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

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Executive Summary

There is increasing evidence of more frequent and severe climate change-related extreme events in New Zealand (Harrington et al., 2014). These events are likely to have adverse effects on a range of primary economic activities, including pastoral farming. In addition, an increase in climate variability can result in greater operating uncertainty for a sector dependent on consistent climatic conditions.

This research aims to support adaptation and enhance the resilience of sheep and beef land management systems by:

- producing insights into the resilience sheep and beef farming systems to climate change, specifically by applying the 'stability landscape' model (Walker et al., 2004) to characterise resilience in terms of farms' resistance, latitude and precariousness;
- identifying proxies or surrogates for resilience that will deliver new understanding of farm-level exposure and sensitivity;
- producing an indicators-based framework that can support on-farm decision making by assisting farmers with monitoring and evaluation of movement towards or away from critical decision thresholds; and
- contributing to international research exploring the practical application of resilience as a conceptual and methodological framework.

To achieve these aims, this study:

- identifies three aspects of resilience related to the capacity of sheep and beef farm systems to manage current and anticipated climatic risks: resistance, latitude and precariousness;
- develops an indicators-based framework, which is tested and refined through deliberation and consultation with stakeholders and quantitative economic modelling;
- provides the basis for a decision support system to be incorporated into farm management plans, or refined and applied to different pressure states (e.g. market, policy, or oil price shocks) and different primary production activities (e.g. dairy, horticulture, viticulture).

Most definitions of resilience are derived from the capacity of a system, community, or society to resist disturbance while maintaining an acceptable level of functioning and structure (UNISDR 2004). The Rockefeller Foundation (2009), inspired by Folke (2006), defines climate change resilience as "the capacity of an individual, community, or institution to dynamically and effectively respond to shifting climate impact circumstances while continuing to function at an acceptable level" (Rockefeller Foundation 2009, 1). Other elements frequently seen in resilience definitions focus on resisting, maintaining integrity, bouncing back, and improving risk reduction (OECD 2006, 15). Resilience definitions often depart from capacities to be developed and used, with an active role for those affected, and a longer-term systemic transformation element that reflects dynamism.

Resilience is used here to describe the ability of socio-ecological systems to cope with changes. It has its origins in ecology, where it was first used to describe a 'measure of the persistence of systems and of their ability to absorb change and disturbance and still maintain the same relationships between populations or state variables' (Holling, 1973, p. 14). More recently, additional concepts have been added including reorganisation, identity and feedback

(Resilience Alliance, 2007; Walker et al., 2004; Walker and Salt, 2012), and the capacity to adapt and learn (Berkes & Seixas, 2005; Smith et al., 2011). Though useful in theory, there are few models to guide the practical application of 'resilience thinking' in practice. An exception is the stability landscape model of Walker et al. (2004), which identifies three components of resilient systems: resistance, latitude and precariousness. Resistance refers to the ease or difficulty of changing a particular socio-ecological system (SES); latitude is the extent to which a system can be changed and the number of states it can assume before losing its ability to recover; and precariousness is the 'closeness to the edge'. The stability landscape model addresses the question: How far is the current state of the system from the threshold beyond which recovery is impossible?

Research Methods

Resilience cannot be measured directly. It is an emergent property, arising from the complex interaction between different elements of a social-ecological system. To overcome this difficulty in transferring key theoretical concepts to the applied context of land management, the use of surrogates has been proposed (Berkes and Seixas, 2005). Examples include surrogates related to institutional change, economic structure, property rights, risk perceptions, and level of interest (Klein et al., 2003; Marshall, 2010).

To address this challenge of measuring resilience, a deductive-inductive approach is used. An existing conceptual model informed the empirical research, and a new sheep and beef farming specific framework driven by the data from different farming systems is then developed. Qualitative interviews form the core of the inductive analysis, as these allow collecting information on multiple realities, including those that cannot be predicted, based on theoretical reasoning (Riley and Love, 2000). This qualitative approach is in line with Walker et al.'s (2004) suggestion that, while exact measurement of latitude, resistance, and precariousness might be challenging, a qualitative assessment of each of these components of resilience can be made. The resilience surrogates derived from the qualitative analysis then serve as a basis for the identification of potential indicators which might be used in future attempts to measure and monitor resilience. Miller et al. (2010) advocated such a hybrid approach as it provides a holistic picture of disturbances and response options in the context of bridging resilience and vulnerability research (*Figure 1*), which we follow in this analysis.

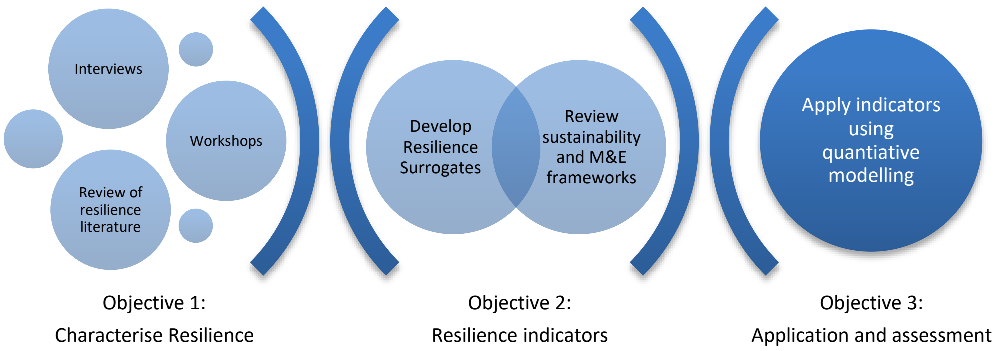


Figure 1: Interrelated research objectives aimed at characterising resilience, and identifying and applying relevant indicators to support adaptation.

The qualitative interview and workshop data was used to define twenty surrogates for the three dimensions of resilience: resistance – the degree to which a farm is exposed to risk; latitude – the capacity to respond, and precariousness – movement towards thresholds. The surrogates for resistance, latitude and precariousness, are shown in Table 1.

Table 1: Surrogates for resilience

Stability landscape aspect	Surrogate	Description
Resistance	Exposure	Extent to which farming system is exposed to adverse climatic conditions (e.g. location, aspect, etc.).
	Sensitivity	The degree to which the farming system is sensitive to adverse climatic conditions.
	Coping range	Level of critical threshold above or beyond which, normal operation is not possible.
Latitude	Age	Degree to which capacity to absorb losses or respond to adverse events is influenced by age of farmer.
	Debt	Degree to which flexiblity and responses are constrained by debt levels.
	Information	Climatic and farm management information that is used in decision making.
	Communication	Access to reliable communication.
	Access	Dependence on a particular resource or location.
	Product	Diversity of products produced on the farm.
	Markets	Diversity of market segments (e.g. early season) or segments a farm is producing for.
	Productivity	Amount/total yield of products produced on the farm.
	Suppliers	Diversity of suppliers for inputs (e.g. lambs, feed, fuel).
	Processors	Diversity of processors that the farm is able to supply.
	Networks	Connectedness of the farm and its activities, within and across a region to allow for greater diversification in the face of adverse conditions (e.g. neighbors assisting in flood events)
	Pluriactivity	Access to off-farm income, not affected by adverse climate.
	Health and well-being	Physical and emotional well-being of farmer/staff and family.
Precariousness	Frequency	Extent to which activities on the farm are disrupted under current climate conditions.
	Severity	Degree to which activities are affected under current climate conditions.
	Recurrence interval	Frequency with which farm is affected under current climate conditions.
	Climate change	Extent to which climate change will exacerbate climatic impacts for farm.

