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Technical Report

July 2012

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Edited by

Anthony Clark DairyNZ

Richard Nottage NIWA

NIWA Taihoro Nukurangi

DairyNZ

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Preface

New Zealand's land-based production sectors face the challenge of providing food and fibre to a growing world, and continuing their important contribution to the national economy as efficient, profitable and sustainable industries. The land-based sectors have faced numerous market-based challenges in the past, the most significant being financial deregulation of the industry in the early 1990s and associated reforms. In the face of these challenges the industries demonstrated remarkable resilience, with the sectors improving their efficiencies, competing successfully in the international market place and reinforcing their importance in the national economy.

One of the cornerstones of New Zealand's primary industries is the country's climate which supports relatively reliable levels of crop, animal and tree production compared with other parts of the world. The surrounding ocean means that New Zealand has a dependable 'water bank', but seasonal drought and extreme weather events do occur, creating distinct challenges for primary producers. Managing variability has always been a feature of the production environment, and many of these techniques will provide a degree of resilience to climate changes that may happen in the future.

Global climate change has received attention for some time now, with New Zealand's land-based sectors focussing on solutions to reduce greenhouse gas emissions. Adaptive responses to climate change have also received attention. New Zealand has numerous adaptation options, from well-understood responses (ways of adjusting and changing the way production systems respond to climate), through to more transformational changes via innovation and the development of new industries.

This technical report is the first comprehensive evaluation of climate change that focuses on adaptation options for the land-based sectors to be undertaken in New Zealand. It brings together existing information and also makes some advances in our knowledge surrounding climate change adaptation. It provides a reference document for land management professionals, describing which factors should be considered when implementing adaptation options in their sectors. For the first time, New Zealand's land-based sectors will have access to a comprehensive bank of knowledge that will provide a basis for the next phase of implementing adaptation. Its companion document, the stakeholder report, provides a more succinct and targeted summary of this knowledge.

Introduction

This technical report supports New Zealand's land-based production sectors by reviewing impacts and identifying climate change adaptation options. This is achieved by examining ways to build resilience which also reduce vulnerabilities to both current and future climate variability.

To date, production systems have been developed that take account of historic climate variability. Any changes to this variability could, therefore, bring about new pressures. This work is concerned with how sectors can adapt to reduce their overall exposure to climate change, as well as capturing any opportunities that may arise.

The motivation for examining adaptation in New Zealand land-based sectors is twofold. Firstly, the expectation that in a warming world New Zealand's climate will enter a new regime in the coming 30 years – a warmer and more variable climate than experienced now or in the immediate past. Secondly, recent climate variability has challenged current levels of resilience in New Zealand. This includes the run of intense regional droughts experienced since 2007 during the main growing seasons; the cold spring of September 2009 in Southland; damaging floods in Hawke's Bay during 2010; and out of season winter growth in many regions during 2011.

Understanding impacts and looking for viable adaptation options provides a constructive approach to managing current climate variability and the medium- to long-term changes into the future. Forming these responses relies on understanding: the degree to which New Zealand is exposed to both short- and medium-term climate change; the extent to which current levels of adaptive capacity are adequate for coping with climate variability and change; and where these levels are deficient, how to expand adaptive capacity in line with realistic projections of future climate change.

Assessing adaptation to climate change is not straightforward. As it is 'future focussed', uncertainty features prominently and robust approaches to decision making like adaptive management are required. Detailed information about vulnerability and ways to reduce it is often lacking, and basic questions from operators can sometimes outstrip the capacity of current research tools and methodologies.

Despite these challenges there are a range of actions that can be undertaken to respond to climate change, particularly with uncertainty in future projections. However, land managers make decisions today in the absence of perfect information to manage current climate variability. Given this, New Zealand has some existing knowledge with which to shape adaptive capacity in the land-based sectors. The task of this report involves not only bringing this knowledge together, but also making some progress toward building upon it to enhance adaptive capacity in the future.

Outline of the Technical Report

Following some introductory and background material, adaptation knowledge is presented on a sector-by-sector basis for the land-based industries. The outline of this technical report is as follows:

Chapter 1 *General approach and evaluation methods for land-based sector adaptation provides* some necessary background, reviewing concepts and frameworks used to define adaptation. It then details the approach taken in the technical report to evaluating adaptation. This provides a degree of consistency and comparability across the sectors. It outlines some of the important assumptions and decisions about scope that have been made to focus the reviews.

Chapter 2 *The changing climatic environment for New Zealand's land-based sectors* briefly critiques evidence of global climate change as this is a key rationale for considering adaptation. Its main focus is on change in the New Zealand region, examining observational evidence and understanding the operation of key regional climate processes in the changing global climate. The main climate scenarios used in New Zealand are presented, as well as a new set of Primary Sector Adaptation Scenarios (PSAS). Collectively, the knowledge and scenarios described in this chapter provide the platform for reviews and model-based analyses of impacts and adaptations in the sector chapters.

Chapter 3 *Adapting dairy farming systems in a changing climatic environment initially* reviews the full range of potential impacts on the pasture base and dairy cow. Whole farm system modelling is then applied to five representative case study farms to examine a narrower set of impacts and adaptations under the PSAS. The modelling supplements a broader review of adaptations, which identifies the full range of options available to dairy operators under the broad range of potential impacts.

Chapter 4 *Hill country sheep and beef: impacts and adaptations to climate change* undertakes a detailed analysis of the three major farming systems which represent approximately 70 per cent of the management range across the industry. Using a systematic means of assessing adaptations, key changes like altering timing of production and lamb growth rates are investigated in a changing climate. New Zealand's unique hill country farming systems are given special attention. There is considerable diversity that can be built upon, and a range of adaptation options available.

Chapter 5 *Adapting broad acre farming to climate change* critically evaluates adaptation options in New Zealand's crop rotations. A number of contextual factors are also formally considered, along with targeted modelling evaluation of options like improving irrigation efficiency through technological change. A broad-based review helps to build some clear recommendations for managers seeking to expand adaptive capacity.

Chapter 6 *Adapting the horticultural and vegetable industries to climate change* examines the challenges facing these key export and domestic industries. Horticulture has readily adapted to economic change in the past, and the chapter considers how this success can be translated into specific climate change adaptations. Targeted modelling then looks at the challenges facing the sector, like curbing biomass to maximise yield. A broad suite of practical interventions to secure economic yields are evaluated, as are larger transformational shifts like expanding irrigation infrastructure and shifting locations.

Chapter 7 *Long-term adaptation of productive forests in a changing climatic environment* examines the forestry sector. It uses a different planning horizon to the other land-based sectors given forestry's slow biological response rate and long harvest cycle. This chapter examines both direct and indirect impacts of climate change over this time frame. Industry currently takes a long-term view and uses sophisticated adaptive risk management tools to manage the effects of climate variability. Careful consideration is given to how this approach can be adjusted to implement climate change adaptation over future wood harvest time frames. Other options to future proof the sector given indirect impacts from fire as well as pests and diseases are considered.

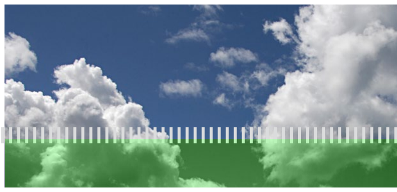
Chapter 8 *Water resource impacts and adaptation under climate change* reviews the main foreseeable implications of climate change on New Zealand's water resources. The chapter identifies a range of adaptation options that have the potential to ameliorate these impacts. Key knowledge gaps are identified, and a way forward is outlined whereby water resource stakeholders can work constructively in a risk management framework that balances feasibility, costs and benefits, as well as prioritising important knowledge gaps.

Chapter 9 *Multi-sector adaptation and sector-wide implications acknowledges* that the sector-based approach has provided some important findings, but that there are a number of impacts and adaptations that are not identified. This chapter looks at adaptation options not covered so far, such as the multiple land-use model in New Zealand; as well as examining some of the broader institutional- and regional-level responses. Key implications for the whole programme are also detailed in this section, examining issues that arise in the implementation phase of adaptation.

This technical report underpins a companion document, the *stakeholder report*. The *technical report* is a reference document, designed to provide a more comprehensive treatment for a broader audience that encompasses researchers, educators, land management professionals and producers. The *technical report* is a detailed synthesis of scientific, professional and experiential knowledge about impacts and adaptation. The *stakeholder report* is a more streamlined version of the review, synthesising key concepts and outcomes and with an audience of land management professionals in mind.

