring increased use of pesticides and fertilisers or the use new approvals leading to food residues.	Rejected from the food chain. Increased or new residues in food.	Genetic variability in existing food crops including those that are able to increase their nitrogen intake in order to reduce eutrophication and greenhouse gas emissions.	Fedoroff et al. (2010, Wheeler et al., (2015)	Global
Changes to available suitable agricultural land, as sea levels rise, and low lying coastal areas will become inundated with saline water.		Decreased production.	Use of new resistant commercial crop types and/or new species. Movement of some crops including their biocontrol systems away from coastal farmland.	Kean et al (2015) and Gerard, (2010)	Global and NZ
Increased use of energy and demand from the all food supply sectors.	Direct and indirect effects on food safety systems.	Increased costs associated with energy, in particular cooling.	Improved energy efficient cooling. Use of sustainable energy sources.	Clark et al (2010), Comment at Workshop 1	NZ
Changes to temperature and rainfall	Changes in food yields and food quality in terms of nutrition.	Decreased ability to supply and retain nutrients. Increased need for fertilisers. Change to production may be required to avoid contamination of food allergens.	Use of technologically advanced foods (GMO), functional foods and nanotechnology.	(Edwards et al 2010; Fitzgerald et al ; Ziska et al 2016)	NZ, USA, Australia
	Increased use of potentially contaminated alternative water sources.	Water security measures or movement to areas with more reliable rainfall/water supply	Water security measures or movement to areas with more reliable rainfall/water supply	(Hellberg and Chu 2016)	Global

	Severe water stress including projected drought in eastern or northern parts of the country.	Decreased production. Poor quality food. Drier, drought conditions may lead to more viruses. Increased costs associated with losses or increased need for irrigation.	Drought-resistant plants. Water security measures or movement to areas with more reliable rainfall/water supply. Improvements to irrigation practises.	Ziska, et al, (2016), Gregory, (2010), Kean et al (2015), van Munster et al 2017	USA, Global, NZ
Change to temperature, precipitation (patterns), and increased CO_2.	Some food safety risks are associated with adaptation measures including development of GM crops.	Barriers to the use of GMO.	Increased use of technologically-advanced foods (GMO), functional foods and nanotechnology may be required for adaptation.	Fedoroff et al. (2010)	Global
	Mycotoxins are expected to increase. The dominant fungal species will be determined by meteorological conditions such that toxins produced are likely to be predicted by climate. Insects can also strongly influence the development of mycotoxins.	Mycotoxins, including aflatoxins, particularly in stored grains, nuts (including imports) will increase in range, type and amount due to increasing hot humid conditions. Harmful fungal metabolites under dry, hot conditions can also contaminate cereals and pulses during crop growth and post-harvest.	Use of new resistant commercial crop types and/or new species.	Miraglia et al (2009), Comment at Workshop 1	Europe, NZ
	There may be areas where yields increase due to expansion of suitable land. In other areas the opposite effect will occur due to decreases in water	Chemical residues in food. Poorer quality food products.	Ecologically sound farming practices. Improvements to rural transportation and sustainable water supply.	(Miraglia et al 2009; Orwin et al 2015)	Europe, NZ

	availability and increases in extreme weather.				
	Increases in heavy rainfall will cause flooding, contaminating land, spreading anti-biotic resistant organisms and increase the risk of fungal growth.	Increased or new residues in food. Increased risk of foodborne disease.	Strengthening of food safety management programmes. Integrated management of water sources, soil, wildlife intrusion and manure application.	(Britton et al 2010; Hellberg and Chu 2016; van der Spiegel et al 2012)	The Netherlands, Global, NZ
Variation in the timing of the seasons, modification of the local environment such as soil.	Lack of sufficient refrigerated capacity leading to food safety concerns.	Rejected from the food chain.	Improved energy efficient cooling.	Edwards, et al (2010)	Australia
	Degraded and drier soils, leading to reduced quality foods. Poor soils may result in increased use of fertilizers.	Chemical residues in food. Poorer quality food products.	Ecologically sound farming practices. Improvements to rural transportation and sustainable water supply.	Miraglia et al (2009), Orwin et al (2015)	Europe, NZ
Changing of the microbial population of the macro-environment (soil, air and water).	Biotic diseases attributable to (micro) organisms such as fungi, bacteria, viruses and insects may occur due and the population of pests or other vectors.	Rejected from the food chain. Increased or new residues in food.	New biocontrol agents may be required	Wheeler et al., (2015)	Global

Table C5: Food System issues arising from changes in primary production practice as a result of climate change and adaptation measures for horticulture.