These surrogates were then used as the basis for the identification of a suite of qualitative and quantitative indicators across four domains: social, economic, governance and environment. Selection of indicators was based on analysis of the empirical data and a review of existing farm sustainability monitoring and evaluation frameworks. The proposed indicators can be used to assess future resilience of farm operations by providing insight into a farm's resistance, latitude and precariousness in relation to climate change. The selected indicators are sensitive to changes in climate (i.e. they are able to measure changes in temperature or preciptiation); extreme events; and/or changing seasons. The data used as inputs for these indicators is also currently gathered or available at no cost. The proposed indicators are shown in Table 2 (overleaf).

Table 2: Proposed indicators for resilience

Domain	Proposed Indicator	Measure
Economic	Efficiency	Farm Working Expenses as a percent
	Liquidity	Debt to equity ratio
	Cashflow	Bills paid on time
	Farm productivity	Kg meat/ha, product/ha
	Transportation infrastructure	Roading quality (both on-farm and in district)
	Diversification	Product diversification
		Market diversification
		Land diversification
		Off-farm income
		Pasture as percentage of feed consumed
	Risk strategies	Stocking rate flexibility
		Stored feed on hand
	Product quality	Price premiums available
Environment	Biodiversity	Protection of endemic species
	Land	Erosion prone/erosion control
		Flood prone
		Weeds
	Soils	Soil fertility levels
		Area of 'no or minimal till' vs cultivation
		Nitrogen conversion efficiency %
	Water quality	Biological health of rivers and streams
		Phosphorus runoff
		Nitrogen loss to water
		Sediment loss to waterways
		Current nutrient budget/management plan
	Water yield	Groundwater resources
		Reticulated stock water
		Water storage/harvesting
Social	Employee working conditions	Staff retention/employee turnover
		Working hours/work life balance
		Lost time due to injury/ACC claims/sick days
	Community health	Counselling services available
		Rural support/Task Force Green
	Family	Time for family
		Scope for farm succession
		Number of generations involved in the business
	Knowledge and skills	Use of technology
		Use of computers on farm
		Skills enhancement
		Educational attainment of farmers and staff
		Use of internet and email (good broadband access)
	Infrastructure/Isolation	Distance to services and education
		Access to health and social services

	Interaction with community	Level of involvement in the community
Governance	Decision making and implementation processses	Effective governance culture
		Written agreeements
	Methodology and tools to monitor and implement sustainability	Making good decisions at the right time
		Benchmarking
		Use of advisors
	Risk management	Attitude to risk
		Managing risks effectively
	Internal communication	
	Animal welfare	Stock condition
		Shelter and shade

Lastly, a sub-set of indicators were applied to economic farm systems modelling under a single climate change scenario for three regions, Canterbury, Hawke's Bay and Northland.

Key findings and recommended next steps

The central focus of this study was farm-level resilience. However, a farm is only as resilient as the resources and people on which it depends, and the research also identified the importance of factors at the sub-regional, regional and national/global level that impact farm-level resilience. In this way, this study further validates other socio-ecological resilience studies, which have found that resilience dynamics need to be assessed across multiple spatial scales and domains.

The assessment framework developed and presented here provides a robust methodology to determine which farm system components influence both the farm's and the farmer's resilience to a range of risks and which are critical for specific risks. This framework can help the sheep and beef sector identify system vulnerabilities and risks, and develop and support specific adaptation or resilience-building strategies.

Key findings from the research include:

- *Indicator selection is enhanced by the participation of affected stakeholders.* Planning processes are strongest when they are participatory and inclusive. Wide consultation with stakeholders can and should inform the indicator selection process. Doing so can (1) contribute to establishing the focus for the indicators, (2) clarify the methods of data collection and evaluation, (3) frame what success looks like according to beneficiaries, and (4) promote shared ownership and transparency. Stakeholder involvement can also bring a critical perspective on how to define appropriate steps toward the achievement of future outcomes (Sniffer 2012).
- *Both qualitative and quantitative indicators and data are required.* Indicators can be either qualitatively or quantitatively defined. *Quantitative indicators* express numerical information (e.g., percentage increase/ decrease), while *qualitative indicators* are descriptive observations or assessments (e.g., results of an open-structured interview). Usually, one type of indicator is not sufficient to provide all of the information needed to assess resilience. Assessing resilience to support adaptation planning therefore should include a suite of different indicators and indicator types.

- A related consideration is that 'big picture' thinking and approaches are key to assessing resilience. Maladaptation and other unexpected findings often first manifest in more open-ended, qualitative data and/or measures of broader conditions. Qualitative analysis therefore is essential in capturing (local) knowledge regarding likely impacts of shocks and stresses. However, climatic variation is not the only long-term factor; social, economic, and environmental factors are also part of the wider enabling environment for pastoral farming and should be taken into account.
- *There is no single set of universal or standard resilience indicators.* One of the main findings of the study is that there is no single set of universal or standard resilience indicators. While climate change is a global phenomenon, resilience is fundamentally local, and it is best to select indicators that reflect the specific scale and context at hand. Given the local manifestations of climate change impacts, adaptation planning and resilience assessment lends itself well for local stakeholder consultation and other forms of participatory engagement. This engagement should include the processes of indicator development and selection, and data collection to capture both the local context and the wider enabling environment. The local climate system is dynamic, and there is uncertainty about how climate change will manifest itself at the local level.

Based on these findings, we recommend the following:

- *Incorporate resilience indicators in Land and Environmental Planning Toolkit or Farm Environment Plans.* Indicator-based monitoring and evaluation frameworks can support on-farm decision making. In particular, we recommend incorporating all the proposed resilience indicators into the Land and Environmental Planning Toolkit (Beef+Lamb) or Farm Environment Plans. Mainstreaming such monitoring and evaluation frameworks will help to build the capacity for foresight and strategic adaptation, help to 'normalise' adaptation planning within the primary sector, and help to increase adaptation planning efforts. The proposed indicators also provide an additional risk management tool to support farmers to better manage impacts related to other, non-climatic risks such as pest incursions, market shocks or personal loss or injury.
- *Further develop and refine the proposed resilience indicators.* While this study provides an initial set of indicators for assessing farm-level resilience specifically for the sheep and beef sector, it can be further advanced by:

  a) undertaking farm systems modelling to determine the extent to which the proposed indicators accurately reflect local, regional and national-level farm conditions, as well as variations between different farm types (e.g., extensive vs. intensive) and landscapes (e.g., hill country vs. plains);

  b) applying a similar process of characterising resilience and then identifying indicators for other sectors also likely to be affected by climate change, for example, the dairy or horticultural sectors;

  c) further applying the stability landscape model at other scales to explore interactions and influences on resilience and its variability at regional or catchment scales;

d) developing a learning component for future resilience assessments. Climate change impacts and related adaptation interventions are complex, interconnected and characterised by inherent uncertainty. Any subsequent assessments therefore should contain a social learning component to inform interventions and to further mature the evidence base (Dunningham et al., 2015). This could include participatory workshops involving scenario develop with stakeholders to explore potential futures and possible responses. Learning plays a central role in resilience of social-ecological systems, in particular the recombination of experiences from different areas and diverse fields that may lead to new insights and pathways for development.