Chapter 1. Background

General approach and evaluation methods for land-based sector adaptation



Anthony Clark DairyNZ

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1 Introduction

Adapting to climate change is a relatively new approach that extends traditional understanding and develops new ways of managing climate variability (Tubiello & Gunther 2007). A key difference is that adaptation relies less on knowledge of past climate and accounts for changes in future climate over a longer time frame. This changes the emphasis in management of climate variability from using past experiences and observations to approaches which incorporate future expectations. Adaptation is an anticipatory response to the risk that climate variability is continually changing and will enter a different regime in the future, as influenced by longer term change. Adaptation is both a challenge and opportunity for all engaged in the primary sectors: the farm and forest manager, professional advisors and analysts as well as the industry and other institutions that support them.

Adaptation in itself is a difficult concept to define and there is open debate around what it means and how it could be applied (O'Brien et al. 2004). Currently there is considerable innovation in management approaches and evaluation methods to support adaptation. For this reason, it is necessary to outline some background concepts before the sector-based chapters are presented. This provides land management professionals with a summary of useful management theory, as well identifying the role of the coming sector chapters. The core methodology and framework used to construct the sector chapters is also detailed. These concepts underpin a rigorous and information-rich evaluation of climate change adaptations for New Zealand's primary sectors.

2 Concepts of adaptation

2.1 Theoretical understanding

The fundamental principle of climate change adaptation is reasonably well understood, as it is about making ***some sort of change in order to cope with a different climate***. However, as with all change management, moving beyond simple definitions is problematic. There are a wide range of formal definitions that describe climate change adaptation. The official Intergovernmental Panel on Climate Change (IPCC) definition of adaptation follows McCarthy et al. (2001) and Parry et al. (2007) and states:

Adjustment in natural or human systems in response to actual or expected climatic stimuli or their effects, which moderate harm or exploit beneficial opportunities.

Whereas the United Nations Development Program gave the following definition of adaptation (UNDP cited in Adger et al. 2003):

Adaptation is a process by which strategies to moderate, cope with and take advantage of the consequences of climate events are enhanced, developed and implemented.

These two definitions are examples of the two main perspectives on what adaptation means. The IPCC's definition is a more scientific view, drawing into focus 'adjustments' or 'tangible action options' under the prospect of both threats and opportunities of climate change. The UNDP focusses on adaptation as a 'management process'. Other definitions of adaptation differentiate it based on: timing being either an immediate reaction or more pre-emptive of change; the sphere in which it is taking place, such as the public or private sector; or the process by which it is bought about – being either autonomous or planned. There are also economic definitions which view adaptation as a series of trade-offs between the costs and benefits of climate change.

There are many reasons for this diversity of views. The impacts of climate change are complex, expected to be uncertain, pervasive and diverse (Fankhauser et al. 1999). Adaptation is also concerned with the future and, as with any discussion of what the future might look like, it encompasses values and aspirations that go well beyond scientific analysis (Mastrandrea & Schneider 2010). Adaptation is also highly context dependant and definitions will form around its operational application and other influences.

Definitions are important as they help shape frameworks that determine policies and outcomes, and ultimately the adaptations that are implemented operationally. Given this importance, there has been considerable development by theoretical researchers over the past decade leading to many alternative definitions and new frameworks (Faussel 2007). Providing a detailed account of this discussion is out of the scope of this review, but those interested are encouraged to access critiques such as Daffara et al. (2010).

Table 1.1 simplifies the discussion, identifying the two main conceptual frameworks which have influenced adaptation theory over the last decade or more. The first is the ***vulnerability*** framework which has its origins in hazards analysis research and management. The second is the ***resilience*** framework which is drawn from ecological systems theory.

Table 1.1. The two main theoretical frameworks of climate change adaptation, vulnerability and resilience.

	Vulnerability	***Resilience***
Origins	Hazards research & analysis	Ecological systems theory
Main concepts	Risk management Exposure Impacts Thresholds Vulnerability Coping range	Tolerance & recovery of systems Persistence Transformability States Interconnectedness & dynamics

2.1.1 Vulnerability

The main concepts in the vulnerability framework are shown in Figure 1.1. Here the climate is split into two distinct periods of variability, the first a stationary climate period where there is little change beyond normal variability, and the second where there is climate change. Exposure to negative impacts occurs when climate variability moves outside the coping range of a production unit, represented by the green shading. There are critical thresholds, the points which represent the level of variability where there are negative impacts, and these are known as vulnerabilities. Examples of moderate primary production impacts might include small declines in average yield or short periods of lost production. Impacts can also be severe, like a long-term collapse in return on investment for a given sector or 'forced sale' of a production unit given long term decline in profitability.

As shown in Figure 1.1, past exposure to climate variability has been relatively stationary over the long term. In a changing climate - when there is a long run trend with associated 'highs and lows' - variability is pushed into a new regime, and correspondingly the thresholds defining vulnerability are reached more often and frequently as shown in Figure 1.1 (a). As shown in Figure 1.1 (b), adaptation seeks to change the critical thresholds that define vulnerability, and in so doing, expand the range of exposure that a production system can cope with. Adaptations can be formed at the current time (the vertical line in Figure 1.1) in anticipation of future change given a certain planning horizon.

The vulnerability approach has a broad basis, drawing from concepts found in economics, and the natural and social sciences. It draws on principles and practices from the field of risk management (Miller et al. 2010) and applies them to climate change adaptation, for example:

- the IPCC's vulnerability framework is an example of risk assessment (McCarthy et al. 2001; Parry et al. 2007)
- the widespread use of scenario analysis in climate change impact assessment, which is a form of risk analysis
- the process used to assess adaptations defined by the united Kingdom's Climate Impacts Program (UKCIP 20101)
- in New Zealand, the Ministry for Agriculture and Forestry's adaptation toolbox2 which provides a framework to assess different climate change adaptation.

These impact-adaptation frameworks draw on concepts and principles that are also described in the generic risk management process outlined as the Australian and New Zealand Standard (AS/NZS4360: 2004). This gives

[1]http://www.ukcip.org.uk/wizard/ (accessed 8 April 2012).

[2] The Ministry for Agriculture and Forestry Adaptation Toolbox aids in selection of adaptation options using a risk assessment process: http://www.maf.govt.nz/environment-natural-resources/climate-change/resources-and-tools/adaptation-toolbox/ (accessed 8 April 2012).

insight into a distinct advantage of the vulnerability approach, that many of the core principles are already widely understood and implemented operationally (Miller et al. 2010). A criticism is that current forms of risk management may not be adequate for guiding adaptation to the new environment that climate change poses and devalue the role of adaptation research (Nelson et al. 2010, Parts I and II).