SECTOR: HORTICULTURE					
Climate Change Impact(s) on Primary Industries	**Food System Risks Identified**	**Implications for Industry**	**Proposed Adaptation Measures**	**Reference**	**Study Location**
Establishment of new exotic pests, sleeper pest's natural enemies, weeds and diseases resulting in disease outbreaks.	Use of new biocontrol agents and new approvals. Pesticide residues in the environment will increase in response to changes in pests. New or higher residues in food may occur. Pesticides may also degrade faster. There is also an increased risk of antibiotic-resistant pathogens developing.	Increased cost. Rejection from the food chain. Increased consumer demand for chemical or bio-free foods.	Use of new resistant commercial crop types and/or new species. Southward movement of some crops including their biocontrol systems	Kean et al (2015), Gerard, (2010)	Global and NZ
	Pesticide and veterinary drug residues in the environment will increase in response to changes in pests. New or higher residues in food may occur. Pesticides may also degrade faster. There is also an increased risk of antibiotic-resistant pathogens developing.	Increased or new residues in food. Increased cost. Rejection from the food chain. Increased consumer demand for chemical or bio-free foods.	New biocontrol agents may be required.	Wheeler et al., (2015), Gerard (2010)	Global, NZ

Simulation of climate change scenarios on fresh produce along the supply chain.	Pathogens that cause disease at very low doses and/or have notable environmental persistence (enteric viruses and parasitic protozoa), will be of greater concern as well as those with stress tolerance responses. Enterohemorrhagic E. coli and Salmonella are examples of such organisms in the context of climate change.	Increase risk of foodborne illness.	Improvements to food cleaning, handling and storage.	(Jacxsens et al 2010; Ziska et al 2016)	Europe, USA
	Contamination of water sources with pathogens particularly where alternative sources of water are used to maintain production.	Increased cost. Rejection from the food chain. Increased consumer demand for chemical or bio-free foods.	Water security measures or movement to areas with more reliable rainfall/water supply	Hellberg et al (2016)	Global
Changes to temperature and precipitation projections	Microbial contamination included water supply, surface run off, splash events e.g. rain, microbial survival in soils, UV and cloudiness.	Increases in contamination of crops, fruit and leafy green vegetables.	Improvements to food cleaning, handling and storage.	(Liu et al 2013; Ziska et al 2016)	Global, USA
Changing of the microbial population of the macro-environment (soil, air and water).	Biotic diseases attributable to (micro) organisms such as fungi, bacteria, viruses and insects may occur due and the population of pests or other vectors.	Rejected from the food chain. Increased or new residues in food.	New biocontrol agents may be required	Wheeler et al., (2015)	Global
	Climate change will affect soil conditions	Impact on some biocontrols (seed treatments, endophyte loss and bacterial treatments).	Integrated pest management is standard practise. Selective breeding, nominal pesticide use (to prevent non-target impacts) will help to minimise resistance of pests and diseases.	Feedback from Foundation for arable research	NZ