1 Introduction

1.1 Climate change and resilience for the primary sector

Scenarios of future climate change indicate likely changes in temperature, rainfall and the distribution and frequency of climate extremes (Harrington et al., 2014; IPCC, 2014). With growing concern that the target of limiting change to within 2°C is unlikely to be met, researchers and policymakers are planning for future climate conditions more than 4°C higher than the long-term, global average (Moss et al., 2010; Smith et al., 2011; Rahmstorf et al., 2012; Herring et al., 2014). For climate-sensitive, resource-dependent industries and sectors, this will require significant changes in management, enhanced adaptive capacity and a commitment to monitoring and evaluation of long-term trends in order to minimise risk, and enhance resilience to a range of shocks and stressors (Howden et al., 2007; Fleming and Vanclay, 2010; Kenny, 2011; Marshall, 2011).

The ability of socio-ecological systems to cope with the predicted changes is shaped by complex, interactive and non-linear dynamic processes (Folke, 2006; Westley et al., 2013). Thresholds, amplifying feedbacks and time-lag effects are widespread and make the impacts of global change hard to predict, difficult to control once they begin, and slow and expensive to reverse once they have occurred (Berardi et al., 2011; Dakos et al., 2015). Global change shifts the sustainability challenge from preserving natural resources for future generations to strengthening resilience and adaptive capacity in socio-ecological systems (Benson and Garmestani, 2011; Fischer et al., 2015). Decision makers and concerned citizens urgently demand reliable, science-based information to help them respond to climate change impacts and opportunities for adaptation (Fazey et al., 2007; Ford and Pearce, 2010; Measham et al., 2011; Kristjanson et al., 2014).

This is of particular importance for New Zealand; a peripheral economy in the global context, largely dependent on primary production. The primary sector contributes 6.0% to GDP, and over half of New Zealand's export earnings. Nearly half of the land is in productive pasture and arable cropping. Dairy farming is fundamental to the rural economy, accounting for almost half (47.6%) of agricultural earnings. Horticulture is also growing in importance, predominantly due to niche production of high value wine and kiwifruit (NZ Treasury 2014).

Climate variablility, including extremes, currently has a marked effect on pastoral farming systems, and climate change is likley to have significant impacts for a wide range of primary sector stakeholders (Clark et al., 2012; Manning et al., 2014; Cradock-Henry and Mortimer, 2013). The adaptation of primary sector enterprises to a changing climate is therefore of fundamental importance in supporting a sustainable primary sector, and maintaining a strong economic future for New Zealand. Climate change is likely to make organisations and institutions more vulnerable to external shocks that can affect business operations (Dany et al. 2014; Mandryk et al. 2015). Climate change-induced shocks include anticipated changes in the frequency of extreme events, such as fire and drought, as well as the incremental impacts arising from changes in climate, such as disease and loss of biological productivity. Significant knowledge gaps remain in our understanding of potential impacts and implications for New Zealand, in particular for the country's primary sector (Hennessy, 2007; Kenny, 2010; IPCC, 2014; Reisinger et al. 2014; Burton and Peoples, 2015).

As climate change is expected to have a profound impact on natural resources, and thus on the primary sector (agriculture, forestry and fisheries), it is imperative to understand the projected areas at risk and how to be informed on the appropriate adaptation responses (Park et al. 2012; Rickards and Howden 2012; Anwar et al. 2013; Fleming et al. 2014; Olmstead 2014). The sustainability of the primary sector, which contributes to fundamental issues such as food security, social benefits and economic growth, is highly vulnerable to future climate changes and variability due to expected impacts such as increases in extreme weather events, temperature changes, and decreases in rain fall, crop viability and yields (Fitzharris, 2007; Manning et al., 2014; IPCC, 2014; Marshall et al., 2014).

Comprehensive monitoring of changes is needed to improve estimates of potentialfuture change and fill knowledge gaps relating to first and second order effects across all sectors.

1.2 Research aims and objectives

The aim of this research is to support monitoring and evaluation, and on-farm decision making for the sheep and beef sector, through the characterisation of resilience and identification of suitable indicators. This program draws on several diverse fields of study to characterise decision-critical thresholds in sheep and beef land management systems and to identify metrics that can help on-farm decision-making for greater climate resilience.

Resilience is understood as an emergent property of the complex interactions between various components, or subsystems, of social-ecological systems (SES) (Folke, 2006; Benson and Garmestani, 2011). Resilience is a function of the capacity of a system to adapt, self-organise and increase its capacity to buffer against shocks and stresses (Walker and Salt, 2006). In its simplest form, resilience is understood to be a function of adaptive capacity, buffering capacity, and the capacity for self-learning or self-(re)organisation when exposed to stressors (Carpenter et al., 2001; Folke et al., 2011).

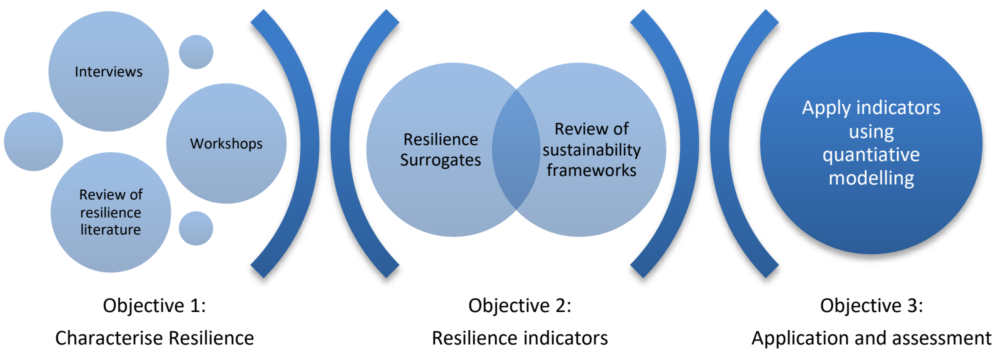


Figure 2: Interrelated research objectives aimed at characterising resilience, and identifying and applying relevant indicators to support adaptation.

While theories and conceptual understandings of the features of resilience have been widely developed, there has been less attention paid to operationalising these concepts, particularly for agroecosystems, which are among the most complex SES (Darnhoefer et al. 2010a). Resilience concepts can provide guidance in the development and selection of indicators (Reed et al., 2008, 2013). Because resilience is an emergent property of systems, it is context sensitive. The measuring methods and metrics of resilience cannot be easily applied to other types of systems (Carpenter et al., 2001, 2005; Dakos et al., 2015). As a result, researchers have suggested that surrogates for resilience be identified first; these can then be applied and evaluated for their usefulness as quantitative indicators (Miller et al, 2010).

The research had three objectives (refer to *Figure 2*):

1. Characterise the resilience of sheep and beef land management systems, by obtaining insight into elements of resistance, latitude, and precariousness as they relate to climate change;
2. Identify suitable surrogates and indicators that might be used to characterise movement towards or away from system-critical thresholds within land management systems; and
3. Apply the indicators through economic and farm-systems modeling to determine their suitability for informing on-farm decision making and monitoring under anticipated changes in climatic conditions.

1.3 Research questions

The following guiding questions were posed:

1. How resilient to increased climate variability and change are sheep and beef land managers and their productive systems? (Objective 1)
2. What are the system-critical social, ecological and economic thresholds for New Zealand sheep and beef land managers as they relate to anticipated changes in climate? (Objective 1)
3. What are the best indicators to identify changes in agroecosystems that can be operationalised at the farm level, to support decision making for climate resilient farm futures? (Objective 2)
4. How can these indicators be applied to help translate uncertainty about the extent of climate impacts into practical knowledge about how best to prepare for specific impacts? (Objective 3)

1.4 Research design and method

The research answered these questions though an interdisciplinary and mixed methods approach, drawing insights from diverse fields of climate change adaptation studies, vulnerability and resilience science, farm-systems science, farm management and economic modelling.