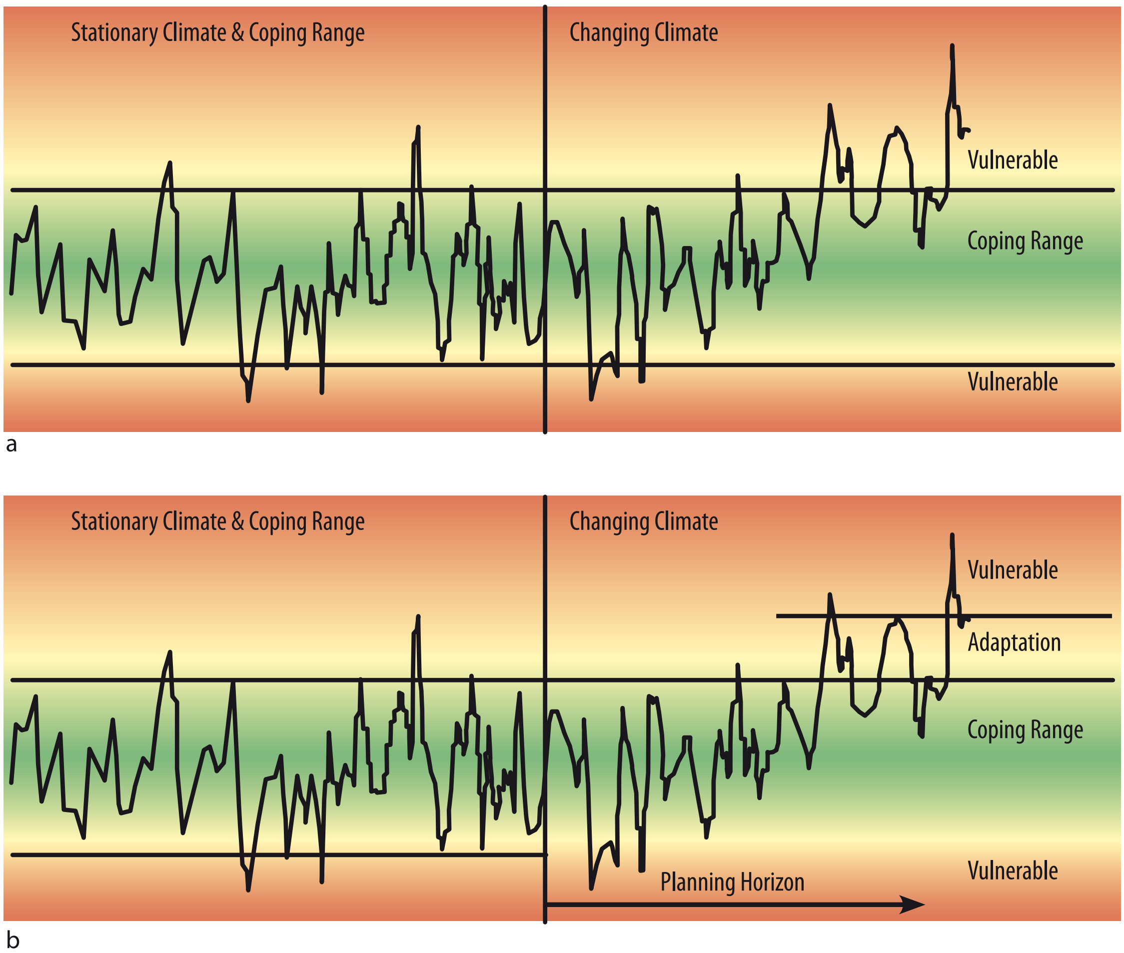

Figure 1.1. The conceptual framework of vulnerability to climate change. (a) Vulnerability thresholds without adaptation. (b) Vulnerability thresholds with adaptation. Based on Parry et al. (2007) and the earlier work of Jones & Mearns (2004).

The main limitation of the vulnerability framework is that it has not always identified ***why*** a particular group or location is more or less exposed or ***how*** the coping range can be changed (Miller et al. 2010). Therefore, it may not be a specific enough guide to frame both policy and practical local level adaptations to climate change. Underpinning the critical thresholds defining vulnerability are a range of enabling factors and processes that characterise 'adaptive capacity' - social, financial and resource capital (Ellis 2000). In the primary sectors this might include:

- current levels of profitability (farm income) and level of debt
- income diversity
- the availability of financial capital
- training and education levels
- other human resources like community networks
- management and production system characteristics
- technologies and infrastructure.

2.1.2 Resilience

The second approach to climate change adaptation is the resilience framework (Table 1.1). It has its origins in ecological systems theory, and is concerned with the functioning of systems under different pressures, given interconnections and feedbacks or 'dynamics'. The view of agricultural production as a dynamic feedback system is an example of applied ecological systems theory, or 'agro-ecology'. Traditionally this has had a narrower basis than the vulnerability framework, being primarily focussed on natural or biophysical systems. However, the resilience approach is increasingly including elements of the socio-economic system.

Resilience refers to the way a system behaves when placed under a stress, i.e., its ability to:

- cope with a pressure in its currents state
- make temporary changes and then return to its current state
- undergo transformations that change the systems state.

High resilience systems have fewer state changes or can transform efficiently under pressure. Low resilience systems undergo significant irreversible transformation to an undesirable state: for example the crop rotation becomes permanently uneconomic in a future climatic regime. At one level, adaptation is an inherent property of the system, its ability to cope or change. At a second level, adaptation is also a form of deliberate transformation – which involves interventions that move the system beyond current levels of resilience. Identifying these interventions relies on greater understanding of system dynamics – we only really have a partial understanding given complexities and uncertainties.

A key concern of resilience research relates to the properties of the system, or its known 'functions', so that necessary interventions can be identified: resilience or adaptability is an emergent property of a system which is defined by a set of 'state variables'. In agro-ecological systems theory two of the main state variables are system intensity and diversity, but there are others like the degree of interconnectedness and nature of feedbacks or controls. One key principle emerging from the resilience approach in primary production is that more diverse and less intensive systems tend to increase the biophysical resilience of production under climate variability. The logical extension is that these properties can be modified in response to climate change.

The focus on systems properties is an advantage of the resilience approach as it supports a very detailed appraisal of ***'why'*** systems respond and ***'how'*** they might be changed. It is tightly linked with a biophysical science understanding of primary production, which is appealing to many land management professionals. A distinct disadvantage is a general lack of translation of systems theory into operational management (Miller et al. 2010).

2.1.3 Integration of vulnerability and resilience

Both the vulnerability and resilience frameworks have been broadened in recent times, to include socio-economic factors. This reflects an understanding that traditional exposure and impact assessment does not fully capture vulnerability or the factors that determine it. An understanding of how factors like culture, demographics and education – or other concepts like 'social capital' – increase or decrease vulnerability to climate change is increasingly recognised in research. Similarly, in the resilience approach there is a push toward inclusion of these factors into the systems boundary, in order to better understand system states and transformability.

This has seen an expansion of social and economic research in the analysis of adaptation, and/or the development of integrated methods. An example of a definition of adaptation that emerges from inclusion of socio-economic factors is provided by Ellis (2000, p. 7):

- Adaptive capacity as an emergent property of the diverse forms of human, social, natural, physical and financial capital from which rural livelihoods are derived, and
- the flexibility to substitute between them in response to
- external pressures.

2.2 *Connecting theory to practice*

Although it is necessary to briefly explore the theory behind adaptation, the role of this chapter is to begin to connect theory to practice. Adaptation research is currently evolving rapidly to a more operationally focussed activity as there is urgent need to move beyond distinctions based on theory to activities led by practitioners (Miller et al. 2010). This is what Meinke et al. (2009) describe as 'solution-oriented adaptation science'. For practical purposes there is enough common ground between the frameworks to use many of the concepts interchangeably and they are given equal preference in the coming chapters.

It is at this point that the more theoretical approaches to adaptation intersect with mainstream management theory and practice. As a result, a new set of theories is currently emerging that is helping to guide this transition. This solution-based approach brings about a fundamental shift in adaptation knowledge, in that there are much closer linkages between researchers engaged with theory and methodology on the one hand, and practitioners on the other. The question is not about the theoretical correctness of the resilience or vulnerability frameworks, but asking which methodologies and concepts are more relevant to a given set of stakeholders. This is consistent with the coming chapters, which focus on the needs of New Zealand's professional community of land managers.

Sections 2.2.1 to 2.2.3 outline a subset of this emerging theory, which is more consistent with the goal of 'operationally focussed assessment'. This is necessary background to bridge between the theory and practice of climate change adaptation, not just for this review but for implementing tangible change across the primary sectors.

2.2.1 *Adaptive management*

Adaptation to climate change is not a static activity and is continually repeated over time. It is more valuably understood through the framework of adaptive management, which in general is an on-going cycle of 'monitoring', 'review', 'planning' and 'implementation' (Figure 1.2). This cycle is repeated many times so that management responses are always updated to reflect changing conditions and/or improved information. This is important, as uncertainty is a key factor to consider in climate change adaptation.

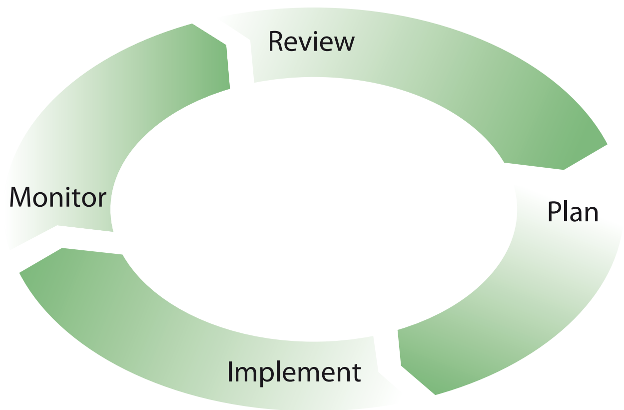

Figure 1.2. Adaptive management for climate change – a process of continual improvement.

This general process of continual improvement can be initiated to build climatic resilience or reduce vulnerabilities. ***Monitoring*** involves the collection of information about current climate as well as expectations of future climate, and understanding the current and future levels of exposure, vulnerability and system responses. ***Review*** involves identifying potential to expand adaptive capacity through analysis and critique, then ***planning*** how these can be ***implemented*** to enable this capacity. Any changes implemented are critically monitored and the cycle is repeated. Depending on the level of adaptation this might occur seasonally, annually, or every five or ten years.