Changes to abiotic factors such as nutrient deficiencies, air pollutants and temperature/moisture extremes.	Effects on plant health and productivity requiring increased use of pesticides and fertilisers or the use new approvals leading to food residues.	Rejected from the food chain. Increased or new residues in food.	Genetic variability in existing food crops including those that are able to increase their nitrogen intake in order to reduce eutrophication and greenhouse gas emissions.	Wheeler et al (2015), Fedoroff et al. (2010	Global
Increases in heavy rainfall	Can increase pathogenic bacteria due to runoff, drainage. It can also transport bacteria to other land and water bodies that produce food.	Increased or new residues in food.	Integrated management of water sources, soil, wildlife intrusion and manure application.	(Hellberg and Chu 2016)	Global
	Possibility of splash dispersal and plant internalisation.	Increased risk of foodborne disease.	Strengthening of food safety management programmes	van der Spiegel, (2012)	The Netherlands
Changes to temperature and rainfall	Mycotoxins are expected to increase. The dominant fungal species will be determined by meteorological conditions such that toxins produced are likely to be predicted by climate. Insects can also strongly influence the development of mycotoxins.	Increased or new residues in food.	Use of new resistant commercial crop types and/or new species.	Miraglia et al (2009)	Europe
	Changes in food yields and food quality in terms of nutrition. Increased need for fertilisers. Increases in food sensitivity.	Decreased ability to supply and retain nutrients. Increased need for fertilisers. Change to production may be required to avoid contamination of food allergens.	Use of technologically advanced foods (GMO), functional foods and nanotechnology.	Fitzgerald et al, Ziska et al (2016), Edwards et al (2010).	NZ, USA, Australia

	Increased use of potentially contaminated alternative water sources.	Increased contaminants in food.	Water security measures or movement to areas with more reliable rainfall/water supply.	Hellberg et al (2016)	Global
	Severe water stress including projected drought in eastern or northern parts of the country.	Decreased production. Poor quality food. Drier, drought conditions may lead to more viruses. Increased costs associated with losses or increased need for irrigation.	Drought-resistant plants. Water security measures or movement to areas with more reliable rainfall/water supply. Improvements to irrigation practises.	Ziska, et al, (2016), Gregory, (2010), Kean et al (2015), van Munster et al 2017	USA, Global, NZ

Table C6: Food System issues arising from changes in primary production practice as a result of climate change and adaptation measures for seafood and aquaculture.

SECTOR: SEAFOOD & AQUACULTURE					
Climate Change Impact(s) on Primary Industries	**Food System Risks Identified**	**Implications for Industry**	**Proposed Adaptive Measures**	**Reference**	**Study Location**
Reduction (ca. 6%, RCP8.5) in phytoplankton production in surface waters. Decline in particle flux (2.2 to 24.6% by 2100) affecting food availability for some commercial fish species.	Increased imports of seafood from areas with minimal food safety practises, increasing risk of foodborne illness. Increased fish adulteration.	Decrease in fish stocks or quality of fish.	Strengthening of food safety management programmes.	(Edwards et al 2010; Law et al 2016)	Australia, NZ
Increased pH of seawater	Potential threat to safety through acidification-induced increase in Cd accumulation in seafood (bivalves).	Rejected from the food chain. Decrease in fish stocks or quality of fish. May potentially reduce survival rates of fish by altering their behaviour.	Movement of fisheries to areas with lower seawater pH. Increased aquaculture.	(Munday et al 2010; Shi et al 2016), SLMACC PROJECT IDEA	Global
Rising ambient sea temperatures	Increased incidence of harmful algal blooms (HAB), production of toxins including ciguatoxins, histamines toxins in shellfish.	Rejected from the food chain.	Continuous monitoring and faster detection of HAB. Movement of fisheries away from HAB areas. Improved management of terrestrial effluent/outputs.	(Fleming et al 2006; Vermeulen et al 2012)	Global, experimental

	Increased heavy metal and dioxin concentration in predatory fish e.g. methylation of mercury and subsequent uptake by fish.	Rejected from the food chain.	Strengthening of food safety management programmes. Movement of fisheries to cooler waters.	Edwards et al (2010) and Wheeler et al., (2015), SLMACC PROJECT IDEA	Australia, Global
	Accumulation of toxins by filter feeders, an increase in water temperatures promotes the growth of pathogenic organisms and subsequent consumption of contaminated foods can serious implications for health.	Rejected from the food chain.	Strengthening of food safety management programmes. Movement of fisheries to cooler waters.	Wheeler et al., (2015), SLMACC PROJECT IDEA	Global
	In general, climate change is likely to reduce food safety due to higher rates of microbial growth at increased temperatures and fisheries supply chains.	Rejected from the food chain.	Strengthening of food safety management programmes. Improvements to chilling, storage and handling, procedures and transportation of seafood under higher ambient conditions. Movement of fisheries to cooler waters.	(Hammond et al 2015; Marques et al 2010)	Global
	Increase ambient sea surface temperatures have been correlated with increases in Vibrio from in seafood.	Rejected from the food chain.	Strengthening of food safety management programmes. Movement of fisheries to cooler waters.	(Baker-Austin et al 2016; Baker-Austin et al 2017; Martinez-Urtaza et al 2016; Wheeler 2015), SLMACC PROJECT IDEA	North America, Sweden and Finland, Global, NZ