A qualitative approach was used first, to characterise resilience across diverse regional contexts, and gain insight into the precariousness, latitude and resistance of different farming systems. Through workshops and interviews, empirical data was obtained on the perceived drivers of vulnerability, potential impacts and responses to climate change, and tipping points for land management. Existing indicators frameworks were reviewed to assess their value and relevance for resilience and the New Zealand context. Elements of different frameworks were selected, compared with the resilience surrogates and deliberated with stakeholders. Lastly, quantitative economic modelling of the indicators on different farms was undertaken to assess the value of the selected indicators, and develop case-study narratives.

The research team had experience and interest in collaborative approaches and the co-production of knowledge. Because of this, working closely with primary producers and affected stakeholders was central to the identification of risks and responses, the characterisation of resilience, and the identification of relevant indicators.

1.5 Report structure

The report is organised as follows:

Section 2 reviews the literature on vulnerability, resilience and adaptationto establish a theoretical and conceptual basis for empirical investigation;

Section 3 outlines details of the research methodology;

Section 4 critically analyses findings from workshops, interviews and the literature review to characterise three dimensions of resilience for sheep-and-beef land management systems: resistance, latitude and precariousness. Surrogates for these aspects of resilence are presented and provide an empirical basis for the subsequent selection of quantitative indicators;

Section 5 presents a review and analysis of an indicators-based framework that was evaluated through consultation and deliberation with stakeholders, against the conceptual and theoretical framework developed;

Section 6 presents the results of case-study analysis using quantitative farm-economic modelling to evaluate the effectiveness and relevance for decision-making of the proposed indicators; and

Section 7 concludes the report with a series of recommended next steps.

2 Vulnerability, resilience and adapting to a changing climate

Weather-related stressors have a significant influence on New Zealand's primary sector. In 2007, annual weather-related agricultural losses topped NZ$1.0 billion for the first time (MAF, 2008). Since then, the country has endured near consecutive summer drought-like conditions (MAF, 2010). In 2009, a widespread dry spell across the North Island resulted in a 15% drop in dairy production (DairyNZ, 2010). The summer of 2011 was the hottest and driest in Northland in almost 60 years, and created significant concern among farmers as it was the fourth drought in a row (NIWA, 2011). Losses from the 2012/13 exceeded $2 billion, and the cost of the 2014/15 drought has yet to be determined. There is growing evidence for the influence of climate change on recent extremes in New Zealand (Harrington et al., 2014).

Of all human activities, agriculture is uniquely dependent on ecosystems function and provision, ranging from water availability, climatic conditions and nutrient cycling (Howden et al., 2007; Meinke et al., 2009; Crimp et al., 2010). In New Zealand, agricultural production is often the dominant economic activity for large regions, and the wellbeing of tertiary activities and local populations is dependent on its viability (Patterson et al., 2006). National agricultural exports for 2009/10 were worth over NZ$18 billion (MAF, 2010) and the country's trade-oriented agricultural economy is already markedly sensitive to climatic variability and extremes (Stroombergen et al., 2006), as demonstrated by the effect of floods and droughts on GDP and rural activity (Tait et al., 2005; Buckle et al., 2007). Pastoral farming (which in New Zealand has traditionally relied on year-round grazing of animals in open pasture) (Jay 1999; Verkerk 2003; Clark et al. 2007), horticulture, viticulture, and forestry are sensitive to climate variability and extremes because of their immediate dependency on the natural environment (Clark et al., 2012; Kalaugher et al., 2013).

These climate-related stressors occur against a backdrop of conventional drivers including economic, biophysical, institutional, cultural and political pressures (Leichenko and O'Brien, 2008; Burton and Peoples, 2014). Thus, the capacity of resource-dependent enterprises to cope with the compounding influence of stress and shocks change is largely uncertain (Berardi et al., 2011). As a result, it has never been more important to assess, influence and monitor the resilience and adaptive capacity of resource-dependent industries (Vogel et al., 2007; Moser, 2010; Kythreotis et al., 2013). Resource users will need to anticipate and prepare for change, and institutions will need to be particularly supportive, if resource industries and the extended social systems dependent on them are to be sustained (Agrawal et al., 2013).

A strategy for industries, communities and policymakers to adequately support the capacity of resource users to cope and adapt to future change, is through maintaining the properties that confer resilience (Gunderson, 1999; Kates *et a*l., 2000; Walker et al., 2002). This resilience-based approach is useful for guiding and supporting more inclusive and effective approaches to the management of ecosystems and the dependent societies (Ludwig et al., 1997; Berkes and Folke, 1998; Levin et al., 1998). Whilst other approaches are available, such as those used in the sustainability sciences (Hodge, 1997; Brunckhorst, 2002; Costa and Lyon et al., 2011; Mace, 2012; Kropp, 2013), the resilience-based approach offers a systematic thinking for understanding the adaptation process (Walker et al., 2009; Walker and Salt, 2012, 2006). Briefly, the basis of resilience theory is that social and ecological (socio-ecological) systems are intrinsically coupled and constantly face change, the outcomes of which are inherently unpredictable.

2.1 Resilience

Over the last decade, resilience has become an increasingly popular concept in research and policy considering the impacts and implications of climate change, with all major Australian Governmental environmental strategies making resilience a key component of problem definition (Cork 2010:3). It has been developed and applied in diverse contexts, and its conceptual and theoretical evolution has been advanced within very distinct research fields including engineering (Gorden 1978), human development and mental health (Luthar 2006), disaster management (Paton 2006; Coles and Buckle 2004; Bruneau et al, 2003; McManus 2007; Norris et al 2008), ecology (Holling 1973, Walker and Salt 2006), and regional economics (Pendell 2010). Examples of the diverse types and meanings ascribed to resilience are shown in Table 3.

Table 3: Definitions of resilience

Resilience concept	Description and sources
Ecological resilience	"A measure of the persistence of systems and their ability to absorb change and disturbance and still maintain the same relationships between populations or state variables" (Holling 1973). The magnitude of disturbance a system tolerates (can tolerate) before moving into a different state space and set of controls (Holling 1973; Carpenter et al. 2001; Walker et al. 2002).
Population ecology	Resilience is "how fast a variable that has been displaced from equilibrium returns to it. Population resilience is the rate at which populations recover from their former densities."; Resilience as an element of stability; as a central feature of population dynamics (Pimm 1984, 1991).
Social resilience	"Social resilience is the ability of groups or communities to cope with external stresses and disturbances as a result of social, political and environmental change." (Adger 2000, Obrist et al. 2010).

Economic value of resilience	Resilience as distance to a threshold; this distance is a stock variable, where the level of the stock is equivalent to the resilience of the system (Walker et al. 2010).
Social-ecological resilience	Resilience to a specific disturbance or event involves identifying a particular threshold effect beyond which the system is unable to recover its earlier pattern of behaviour.
Spatial resilience	Resilience as maintaining identity over time: "maintenance of key components and relationships and the continuity of these through time". "If resilience is low, identity may be lost and if identity is lost, resilience was low" (Cumming 2011:13; Cumming and Collier 2005).
Social ecology of resilience; psychology and anthropology	Resilience reflected in "lives well lived despite adversity". Under exposure to significant adversity, "resilience is both the capacity of individuals to navigate their way to the psychological, social, cultural and physical resources that sustain their wellbeing, and their capacity individually and collectively to negotiate for these resources to be provided and experienced in culturally meaningful ways (Ungar 2005, 2008, 2011)

There is no universally agreed definition or general theory of resilience (Simmie and Martin 2009), and there are marked distinctions in how resilience is conceptualised due to the different disciplinary foundations used (e.g. ecology versus psychology), and the nature of the primary object or system under examination (e.g. the human impact on a fisheries stock versus the impact of an earthquake on a human community). There does not appear to have been, until recently (see Paton 2006a), substantive theoretical integration across these different disciplinary areas. Cork warns that the rapid popularity of the concept of resilience may be leading to the 'uncritical application of the term in many fields' (2010:3). For example, while resilience in the field of disasters is increasingly understood as the ability to adapt or transform, mirroring the understanding of resilience of socio-ecological systems (Walker and Salt, 2012), resilience is sometimes distinguished from adaptability and transformation and is often understood by policy agencies as the ability to bounce back to normal, as evidenced by the indicators frequently used to measure post-disaster recovery (Miller et al., 2012; Downes et al., 2013; Hayward, 2013). Because of these differing understandings of the term resilience, it is important to define resilience when it is used, and to acknowledge there are different disciplinary understandings of the term.