The process of adaptive management is used in many spheres including Government and Business as a way to make decisions when there are uncertainties or on-going changes in the external operating environment. It is also not new to the primary sectors and in some cases it is standard practice and a part of industry culture. For instance, farm benchmarking is an applied form of adaptive management. Here, groups of producers compare how their strategies perform seasonally so as to learn from each other's successes and failures. Typically this has been initiated to improve profitability year-on-year to manage the ongoing price-cost squeeze. In New Zealand there are both formal benchmarking processes initiated by industry, as well as informal benchmarking which may be part of regional community culture. What is relatively new, is initiating adaptive management specifically to build climate resilience in a way that anticipates climate change.

Adaptive management is also a form of ***participative*** or ***action*** research if stakeholders are engaged throughout the process. In this case undertaking research or evaluation in itself is part of adaptation, not distanced from it. This is very much the case for the coming chapters which represent a 'snapshot' of New Zealand's adaptation knowledge aimed a key group of stakeholders. ***The information presented in the coming chapters is strongly embedded in the current adaptive processes in New Zealand.*** The function of the work in this context is the 'Review' phase of the general adaptive management cycle shown in Figure 1.2. To provide a more tangible context for the coming chapters, an applied version of adaptive management is presented in Figure 1.3, highlighting the intended position and function of the sector reviews of adaptation.

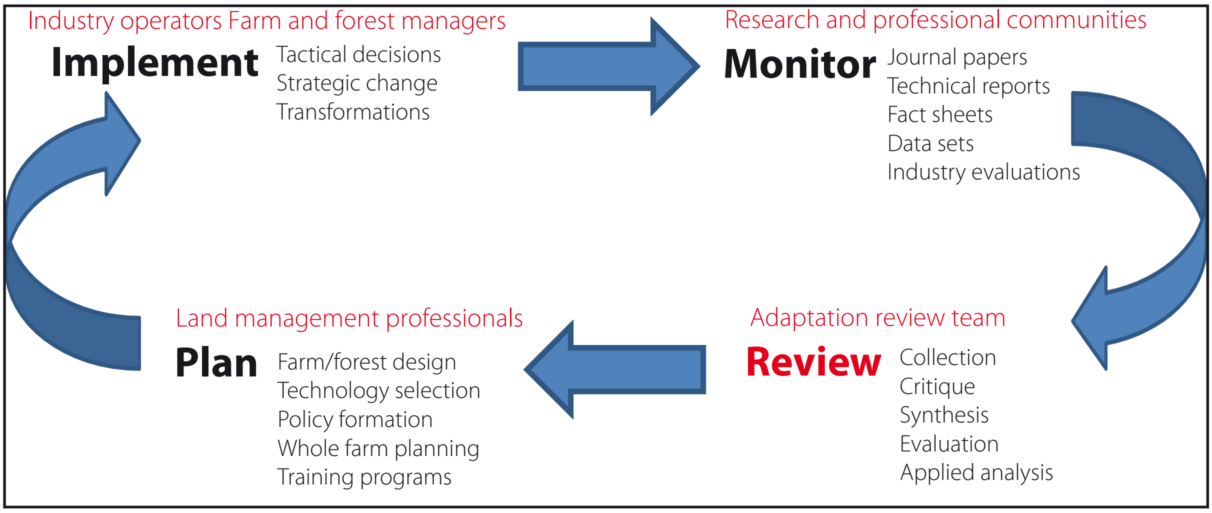

Figure 1.3. Detailed schematic of the adaptive management review process, providing context for this report (which fulfils a 'Review' function in adaptive management).

The review stage in Figure 1.3 (highlighted in red) is undertaken by the author team engaged to produce the sector-based chapters in this report. It involves a range of activities, including critique, synthesis and applied analyses which are described in more detail below. The review draws from a broad range of 'monitoring' evidence that has been developed in New Zealand and elsewhere over the last decade or more. This involves a wide range of sources including, but not restricted to, journal publications, professional documentation and technical reviews, developed by the broader research and professional communities. It is an unstructured review, in that there has been limited scope to commission or direct what research, monitoring and assessment has been undertaken, but draws on existing sources. The exception is some targeted analysis that is described below.

Referring to Figure 1.3, the review targets land management professionals, with the intention that they integrate the information into their ***planning*** practice, for example when undertaking whole farm planning, forest landscape design or in general advisory work. There will be a wide range of implementable activities, which are the responsibility of industry operators like farm and forest managers. At some point in the future there will be a need to repeat reviews like this, as information changes and evolves.

While this process gives some context to the work presented in the coming chapters, it is also a simplification of the exchanges and information flows that occur in practice. There is often robust feedback between industry operators and their professionals and many interconnections between the groups and stages identified in Figure 1.3.

2.2.2 *Risk management*

Risk management is an approach that is increasingly being applied to achieving climate change adaptation, but requires careful consideration of the operational context (Jones & Preston 2011). Risk management is commonplace in New Zealand primary production. More formerly, it is ***a logical and systematic management process that will help organisations minimise losses and maximise opportunities from a range of internal and external factors*** *(*AS/NZS4360 2004). It is also a form of adaptive management, designed to be continually improved and updated. It mixes objective information from quantitative analysis and monitoring to improve risk awareness, with sound strategies and a structured rational approach to making decisions that also integrates values and aspirations.

The broad risk environment for modern New Zealand farm businesses is mapped out in Figure 1.4. While the timeframes of the risk environment for forest operations are different, some of the key elements and principles remain the same. For many years New Zealand's farmers managed climate variability as it relates to production levels (the top layer of boxes and arrow in Figure 1.4). In general terms this involves smoothing out variability in yields or avoiding the physical and financial impacts of shocks like drought. For the most part New Zealand farmers were protected from financial variability by institutional arrangements. Beginning in the mid-1980s, a series of financial market and institutional reforms increased exposure to market risks.

Some 20 years after these reforms, primary producers in New Zealand are skilled in the management of risks posed by input and output prices, credit markets (interest rates) and land valuation. This does not mean that climate and production risks are not important, as quite to the contrary their management has become more sophisticated. A survey by Martin (1996) a few years immediately after the reforms found that production risk ranked just second behind price variability in order of perceived importance by producers. This is against a background of considerable regional variability where production risk was the most important for many producers depending upon regional differences in exposure. Production risk management measures were the most widely implemented risk management tool across all New Zealand farms at that time, and more recent work by Nartea & Webster (2008) indicates that this is still be the case today.

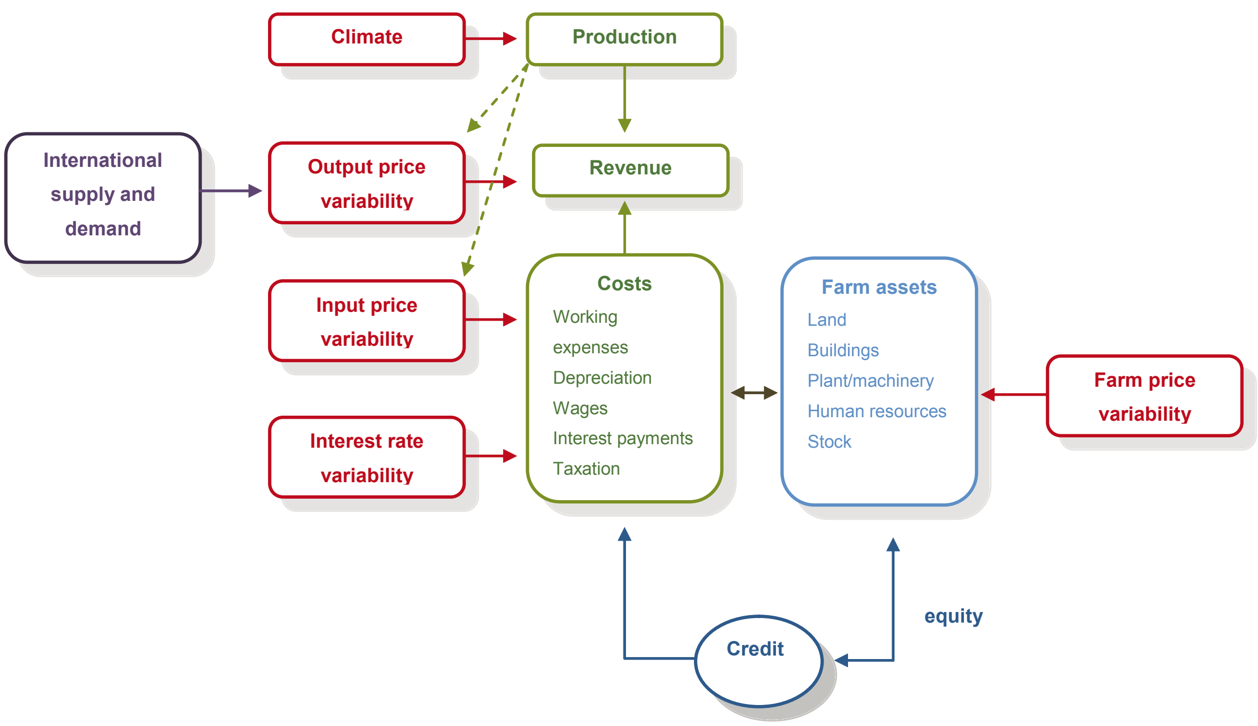

Figure 1.4. The environment of risk managed by New Zealand farms in a deregulated financial market.