Table C7: Food System issues arising from changes in primary production practice as a result of climate change and adaptation measures for aquaculture.

SECTOR: SEAFOOD AND AQUACULTURE					
Climate Change Impact(s) on Primary Industries	**Food System Risks Identified**	**Implications for Industry**	**Proposed Adaptive Measures**	**Reference**	**Study Location**
Projected increases in heavy rainfall changing sediment characteristics and reducing suitability of habitats for aquaculture species in intertidal areas of estuaries	Increases in contamination of shell fish through remobilisation of sediments, and terrestrial runoff of pathogens.	Changes in production and profit of aquaculture species such as salmon, mussels and oysters.	Integrated management of water sources, soil, wildlife intrusion and manure application.	(Cummings et al 2016; Hellberg and Chu 2016)	NZ, Global
Increased sea surface temperature (SST) and ambient temperatures	SST peaks in late summer correlated with increased numbers of *V. parahaemolyticus*[1]	Rejected from the food chain.	Timing of the collection of seafood may become more important.	(Cruz et al 2015)	NZ
	Increased stressors resulting in reduced growth rates and increased recovery times from energy expenditure leading to reduced immunity and more diseases. Use of pesticides and veterinary medicines leading to residues.	Potential negative effects on non-target organisms. Increased cost. Increased consumer demand for chemical or bio-free foods.	A number of infrastructure modifications may allow farmers to be able to predict when interventions are required and restrict costly control measures that may be required in the future. Ecologically sound farming practices.	(Morash and Alter 2016)	NZ
	Increasing incidence and intensity of harmful algal blooms (HAB) and toxins in shellfish, in part due to climate warming.		Continuous monitoring and faster detection of HAB to improve public warning.	(Fleming et al 2006; Lloret et al 2015;	Global, UK

	This includes increased risk from ciguatera poisoning.		Increased citizen science initiatives. Improved management of terrestrial effluent/outputs.	Vermeulen et al 2012)	
	Increase in pathogens, contaminants (particularly anthropogenic and emerging) and biotoxins. Changes in the distribution and occurrence of pathogens found in fish such as microbes and parasites that are harmful for consumers. In particular, increases in the Vibrio genus, including *Vibrio cholera*.		Elimination of point source sewage and indirect runoff. Continuous monitoring and faster detection of pathogens. Increased citizen science initiatives. Improved management of terrestrial effluent/outputs.	(Lloret et al 2015; Vezzulli et al 2016), SLMACC PROJECT IDEA	UK, North Atlantic
	Increased growth rates of parasites in fish hosts. Increased bioavailability and toxicity of some contaminants (e.g. (methyl) mercury and persistent organic pollutants (POPs)) leading to use of more pesticide and veterinary medicines.		A number of infrastructure modifications may allow farmers to be able to predict when interventions are required and restrict costly control measures that may be required in the future. Elimination of point source sewage and indirect runoff. Ecologically sound farming practices. Training in fish disease diagnosis and health management and alternative approaches to disease control.	(Lloret et al 2015; Morash and Alter 2016; Wheeler 2015)	UK, Global

Increase in ocean acidity (decreased pH)	Affects uptake of cadmium by shellfish		Molluscs are a minor contributor to overall dietary exposure - adaptation may not be necessary Public health messages re shellfish consumption	(EPA 2013)	USA

1 The study was cautious of this inference as some samples taken during the summer had low numbers of *V. parahaemolyticus*

Table C8: Food System issues arising from changes in primary production practice as a result of climate change and adaptation measures for mahinga kai/wild foods.