Resilience theory has challenged how we view and manage our natural systems, and places great emphasis on avoiding stability and on recognising the complexity and dynamic nature of socio-ecological adaptive systems (Colding et al., 2004, Walker et al., 2004; Gallopín, 2006, Acosta-Michlik and Espaldon, 2008). Where 'sustainable yields' or quotas have been set, natural resources and dependent social systems have collapsed or are close to it (Ayensu et al., 1999; Milich, 1999; Jackson et al., 2001; MacKenzie, 2003). In the same way that resources cannot be harvested according to set limits, but must be managed fluidly through monitoring, and adaptation (Ludwig et al., 1997; Berkes and Folke, 1998), resource users cannot be made to change their behaviour and become adaptable. Like developing resilience in systems, resource users must be politically, culturally and financially supported to plan, experiment and learn if they are to adapt to stresses and shocks and changes in policy and legislation to support more changes in land management practice (Armitage et al., 2011; McDowell and Hess, 2012; Westley et al., 2013).

The resilience-based approach is particularly apt for managing the uncertainty inherent in much of our planning for the future (Dessai et al., 2007; Mander et al., 2007; Berman et al., 2012; Fowler et al., 2013; Hammond et al., 2013). Managing for resilience is a means by which communities and resource managers can design strategies that allow both social and ecological systems to cope with uncertainty and adapt (Adger, 2006; Dessai and Hulme, 2007; Smith, 1997). Through the maintenance of properties that can support greater resilience, the sustainability of natural resources and the social systems dependent upon them is not only possible but essential for the prosperous development of society (Lane and Rickson, 1997; Levin et al., 1998; Kates et al., 2000; Gunderson, 2004). Through managing for resilience, resource-dependent industries will move towards possessing the necessary pre-conditions for successfully incorporating and adapting to stresses, shocks and processes (Benson and Garmestani, 2011; Hammond et al., 2013).

Despite the diversity within resilience thinking, and growing critiques of its ability to address normative issues such as human agency, power relations and justice (Olsson et al., 2015; Tanner et al., 2015), resilience concepts can be a useful basis for empirically exploring farm systems and land management (Meinke et al., 2009; Benson and Garmestani, 2011; Berardi et al., 2011; Hammond et al., 2013). Resilience concepts, such as thresholds, self-organisation and buffering capacity, can serve as the basis for exploring some fundamental and increasingly relevant questions for land management including, but not limited to:

1. What factors enable agencies and land managers to recognise risks and take proactive action to address risks?
2. Are some patterns of natural resource use and land management better equipped to cope with a range of different future shocks than others?

This research drew on two key resilience concepts, with direct relevance for the rural sector and the characterisation of its capacity for responding to environmental and socio-economic pressures. The first is socio-ecological resilience, which examines the interface between an ecological system and human use and/or impact on that system. The second is the stability landscape model, which is a model to help operationalise resilience concepts for practical application. We discuss both of these in turn.

Defining socio-ecological resilience

Socio-ecological resilience examines the interrelationships between an ecological system and the human use or management of that ecological system (Adger et al., 2005; Bardsley and Bardsley, 2014). It describes these relationships as a socio-ecological system, which can be defined as a

> *multi-scale pattern of resource use around which humans have organized themselves in a particular social structure (distribution of people, resource management, consumption patterns, and associated norms and rules).*
>
> *(Resilience Alliance www.resalliance.org/index.php/key_concepts).*

Research within this field has sought to explain why some socio-ecological systems adapt and therefore persist in response to shocks and pressures created by human interaction with ecological systems, while others do not (Adger 2008). The resilience of a socio-ecological system has been defined as

> *the capacity of a system to absorb disturbance; to undergo change and still retain essentially the same function, structure and feedbacks. In other words, it's the capacity to undergo some change without crossing a threshold to a different system regime - a system with a different identity. A resilient social-ecological system in a 'desirable' state (such as a productive agricultural region or industrial region) has a greater capacity to continue providing us with goods and services that support our quality of life while being subjected to a variety of shocks (Walker and Salt, 2006).*

Socio-ecological resilience is essentially about understanding the world as a complex adaptive system (Darnhofer et al., 2010:187). As suggested by Pomeroy (2011), it is predicated on the fact that change is constant, and that resource management must accommodate this (Walker and Salt, 2006). Socio-ecological research has identified, for example, that natural resource management regimes frequently attempt to 'control natural resources for stable or maximum production' and 'ignore the dynamic nature of ecological systems'. Over time this reduces the resilience of these systems, causing them to fundamentally change their structure and function. Examples include where grassland systems permanently shift into shrubland systems due to overgrazing by cattle (Resilience Alliance, 2010), or where forests become less resilient to fires where forest management has consistently excluded forest fires over an extended period of time (Walker, 2012).

Socio-ecological resilience is understood as a system property rather than a normative state (Bahadur and Tanner, 2014; Tanner et al., 2015). An ecological system may be very resilient but be undesirable in terms of human goals (e.g. an eutrophic lake) (Carpenter et al., 2005; Milestad et al., 2014). This non-normative framing can be problematic when resilience is understood as a normative concept by other fields and policy agencies, and when socio-ecological resilience scholars are linking resilience to sustainability concepts (Ang and Passel, 2012; Fischer et al., 2015). Possibly to provide a normative concept within this field, some use the concept of transformation to distinguish when a socio-ecological system is currently in an undesirable state, where adaptation within that system will only delay and intensify the collapse of that system, and therefore significant transformation of the system is required (Westley et al., 2013; Bahadur and Tanner, 2014; Calgaro et al., 2014). Walker and Salt (2012) define transformation as 'the capacity to become a fundamentally different system when ecological, social and/or economic conditions make the existing system untenable'. This definition reflects Handmer and Dover's (1999) multiple typologies of resilience, when they distinguished between resilience strategies that simply adjust around the edges of a problem, and strategies that seek to transform the underlying operation systems themselves and is reflected in the growing emphasis on transformation in the environmental and global change literature (Alexandra, 2012; Gliessman, 2013; Dowd et al., 2014)

Resilience has been applied to economic shocks as well as natural ones. Notably the Canadian Centre for Community Renewal (CCCR) developed a community resilience model and participatory toolkit to help rural communities assess their resilience and plan responses for when their major industry (e.g. forestry, mining) closes. Community resilience is defined by CCCR as: '*the ability to take intentional action to strengthen the personal and collective capacity of its citizens and institutions to respond to and influence the course of social and economic change*' (CCCR 2000:1–5). The planning process itself is an opportunity to build five attributes of community resilience identified in research, namely critical awareness, positive outcome expectancy, collective efficacy, community empowerment and trust in public sector institutions.