The focus of the sector chapters is change to climate–production risk relationships (the top layer of boxes and arrow in Figure 1.4). In order to shape a risk management approach for the primary sector, some important context needs to be considered, where:

- The core vulnerability threshold for the primary producer is the level of net operating income (revenue) where the operation would fail to meet its commitments (costs). At this point the survival of the primary sector business is threatened.
- Climate variability has direct effects on this vulnerability threshold by setting production levels, given the technologies and practices of the farming system. Climate also has indirect influences by affecting supply of both inputs and outputs and their prices (dotted arrows in Figure 1.4).
- Climate is not the only factor that influences the vulnerability threshold of a particular farm, region or economy. The full suite of risks in agriculture is interconnected through its influence on the revenue needed to meet commitments. For example, taking on more debt will increase the level of income required to meet commitments. Relying on one source of income that is experiencing declining terms of trade lowers the vulnerability threshold, making a business more sensitive to climate variability.
- Borrowing money to implement an adaptation that changes the risk–production relationship may also influence the level of revenue needed to meet a new commitment.
- The variability from other risks and or management responses to them can change exposure to climate variability. Situations change and the risk relationships change over time, along with climate variability.
- Through current institutional settings, market arrangements, technologies and localities, each primary sector business will have its own risk relationships and linkages with climate variability. For example, horticulture trades products on an open market where product quality is the main supply factor, so it is quite exposed to shifts in temperature which affect product quality, possibly more than rainfall. However, a dryland pastoral enterprise is highly rainfall dependant.
- There is also the risk of maladaptation. This has many forms: adapting to a potential threat which does not eventuate (or is not as bad as it was originally perceived); the risk of an adaptation being detrimental to something else (e.g., to natural ecosystems); and unintended consequences from initiatives that are positively motivated.

Taking a view strictly from the vulnerability framework, the reviews could be focussed on the shape of the probability distribution of production and the prospect that it may be under a state of continual change as new climatic regime evolves. Risk management as it relates to adaptation in this sense is about changing the probability distribution of production, removing extremes in yields, and smoothing out variability. Using a risk analysis approach would involve empirically quantifying current and future production functions given new management and climate scenarios.

At this stage it is important to recognise the differences between risk analysis and risk management. Often risk management is considered too narrowly, as an exercise in numerically quantifying risks to make decisions. This interpretation,that risk management is just a set of 'analysis tools', can lead to a rejection of the overall approach as a constructive means to respond to climate change (e.g., Nelson et al. 2010, Part II). However, as described by Clark (2001) risk management is a much broader process that can take many forms. Risk management can include sound technical analyses that are fully integrated into a highly communicative and participatory decision making environment. This later approach is consistent with current innovation in adaptation theory that looks at transformational change (e.g., Kates et al. 2012).

Narrowly focussing on the quantification of risk is also a stark illustration of the limitations of a purely hazards-orientated approach to adaptation. It does not detail ***why*** the production distribution is shaped a certain way and ***what*** can be changed through primary sector management. There are entire branches of production science concerned with understanding and modifying this production distribution at a highly specific level. Agronomists, veterinarians, animal science specialists and associated extension networks collectively work on the complex technologies, management practices and interventions that drive production risk. This level of detail is 'fundamental knowledge' for land management professionals who are engaged with making concrete and specific recommendations to farm and forest managers.

2.2.3 *Robust decision making*

Uncertainty is prevalent in climate-related decision making, as for many reasons obtaining reliable single best estimates of changes to the frequency and duration of climate phenomena is not possible. The best climate forecasts and projections are probability based or give a range of likely outcomes (refer to Chapter 2). This uncertainty compounds when the interaction between climate and the primary production system is considered. As described in Section 2.1.1 vulnerability is tied to management or 'on-ground decisions' which vary and are difficult to track objectively. There are also process uncertainties in both climate and production systems, which place limitations on knowledge surrounding how these systems function and respond to change.

Many commentators have noted that this level of uncertainty challenges the traditional decision making paradigm, which is usually focussed on achieving a single optimal solution within a cost benefit framework (Dessai et al. 2009; Wilby & Dessai 2010). Given this approach the uncertainty in phenomena like climate change can lead to a situation of indecision; where the only thing to do is to wait for analysts to improve the uncertainty in information. This is the core 'management dilemma' which underpins most considerations of climate change adaptation. It is sometimes termed 'paralysis by analysis' (Clark 2001), and gives undue weighting to the ability of quantitative tools like climate systems models to make highly precise forecasts (Dessai et al. 2009). Another common response to uncertainty is to ignore it in decision making, which can reduce the level of risk awareness and can severely erode the quality of decision making over time (Clark 2001).

An alternative to the traditional optimal decision making approach is robust decision making. Here, strategies, plans and tangible actions are developed that provide positive outcomes, despite uncertainty. Robust decision making occurs within adaptive risk management, and can even occur in the absence of highly detailed information about a particular risk. In the farm environment robust decision making is applied all the time in the management of seasonal climatic conditions. Producers developed multiple strategies and fall back positions to guard against the full range of climate outcomes in the coming months (e.g., the full range between drought, perfect growth conditions, and very wet). Some use detailed climate information and forecasts to weight these strategies and others do not. They have well thought out systems that are flexible enough to cope with the range of outcomes.

In the context of climate change adaptation, robust decision making means taking actions that would reduce vulnerability to current climate variability as well as a full range of projected future climates. In plainer terms, robust decision making for climate adaptation is about finding 'win-win' solutions. These are approaches that are less likely to lead to maladaptations or establish irreversible pathways. While robust decision making has some commonality with managing seasonal climate variability, using it as part of adaptation response to climate change is relatively new.

3 Operational review framework

To support this comprehensive and robust review of adaptation for New Zealand's primary sectors, a broad framework is required that draws together the elements of past and emerging theory described above. This means developing a methodology that includes, but also looks outside, the traditional model-driven approaches that have tended to be used to quantifying climate impacts. Key concepts used to guide and focus the sector-based operational reviews are described sequentially in the following Sections (3.1-3.4). These are translated into a working review methodology in Section 4.

3.1 *Adaptation categories*

Considering the individual farm or forest unit focus, it is possible to integrate theory from both the resilience and vulnerability approaches into a simple operational framework. A simple three category framework is used throughout the coming sector based evaluations, drawing on some of the concepts introduced by Stokes & Howden (2010). The three categories of adaptation are:

> **Tactical adaptation**. This involves modifying the existing production system using current, well-known management techniques. Primary producers have a number of management responses that they can readily adjust now with good levels of confidence, high levels of knowledge and relatively minimal investment. An example would be using new but already developed varieties in a horticulture or forestry

operation. This extends the current level of adaptive capacity to its full potential and may be an effective response at low levels of exposure to climate change. Tactical adaptations have wide appeal because they are tangible, visible and familiar. Information about tactical adaptations is highly relevant to operational managers in their day-to-day decisions.

Strategic adaptation. This involves changing to another known production system, or making substantive changes to current systems, where practices and technologies are well known. This level of change may be warranted given mid to high level climate change. It happens now as a response to market adjustments given relative pricing across sectors, for example conversions between dry stock, dairy and horticultural land use, or building irrigation infrastructure. There is also a tendency for managers to import and adapt practices from other sectors, regions or countries. There may be a higher degree of risk involved with more capital investment required to make strategic change. Detailed planning and guidance are required from specialists in the planning phase of these adaptations. The short-term outcome is often an increase in vulnerability as a producer takes on more debt to make this level of change. Over a medium- to long-term timeframe the benefits should outweigh the costs. Developing new options and making strategic change is a key point of engagement between land managers and the professional community that supports them.