SECTOR: MAHINGA KAI/WILD FOODS					
Climate Change Impact(s) on Primary Industries	**Food System Risks Identified**	**Implications**	**Proposed Adaptive Measures**	**Reference**	**Study Location**
Establishment of new exotic pests and diseases resulting in disease outbreaks.	Increased food borne illness. Bacterial contamination Chemical baits Shellfish biotoxins, chemicals bacteria and viruses	Climate change may increase the reliance on wild foods as a result of changes in food security	Greater marine protection and enforcement at gathering sites. Increased warnings and education in areas at risk of contamination.	(Gerard et al 2010; Kean et al 2015; NZFSA 2007), SLMACC PROJECT IDEA	NZ
Use of kai moana by Maori, particularly in many rural marae.	For food and water-borne disease, a higher burden for Maori is expected, given the existing higher rates of enteric infection for Maori.	Can no longer gather foods from certain areas due to food safety risks. May indirectly affect good stocks in other areas.	Greater marine protection and enforcement at gathering sites. Increased warnings and education in areas at risk of contamination.	(Jones et al 2014; King et al 2013), SLMACC PROJECT IDEA	NZ
	Increased risk of outbreaks.	Can no longer gather foods from certain areas due to food safety risks. May indirectly affect good stocks in other areas.	Greater marine protection and enforcement at gathering sites. Increased warnings and education in areas at risk of contamination.	SLMACC PROJECT IDEA	NZ

Increased pH of seawater	Potential threat to safety through acidification-induced increase in Cd accumulation in seafood (bivalves).	Decrease in fish stocks or quality of fish. May potentially reduce survival rates of fish by altering their behaviour.	Greater marine protection and enforcement at gathering sites. Increased warnings and education in areas at risk of contamination.	Munday et al (2010), Shi et al (2015), SLMACC PROJECT IDEA	Global
Rising ambient sea temperatures	Increased incidence of harmful algal blooms (HAB), production of toxins including ciguatoxins, histamines toxins in shellfish.	Can no longer gather foods from certain areas due to food safety risks. May indirectly affect good stocks in other areas.	Continuous monitoring and faster detection of HAB to improve public warning. Increased citizen science initiatives. Improved management of terrestrial effluent/outputs.	Vermeulen et al (2012), Fleming et al (2006)	Global, experimental
	Increased heavy metal and dioxin concentration in predatory fish e.g. methylation of mercury and subsequent uptake by fish.	Can no longer gather foods from certain areas due to food safety risks. May indirectly affect good stocks in other areas.	Strengthening of food safety management programmes. Movement of fisheries to cooler waters.	Edwards et al (2010) and Wheeler et al., (2015), SLMACC PROJECT IDEA	Australia, Global
	Accumulation of toxins by filter feeders, an increase in water temperatures promotes the growth of pathogenic organisms and subsequent consumption of contaminated foods can serious implications for health.	Can no longer gather foods from certain areas due to food safety risks. May indirectly affect good stocks in other areas.	Strengthening of food safety management programmes. Movement of fisheries to cooler waters.	Wheeler et al., (2015), SLMACC PROJECT IDEA	Global

	In general, climate change is likely to reduce food safety due to higher rates of microbial growth at increased temperatures and fisheries supply chains.	Can no longer gather foods from certain areas due to food safety risks. May indirectly affect good stocks in other areas.	Strengthening of food safety management programmes. Improvements to chilling, storage and handling, procedures and transportation of seafood under higher ambient conditions. Movement of fisheries to cooler waters.	(Hammond et al 2015; Marques et al 2010)	Global
Changes in sea temperature affecting plankton and algae growth.	Increase ambient sea surface temperatures have been correlated with increases in Vibrio in seafood.	Can no longer gather foods from certain areas due to food safety risks. May indirectly affect good stocks in other areas.	Strengthening of food safety management programmes. Movement of fisheries to cooler waters.	Baker-Austin et al (2016), Wheeler et al., (2015), SLMACC PROJECT IDEA	Sweden and Finland, Global, NZ

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