Socio-ecological resilience literature also strongly emphasises the need for cross-scale analysis of socio-ecological systems and identification of the interdependencies between these scales (Gunderson and Holling, 2002; Bellamy and McDonald, 2005; Charles, 2012). Walker and Salt (2012) suggest you cannot cannot understand or manage a socio-ecological system at one scale only. In terms of rural resilience, the assessment of socio-ecological resilience at the scale of a farm includes farm, catchment and regional levels (Walker et al. 2009; see also Figure 1). Social assessments of resilience within the socio-ecological resilience literature are primarily concerned with examining those groups of actors who are impacting a particular ecological system, and these actors may be situated at different levels. They may involve individuals and their support networks within a small fishing community, or they may be the actors within a major fisheries industry; the fishing companies, their markets and the regulatory authorities who manage the fish stock.

The Resilience Alliance has developed workbooks for scientists and practitioners which provide processes for multiscale assessments of socio-ecological resilience (Resilience Alliance 2007, 2010). The social and biophysical data requirements for these assessments are substantive (Figure 3) and beyond the limitations of all but the largest projects .

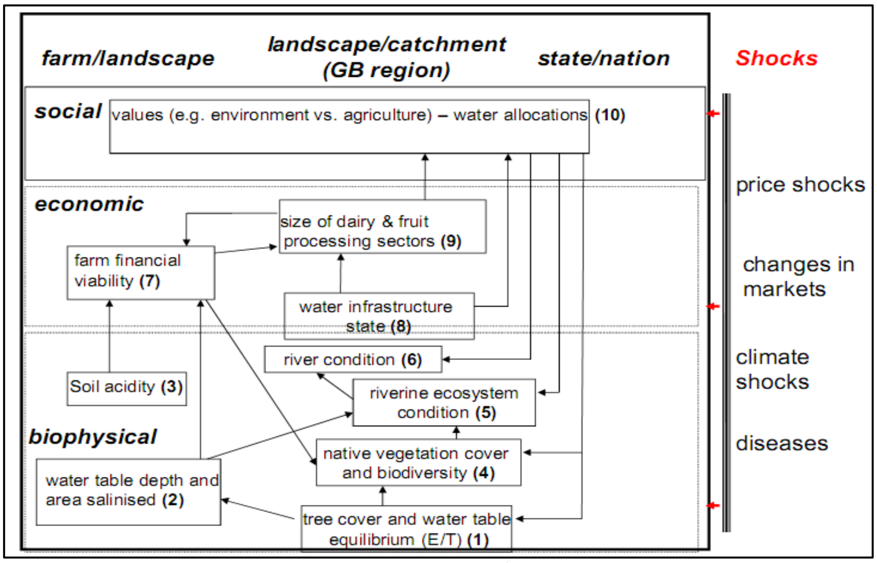


Figure 3: Thresholds in Goulburn-Broken catchment, Australia (Walker et al., 2009)

In assessing resilience, a number of papers stress the need to examine multiple stressors (Belliveau et al., 2006; McDowell and Hess, 2012; Castellanos et al., 2013) and the interaction between climatic and non-climatic risks (Leichenko and O'Brien, 2008; Burton and Peoples, 2014). When we start assessing the impacts of multiple stressors on a system we need to recognise that assessment enters a place of increasing uncertainty (Campbell and Beckford, 2009). If we look at only one stressor on a community or farm at a time, we might be led to believe we can to some degree predict the future state that that farm or community will experience. When we start to look at multiple stressors and look at the potential interaction between them, we start to see that the future is a very uncertain place – which then takes us into questions of how farmers, researchers and policy agencies deal with uncertainty. This also suggests that our perception of the future is to some degree determined by the assessment methods we use and the degree to which policy is siloed into different issues and outcomes.

Stability landscape model

One of the challenges to operationalising resilience is that few conceptual models allow for empirical investigation of resilience in the social sciences (Miller et al., 2012; Olsson et al., 2015). An exception is the stability landscape model of Walker et al. (2004:2). Walker and colleagues use the term 'landscape' to describe the so-called state space of all the 'values adopted by all the variables of the system in question at a given time' (Walker et al. 2004). Within this state space, there are certain basins of attraction that describe areas towards which the system tends to move as a meta-stable state (Anderies et al., 2006; Crimp et al., 2010). Thus, while the system's state may fluctuate considerably, it is resilient when it remains in the same basin (Pawlowski, 2006). Thus, a system's resilience refers to the width or limit of a stability domain (Gunderson, 2000). The stability domain or attractor, as it is also called, can be described through resistance, latitude and precariousness, as shown in Figure 4, based on Walker et al. (2004).

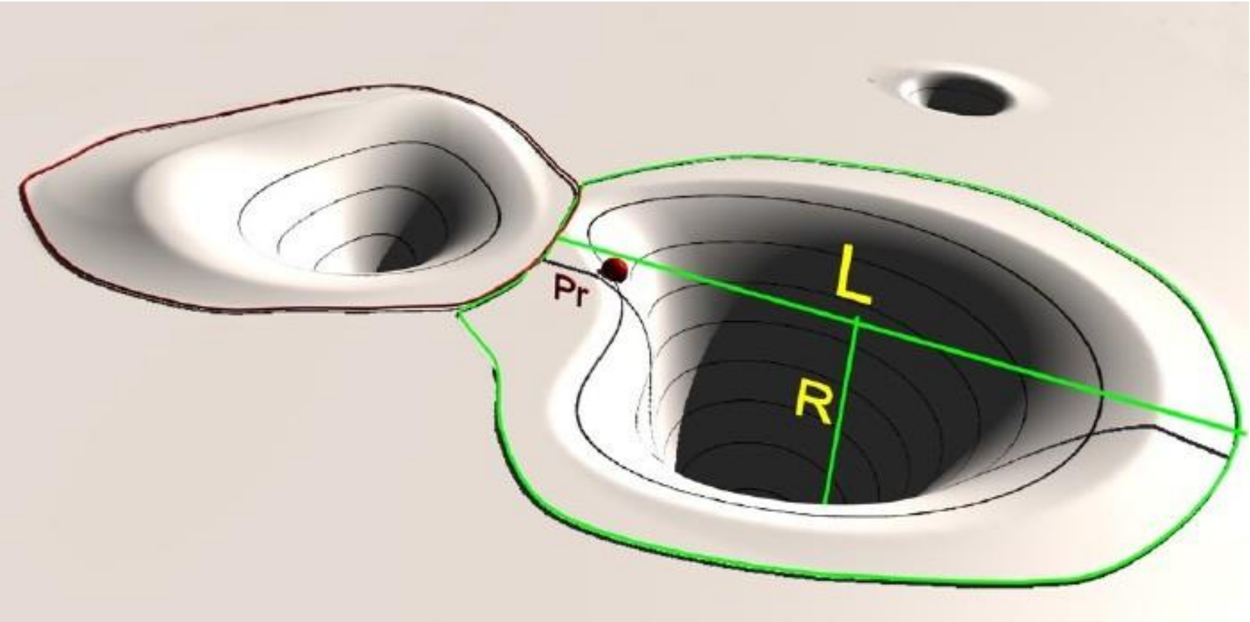


Figure 4: Three-dimensional Stability Landscape with two basins of attraction showing, in one basin, the current position of the system (dot) and the three aspects of resilience, namely Resistance (R), Latitude (L), and Precariousness (Pr) (Walker et al., 2004).