Transformational adaptation. This involves innovation to develop completely new production systems or even industries. It is also described as 'transformational change' (Park et al. 2011; Kates et al. 2012). This is the least well defined level of adaptation as the knowledge is not fully developed let alone realised as adaptive capacity. It can be defined as a process of change, as well as a set of identifiable options. This type of adaptation may be necessary for extreme levels of climate change – where there is clear evidence that climate has moved to a new regime where current practices are not viable. New knowledge and practices are developed from collaborations between producers, researchers and specialists. Larger levels of investment are required to develop new adaptations with arguably more risk. Investment should be justified on grounds of strategic advantage. Transformational change can take many forms. An example might be investment in research to genetically modify pasture species, so that it maintains very high levels of nutritional value in a warmer climate. Widespread land use change, shifting an industry into a new region and other forms of major structural adjustments related to climate pressures are all examples of transformational change. This type of adaptation could take 5 to 20 or more years to realise as adaptive capacity. This level of adaptation will be of most interest to long-term decision makers like research investors, planners, and senior managers.

The advantage of this simple categorisation is that it translates theory into a well-known operational distinction made in primary production between tactical and strategic decision making. By looking distinctively at transformational change it is also flexible enough to examine more innovative solutions to vulnerability posed by climate change. The categories are a simplification and in practice the distinction between them is not always clear, and they should be considered as a continuum. For example distinguishing between tactical and strategic aspects of an operation is not always clear cut - a strategy may be made up of a set of individual tactical decisions. Some transformational changes may be context dependent, for example an extreme farm systems change would have elements of both strategic and transformational change. Stokes and Howden (2010) linked the categories to levels of financial risk, and there is need to verify if these assumptions hold when implementing adaptations.

3.2 Adaptation levels

There is potential for adaptations to occur in all sectors of society, regions and in different institutions. In the context of New Zealand's primary sector adaptations can occur at a number of levels:

- at the individual farm or forest production unit level
- at community level
- at local and regional government level
- at intermediate level institutions such as Crown Research Institutes and advisory agencies
- at industry level (such as processors)

- at central government level
- at the level of international institutions and arrangements.

The focus of this review is the range of potential adaptations ***at the individual farm or forest unit level***. This is a logical unit to focus on as the bulk of practical tangible actions occur here, and it has been the historical focus of research in the primary sectors. It allows detailed evaluation of ***why*** a management unit may be exposed to change and ***what*** can be changed as adaptation. This is done with the aid of an overarching framework that supports the focus on individual farms and case studies, but which also supports a more generalised view and description.

This is not to say that other levels of adaptation, like institutional arrangements, catchment-wide initiatives or community networks, are not important. They are simply out of the scope for this particular review. This creates a set of limitations surrounding the scope of the work, and the review does not give a complete appraisal of:

- institutional factors like the processes and structures around research and development
- market factors and barriers, such as market failure for information concerning exposure to climate risk
- catchment-wide initiatives such as total catchment landscape design
- policy formation or implementation
- broader infrastructural issues, such as road and transport networks
- cultural and social values that contribute to social capital, such as education and training and community networks.

3.3 Adaptation timeframes

It is well known that different interventions and changes in primary production have different planning horizons or investment timeframes. In the context of climate change adaptations some decisions made today will need to consider likely conditions far into the future. Others have a much shorter planning horizon and modifications can be made incrementally.

The example climate series and planning horizons in Figure 1.5 provide clarity for primary sector adaptation around the timing of adaptive responses:

- A decision to modify a significant piece of infrastructure in 2012, such as a drainage or irrigation network, has a long horizon given a 50-year planned asset lifetime. Adaptation design being carried out during 2012 should account for likely climate conditions expected in the 2060s.
- Although elements of farming system change can be implemented relatively rapidly, the sensible design and return on investment of a full farming system change has conservatively a 10-20 year planning horizon. This means that it would be possible to go through the adaptive management process once – or possibly twice – over the next 40 years.
- Implementing tactical adaptations is feasible today or over a one to two year timeframe. Full evaluation of their success or failure may take 5-10 years, making it possible to go through four or five iterations of adaptive management before climate conditions reach their mid-century outcome.

Although Figure 1.5 is only a theoretical example, framing adaptations according to their timeframe raises some important issues that need to be considered in the coming reviews of primary sector adaptation:

- It draws into focus the ability to predict climate on decadal to half century timescales to give guidance for timing of implementation. This will be discussed in more detail in Chapter 3.
- For many primary sector managers planning three years ahead is a challenging task, let alone 10- or even 50-year timeframes. This is sometimes used as a rationale to delay the implementation of any adaptations at all, and should be avoided.

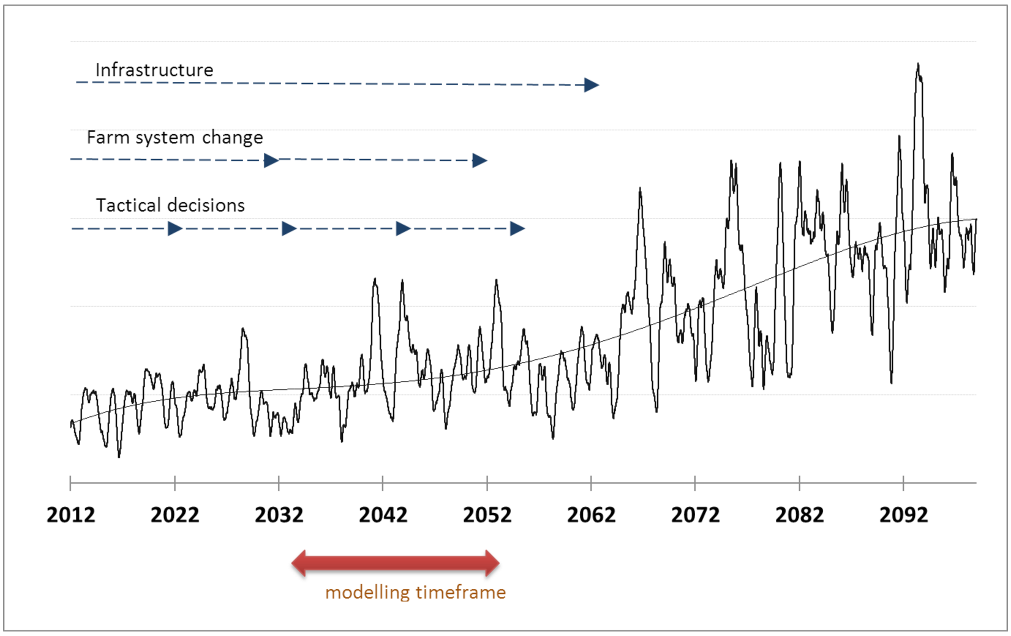

Figure 1.5. Examples of primary sector planning horizons given a hypothetical future climate.

- For a subset of adaptations there is the possibility of incremental implementation, involving cost-effective experimentation and learning more over time. This is a viable option when the adaptation options are reversible, that is implementing them does not establish an irreversible trajectory that would unintentionally and permanently increase exposure to climate change. In these circumstances it is a more constructive approach than delaying adaptation, and for this reason identifying current knowledge gaps are fundamental to operational adaptation reviews.

Considering the time horizons of adaptation also allows a review to focus on a more relevant time frame for their particular set of stakeholders. Given that the longest 50-year infrastructural planning horizon extends to the climate of the 2060s, it is not appropriate to focus heavily on end-of-century climate projections in this review. This is not to say that end-of-century considerations are unimportant, and they are particularly valuable in the context of mitigation, traditional climate impact assessments or for more conceptual analysis. For this reason, the advanced analyses undertaken for this review (detailed below) focus most attention and effort on the period 2030–2049 (2040).

3.4 Examples of adaptation

The simple framework and concepts detailed above have been described at a theoretical level. For this reason it is useful at this stage to provide some examples of tangible adaptation responses that might be pursued in the New Zealand context (Table 1.2), categorised according to the type of response: management, biophysical, or technological.

Table 1.2 illustrate that the division of adaptation responses between tactical, strategic and transformational is 'grey', and depend strongly on the sector. Many of the examples cited in Table 1.2 are based on published case studies like those which have been compiled as part of the Ministry for Primary Industries SLMACC Technology Transfer Programme[3]. While this chapter has so far reviewed the theoretical language and concepts surrounding adaptation, these case studies are a reminder that adaptation is a pragmatic decision and practical activity undertaken by the farm or forest operator. The case studies also illustrate that there are many 'win-win' opportunities in taking action to adapt to climate change, and using a well thought out adaptive management approach is good step toward securing those opportunities.

[3]http://www.maf.govt.nz/environment-natural-resources/climate-change/resources-and-tools.aspx (accessed 8 April 2012).

Table 1.2. Categories of adaptation with generalised examples of farm responses.

Adaptation category	*Management*	*Biophysical*	*Technology*
Tactical – Current production system stressed in new climate – Fully enable current adaptive capacity	– Fully achieve nutrient, feed and water use efficiency benchmarks each year - Reduce production intensity to lower chance of feed deficit in drought	– Plant temperature tolerant species	– Ensure irrigation system is performing optimally
Strategic – Current production system not viable but proven options available – Introduce new options that expand resilience	– Improve precision of resource, production and financial monitoring systems – Traditional risk management techniques like income diversification	– Conversion between production types – Introduce latest crop or pasture species from breeding programs	– Import systems and practices from a drier climate – Develop new crop and pasture species - Introduce irrigation scheme from groundwater

4 Operational review methodology

4.1 Adaptation analysis methodologies

4.1.1 Basis for evaluation

Miller et al. (2010) observed a large disconnect between researchers working on the underlying concepts and theory of adaptation, and those engaged with developing the supporting analysis methodologies. Theoretical development of concepts can often rapidly outstrip the practical tasks of quantifying and evaluating them, particularly in a comprehensive manner. When examining the methodologies used to evaluate adaptation, there is considerable crossover between the two main theoretical approaches. Both draw on a very diverse range of tools and it can be difficult to run comparisons because of different language used to describe essentially the same approaches and concepts.

Within this shifting theoretical basis for defining adaptation, a diverse range of methodologies have been applied to assess it. To provide a degree of clarity, Table 1.3 provides a general breakdown of the types of methodologies employed in adaptation evaluations, grouped according to their application in the biophysical or socio-economic aspects of this task.

As shown in Table 1.3, methodologies can range from highly technical quantitative modelling, through to qualitative social research methods, like participatory action research where stakeholders are engaged. In quantitative methods the system is studied at 'arm's length' and there is a degree of researcher independence. In some of the qualitative approaches, the research itself is part of the process of adaptation. In many studies there is usually a blend between qualitative and quantitative methodologies, or a form of 'integrated evaluation'. For instance, a qualitative research review might be an overview of highly quantitative research findings. The IPCC assessment reports are an example of an integrated evaluation, using a rigorous process to produce science synthesis and judgements which are based on highly quantitative research.

Table 1.3 is also a simplified categorisation of the full suite of methodologies that have been applied in adaptation research and evaluation. Within each category there is also a degree of diversity. For instance Pearson & Langridge (2008) reviewed technical biophysical models used under the vulnerability framework in Australian agriculture, citing 40 separate modelling applications and architectures.

Table 1.3. General types of research methodologies used to evaluate climate change adaptation.

	Biophysical	***Socio-economic***
Quantitative	Systems modelling Risk/scenario analysis Spatial modelling Integrated modelling Monitoring analysis Formal experimentation	Survey Interviews Economic/business modelling Focus groups Ethnographic techniques Network analysis
Qualitative	Research review Integrated evaluation	Case studies Participatory techniques: - Action research - Social learning - Stakeholder engagement

As will be described in more detail in the coming chapters, the New Zealand research base for the primary sector has examples from all of these categories. Methodological innovation is also rapid with agent based modelling and bayesian network analysis being prime examples of approaches that integrate socio-economic and biophysical methods. Integrated, hybrid or mixed methods are increasingly being used, and in many respects proving to be more successful in meeting stakeholder needs (Miller et al. 2010).

4.1.2 Perspective and scale

One area of debate in adaptation evaluation methodologies is scale, identified as the distinction between 'top-down' and 'bottom-up' approaches (Mastrandrea & Schneider 2010). The main trade-offs between the two approaches are shown in Figure 1.6.

The top-down approach is usually a form of scenario based climate impact assessment undertaken using the concepts from the vulnerability framework. These provide generalised comprehensive assessments that are useful in risk identification (Jones & Preston 2011) but are not specific enough to link with local practices and inform action on adaptation.

'Bottom-up approaches', which originate from the field of disaster risk reduction, are typically individual property- or case study-based where the focus is on interactions and management of systems at a fine scale (i.e., individuals, groups of communities and so on). Research at this scale often uses a range of methods, from detailed systems modelling through to qualitative social research. Recently there has been emphasis on the application of social research methods at this scale of inquiry. While these approaches provide locally specific useable knowledge for adaptation, this is often done without an overarching framework. This means the outcomes are not generalisable, or readily transferable.

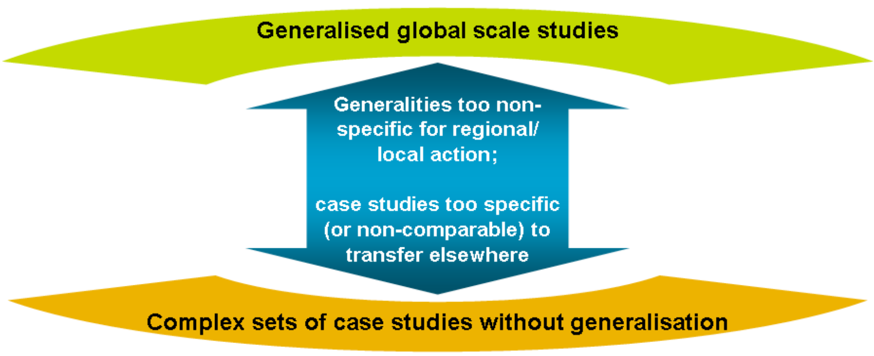

Figure 1.6. Main trade-off between top-down (green) and bottom-up (orange) approaches to assessing climate change impacts and adaptations (Crimp et al. 2009).

While there is often protracted debate about the strengths and weaknesses of the two approaches, the choice between the two depends on the types of questions being asked, and so ultimately on the stakeholders who require information at sufficient detail to inform decisions. The operational review framework described in Section 3 is used to provide a way to generalise across case studies, but still provides an opportunity for sector chapters to explore highly localised effects.

4.2 Integrated evaluation

This operational review uses a 'mixed method', drawing on four of the broad approaches in Table 1.3:

- integrated evaluation
- stakeholder engagement
- production systems modelling within the framework of scenario-risk analysis.

Formal research methodologies to engage stakeholders or undertake participative action research have not been used in the production of the sector chapters. However, standard practice in stakeholder engagement has been followed. This involves high levels of consultation in an effort to improve the relevance of the adaptations identified for land management professionals. The sector chapters are also authored by members of this professional community for their colleagues, where a high priority is given to assessing implementable outcomes. This is consistent with the stated context of the review, to provide information for the planning phase undertaken by land management professionals (Figure 1.3).

Integrated evaluation is one form of multi-disciplinary research which is semi-quantitative. The approach is common in formal risk analysis (Morgan et al. 1990) and programme evaluation and has similarities to the IPCC reporting process. Integrated evaluation differs from traditional literature review or synthesis, in that it collects and evaluates evidence focussed on a core question within a given operational context. Evidence-based integration is only possible when it targets a focussing question, given a relatively straightforward set of criteria. This contrasts from a fully quantitative approach, where evaluation is constrained to available data sets and models.

The aim is to evaluate all available evidence and develop a well-informed judgement on the question. The evaluations of primary sector adaptation undertaken here have emphasis on two distinct sources of evidence:

- 'Advanced risk analysis', which is described in more detail below (Section 4.2.4).
- High level review of existing published and professional work from New Zealand and elsewhere. This includes a broad range of material from the biophysical, economic and social sciences related to each sector.

4.2.1 Evaluating benefits from adaptations

The focussing question has been used to guide the evaluation of evidence that emerges from the risk analysis and reviews:

Which adaptations have clear evidence of production and profitability
benefits to New Zealand's primary sectors?

Evaluating the degree to which specific adaptation options perform under many future scenarios is consistent with a more robust approach to adaptation decision making (Dessai et al. 2009). To keep the terminology used throughout the sector chapters consistent the term ***'net benefit'*** is used to describe this critical evaluation of production and profitability.