Resistance (R) is symbolised as depth of the state space. It is a measure of the ease or difficulty of changing a particular socio-ecological system (SES). In other words, systems that respond to minor perturbations are not very resistant (Pawlowski, 2006; Hammond et al., 2013). The deeper a basin, the greater the force necessitated to move the system away from the attractor and its most stable position at the bottom of the basin. The position at the bottom is the furthest away from the edge (or threshold) of the basin. Latitude (L) is the extent to which a system can be changed and the number of states it can assume before losing its ability to recover. It is symbolised by the width of the basin in Figure 3. If a system has a wide range of response options (i.e. autonomous or intrinsic adaptation) and a high degree of self-organisation (see Gunderson, 2000, p. 430 on self-organisation), its latitude is larger. In contrast, a system that is very limited in its configurations and can only change to a minor degree, has small latitude. Together, resistance and latitude form the topology of the attractor within the stability landscape.

Precariousness describes the closeness of the current state of a system of interest to a limit or threshold; that is the edge of the basin. Thus, Walker et al. (2004) define precariousness as the system's trajectory relative to the (known or unknown) threshold beyond which recovery is not possible. Finally, and not visualised in Figure 4 (but included in Walker et al.'s discussion), is the important effect of cross-scale interactions, referred to as panarchy

(Gunderson and Holling, 2002; Allen et al., 2014). Panarchy is important, as the resilience of a system at a particular scale depends on the influences from states and dynamics at lower or higher scales (Holling, 2001; Simmie and Martin, 2010; Allen et al., 2014).

Adaptive capacity as an expression of human activity refers to the capacity to manage the stability landscape (Fazey et al., 2007; Brown et al., 2010). This involves the ability to influence the trajectory of a system and its position within a basin of attraction, and the shape of a basin (Resilience Alliance, 2007). If a disturbance is sufficiently large and it is not possible to maintain the regime, transformations can occur, including the emergence of new stability landscapes. Conceptually, adaptability describes small changes and transformability describes large, more fundamental changes (Walker et al., 2009; Strunz, 2012).

Sometimes, stability is not desirable, and communities may promote a regime shift towards a new space (Walker et al., 2009). This would raise important questions about societal goals, values, decision-making and power relationships (Bahadur et al., 2013).

It is conceivable that a regional agricultural system, comprised of multiple farms, and possibly processing plants, can take many configurations, just as shown in Walker et al.'s (2004) stability landscape. Some regions will be more stable than others, and the different basins of attraction that a region could find itself in are likely to be characterised by different shapes. Farming regions can be loosely defined according to geographic areas where certain agricultural activities dominate, alongside other economic activities, communities and forms of land use (Simmie and Martin, 2010; Kenny, 2011). Change is the norm for primary production, and the stability landscape model may provide a promising approach for studying agroecological resilience across regional and local-scale farming systems. One of the related objectives of this research program was to assess the value in applying the model for use in agricultural research.

2.2 Conceptualising farm-level resilience

The focus in this research is on sheep and beef farms in New Zealand. Farms provide a suitable, though inherently complex, setting for exploring and developing measures of resilience. First, farms are human dominated, and managed intensively compared to undisturbed land. Farms are geographically bounded, and readily identifiable as integrated social-ecological systems in which human activity is an integral part. Second, agro-ecosystems follow and utilise annual cycles in patterns of resource use. Third, agro-ecosystems are often subject to shocks and stresses and directional changes, such as depletion-and-recovery cycles, making them a good fit with resilience thinking (Benson and Garmestani, 2011; Berardi et al., 2011; Marshall, 2011; Hammond et al., 2013).

The focus in this study is on individual farms within the context of regional, productive landscapes (Adeniji-Oloukoi et al., 2013; Aldum et al., 2014). The farm is conceptualised as an agroecosytem comprised of (1) the components that make up the system; (2) the relationships between components; and (3) the ability of both components and relationships to maintain themselves continuously through space and time (Ison, 2010). Maintaining function and identity is also related to (4) innovation and self-organisation – i.e. whether can the farm adapt to maintain its identity and functionality when exposed to stress. More resilient systems will typically be capable of adjusting to a variety of external conditions (Brown et al., 2010).

At its most basic, the farm consists of ecological or biophysical elements, such as climatic conditions, soil, pasture and water resources (including the availability of groundwater for irrigation). Alongside this natural or biophysical/ecological capital are extensive social and economic networks and actors, including the farmers themselves, who make direct use of those resources. The farm also includes a governance network – both at the individual scale as well as higher scales (regional and above). We use governance here in its broadest sense to include institutions, rules, and both formal and informal decision-making processes (Adger et al., 2003; Charles, 2012; Baird et al., 2014b). Examples include Health and Safety regulations that farmers must follow, and advice and support provided by extension providers and MPI. The final component of the farm is the economic domain, which includes elements related to profitability: efficiency, production and yield, cash flow, and debt servicing. In this way, we characterise the farm in terms of the following domains: social, ecological, economic and governance. The abstraction of the farm into its constituent components helped to facilitate the analysis, especially in discussions with stakeholders (McCrum et al., 2009; Baird et al., 2014a)

Relationships describe the ways in which system components interact or fit together (Berry et al., 2006; Ison, 2010). Relationships include such things as nutrient cycles, economic competition, land tenure systems, and interactions between human actors (for example, Ostrom, 1990, Daily et al., 1997, and Harris De Renzio, 1997). Sources of innovation are those subsets of the system that generate change or novelty. They may include or be closely related to such things as diversity, and the ways in which new technologies are developed and/or adopted. Continuity describes the ability of the system to maintain itself as a cohesive entity through space and time. Some systems are unable to maintain a continuous identity, and so change frequently. Most sheep and beef agroecosystems, however, operate on the same plot of land (even if ownership changes, providing spatial continuity), and over time (successive generations of owners continue to farm, providing temporal continuity) (Burton and Peoples, 2014). In social-ecological systems the key issue is often whether identity can be maintained through times of flux. Continuity is facilitated by system memory, which may take the form of social and biological legacies that remain after disturbances. Although specific components and relationships within a complex system will change over time, the essential attributes that define its identity must be maintained if the system is to be considered resilient. For example, in a ranching system, such as that discussed by Carpenter et al. (2001), we might base the notion of identity on the presence of ranchers, livestock, and a harvesting relationship between them. Loss of ranchers, livestock or the harvesting relationship would constitute a loss of identity. By contrast, and depending on the context, replacement of sheep by goats in a farm system might be seen as a system innovation that entails a degree of reorganisation but no loss of identity (Adger et al., 2011).

A simplified conceptual model is presented in Figure 5. The model is used to illustrate the ways in which climate change will influence the functioning of the farm through its impacts on social, ecological, economic, governance or ecological components. As presented here, the framework does not attempt to represent all factors, interactions, scales or feedbacks, although these have been developed in other analytical models (Crimp et al., 2010; Nelson et al., 2010; Rodriguez et al., 2011; Leith et al., 2012). Instead, the framework highlights those generic elements relating to resilience that are common to sheep and beef farms at a local scale, reflective of the broader scale processes, and which were used to guide the research.