It is important not to confuse the use of the term 'net benefit', as used in this work, with 'full integrated assessment'. The latter is a wider assessment of 'benefit', and a question of valuation which would integrate the economic, environmental, and social values of an individual, group, community or country. The approach taken here is narrower than a 'full integrated assessment'. The decision to focus this work on evidence of benefits around production and profitability has been considered carefully, and relates to two main factors:

- A focus on production and profit is consistent with the value set of many primary producers and land management professionals, who are for the most part, moderately production- and profit-orientated but also value the lifestyle, community and the natural environment in which they live. It also reflects the risk management context described previously, where there is clearly need to examine the current and future production distribution as a first order priority.

- Integrated Assessment Methodologies (IAM) that would evaluate complex future market, resource, environment and production interactions but which do not currently exist or are relatively new. Implementing IAM for adaptation would require considerably more time and investment than available, and focus the work on methodological research rather than an operationally orientated review. A decision was made to build on existing production modelling frameworks readily available to the primary sector and review available information. The limitations of taking this production-focussed approach are described more fully in Chapter 9.

4.2.2 Criterion and indicators

The next stage of integrated evaluation is to establish a relatively straightforward set of criteria that allow the core question to be assessed reflecting the stated values and operational context. To demonstrate benefits this review looks for evidence in a primary criterion, where:

adaptation has potential to stabilise and or improve productivity and profitability in a new climate

Given the differences across the sectors, the indicators used to evaluate this criterion will be a combination of relevant production metrics. These are defined in more detail for each sector in the coming chapters, but include outputs of the production system that integrate a range of climate effects, like pasture growth rates, forest production yields, crop yields, crop quality metrics and animal yields like milk solids and slaughter live weights. Ideally it would be desirable to integrate production effects into one single metric, but this is not appropriate given the different climate-production relationships across sectors.

Where possible and/or available cost-benefit assessment and indicators like net revenue, gross margins, profit and return on equity are examined or undertaken. While in many respects this provides a more integrated metric to understand vulnerability, it is context-specific and difficult to separate from the external market factors shown in Figure 1.4.

The sector evaluations ***assume that the market risks remain static and there have been no systematic attempts to evaluate future market-risk relationships*** in parallel with the climate–production relationships reviewed and analysed. Given the limitations in IAM described above, credibly factoring in future commodity and primary sector input price estimates was not practical. This remains one of the key limitations in most primary sector adaptation studies not just in New Zealand, but internationally.

4.2.3 Evaluating evidence

It is important to understand that the core question focusses the sector chapters on describing the ***strength of evidence*** around benefits. For example they look for consistent performance across a wide range of adaptations and climate scenarios; they seek to place individual modelling results into the context of other studies undertaken in New Zealand; and they gather and synthesise material from a range of traditional production climate and emerging impact science.

Drawing on the core question and criterion, the sector-based evaluations undertaken in this report are broken down into some distinct stages, linked to the evidence and the levels of adaptation defined previously:

Stage 1: Review the evidence that establishes the range of climate change impacts on production and profit under current management for current and future climate regimes.

Stage 2: Identify, and critique the ability of ***tactical adaptations*** to reduce or avoid impacts and provide benefits.

Stage 3: If tactical adaptations do not change critical thresholds under a changed climate, identify and critique the ability of ***strategic adaptations*** to reduce or avoid impacts and provide benefits.

Stage 4: Given failure of strategic adaptations to reduce or avoid impacts, consider options for ***transformational adaptations*** to provide benefits.

The task of the analysts who develop the sector chapters is to established well-informed judgements at each stage – providing an evidence-based perspective on different levels of adaptation, which depends on whether or not they offer potential to provide benefits. In assessing evidence about the adaptation the analyst is looking for:

- any ***agreement*** between individual studies and assessments of an adaptation
- ***consistency*** with current theory and practice
- ***verification*** and quality assurance of the supporting information
- ***independence*** in any supporting evaluation
- the ***robustness*** and quality of reasoning
- ***repeatability*** of supporting experiments, data and theory
- ***sound methodologies*** and analyses that follow processes of knowledge production in a given field.

4.2.4 Advanced risk analysis

Production modelling is a useful methodology to quantify both current and future production distributions. Many production models use climate information to predict yields and in, some cases, profitability. Climate information can be derived from observations or future projections of the climate from other models of the earth's system. Depending upon the production model, they also provide a way of holistically analysing a complex production system where there are many connections, relationships and feedbacks. They provide a powerful addition to field experimentation in primary production, allowing results and knowledge to be transferred to new locations and timeframes with relative ease.

Models have seen widespread use in climate impact and adaptation analysis. In New Zealand, these have generally followed the traditional protocol of the vulnerability experiment (see for example CLIMPACTS, Warrick et al. 2001), although there are a smaller number of applications that have followed the resilience protocol. A schematic of the general approach to these protocols is in Figure 1.6. In a resilience protocol, a production system model might be used to run a sensitivity experiment of assumed changes in climate to test the systems responses. In an impact experiment, a number of results from global climate models are downscaled and passed through an empirical impact model to derive the probability of impact.

The 'advanced risk analysis' undertaken throughout the sector reviews differs from the traditional resilience and vulnerability approaches shown in Figure 1.6, in terms of:

- **Model selection**. Although there are a large number of candidate models in New Zealand, the analysis deliberately uses models which have the production unit as the system boundary. As far as possible given the available models, management factors and economics are included within this system boundary. This allows the detailed examination of the 'what and why' characteristics of adaptation as well as the different levels to be examined. Details of specific models are in the relevant sector chapter.
- **Site selection**. Care has been taken to select case study sites that are regionally representative and as a group provide reasonable coverage of each sector. This provides a careful balance between comprehensiveness, detail and practicality. The time needed to set up and assure the quality of the detailed production systems models is not trivial. Although time-intensive much of this work is not described in the reviews.
- **Climate scenarios**. The modelling draws on Primary Sector Adaptation Scenarios (PSAS) specifically developed to drive detailed production models of this nature. These draw on a mechanistic regional climate model, and so provide a more physical basis for inference about the future. This also allows ***daily variability*** to drive the production modelling process, as in the past monthly values have been adjusted for this task. Details of this model and the PSAS are described in Chapter 2.

While models provide a powerful way to analyse the complexity of primary production, they do not provide a complete and perfect answer to adaptation. There are always limitations associated with the system boundary, adequacy of process descriptions, and genuine lack of scientific knowledge about responses. In an operational setting, there is often a degree of push-back from managers and professionals about production and climate models and the information that is derived from them. For this reason it is critical to look at the broader suite of adaptations identified by the integrated evaluation and consider the results of modelling within this context.

4.2.5 Uncertainty and knowledge gaps

Perfect answers about net benefits from climate change adaptation will not be possible. There are deficiencies in the knowledge of how the climate system will change in the future, and how complex production systems could respond. There may also be limitations in the evidence available, as often it may not adequately target the core question asked in an integrated evaluation.

It is, therefore, important to identify knowledge gaps – where there is the possibility for, but limited evidence of, benefit. This is as important as identifying where there is more or less certainty about adaptation, as it will help build an understanding of activities that might be pursued to reduce uncertainties into the future. It also helps to guide further adaptive management, which aims to fill in gaps in knowledge and so reduce uncertainty over time. Throughout the coming chapter key knowledge summaries are provided that clearly identify these gaps.

5 Summary

This chapter has identified the main theoretical principles of adaptation, as well as management approaches which allow theory to be meaningfully connected to practice. Theoretical discussion of this type is not always received well in the primary sectors, which are focussed on taking pragmatic decisions in a highly operational and practical environment. However, in this case, discussion of background theory has been necessary – as the very understanding of adaptation is continually evolving, and there is increasing recognition of the opportunity to modifying the traditional decision making paradigm.

Discussion of adaptation at the theoretical and general management level has also been necessary to lay out the framework and methodologies that underpin the coming sector chapters. These use a 'mixed method' focussed by the following considerations:

- the sector chapters represent the review stage of a broader adaptive management process
- the sector chapters examine the important climate-production-profit risk relationship for the primary sector but do not explicitly examine changes in other market-risk relationships
- the sector chapters focus on the production unit level, three adaptation categories, and a sensible timeframe out to mid-century to reflect the planning horizons of primary production for adaptation.

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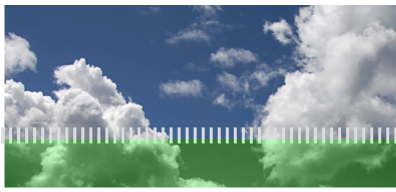
Chapter 2. Climate

The changing climatic environment for New Zealand's land-based sectors



Anthony Clark DairyNZ