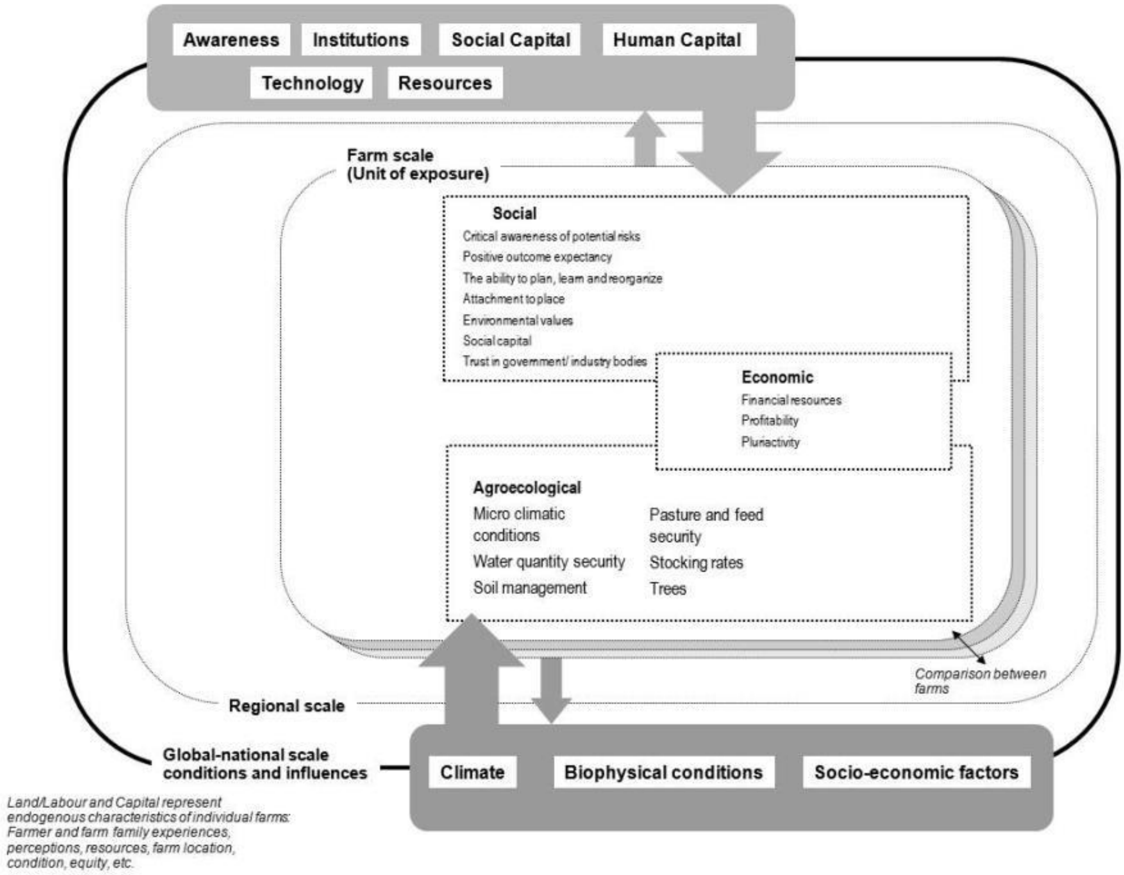


Figure 5: A simple conceptual model of an agroecosystem. The model is a schematic representation of the components, relationships and factors and conditions likely to influence resilience at the farm level.

The farm is conceptualised as the main exposure unit and unit of analysis. Consistent with the literature on agroecology, the farm is understood to comprise nested elements (Morgan and Munton, 1971; Darnhoefer et al., 2012). Endogenous characteristics of the farm include farmers' and farm families' experiences, awareness, and resources; farm location and farm type; and farm condition, indebtedness and equity. The farm operates within and changes in response to external, interconnected systems (Olmstead, 1970; Bowler, 1992; Bryant and Johnston, 1992; Giampietro, 2004). External forces provide risks, opportunities, and constraints to the functioning of the farm, and influence decision-making (Bryant and Johnston, 1992). It follows that these external forces and local farm characteristics influence the farm system's exposure to risk, adaptive capacity, and ability to self-organise (Meinke et al., 2009; Rodriguez et al., 2011; Darnhofer et al., 2010a, 2012).

Farm-level resilience is an emergent property of the interaction between these components (Darnhofer et al., 2010b; Hammond et al., 2013). The farm is resilient to climate change to the degree that it is able to adapt, self-organise and learn, and is buffered against shock and stress (Rodriguez et al., 2011). While the external drivers of exposure and the determinants of adaptive capacity may be common or similar among farms in a region, the endogenous characteristics of farms can vary greatly (Smithers and Smit, 1997). Among farms in any given area, differences in location, farm characteristics and production characteristics will result in differential levels of resilience (Campbell and Beckford, 2009; Darnhofer et al., 2010b; Hammond et al., 2013).

The farm is nested within and connected to processes and systems at multiple temporal and spatial scales (Young et al., 2006; Eakin et al., 2009). Shocks and stresses may originate at multiple scales, including global pressures and stressors. Potential pathways include biophysical linkages and feedbacks, economic market linkages, and flows of resources, people, and information (Adger et al., 2009). External drivers include broad scale climatic conditions, such as ENSO/IPO, that have an effect on precipitation patterns; biophysical conditions including soil type, topography, hydrology and geology; socio-economic factors, such as currency fluctuations and access to global markets; and the institutional and governmental environment within which producers operate (Fleming and Vanclay, 2010; Berardi et al., 2011; Castellanos et al., 2013). The resilience of any individual farm is an emergent property of the tools and resources available on the farm, the characteristics of the farmers themselves, and aspects of the farm location and production system (Castellanos et al., 2013; Bardsley and Bardsley, 2014). This might include farm income, access to credit, levels of indebtedness, and capabilities of the farmer (Barnes et al., 2013; Downes et al., 2013).

Resilience shifts over time (Belliveau et al., 2006; Ford et al., 2013; Pawlowski, 2006). The framework is presented here in its skeletal form, without the particular factors, variables, linkages, etc. in the components. When applying the framework, the exact pathways, thresholds, and system-critical components relative to each production system were not assumed *a priori*; but rather developed through the subsequent investigation and the nature of resilience was identified empirically as the case studies were developed. The conceptual framework did provide a guide to the identification of appropriate case study regions, and was used to help structure the inquiry and the final selection of indicators.

3 Research Methodology

The research methodology used drew upon the vulnerability, resilience and adaptation literature in designing a bottom-up and mixed methods approach to characterising resilience within sheep and beef land management systems (van Aalst et al., 2008; Kenny, 2011). A bottom-up approach encourages communities to assess and identify their own vulnerability and coping capacities, in order to produce recommendations grounded in the communities' reality. Fussel and Klein (2006) argue that this move reflects a change in informational needs, as the purpose of assessing vulnerability shifts from an impact assessment approach, to one that focuses more directly on developing adaptation strategies. The latter emphasis, they state, is far more grounded in the social determinants of vulnerability, and has a stronger emphasis on stakeholder involvement. This reasoning explicitly identifies that what makes one community vulnerable may have no bearing on the vulnerability of another, requiring locally grounded, flexible and responsive adaptation policy development (Brooks et al., 2005). The shift towards greater stakeholder inclusiveness is supported by the IPCC (2014). A number of studies of community vulnerability have adopted this format, which is able to incorporate stakeholders' knowledge and resource-use patterns, and is flexible enough to look beyond vulnerability to inherent coping capacity within the societies, drawing on historical experiences (see, for example, Campbell and Beckford, 2009, Bizikova et al., 2012, and Hammond et al., 2013).

Closely related to this, is a growing trend towards working more closely with stakeholders to assess and develop solutions for a range of land- and resource-management issues and assessments are increasingly made at the local and regional scale. Engle and Malone (2012) identify two benefits of greater stakeholder participation in any type of assessment. First, stakeholder input ensures that stressors or vulnerabilities that only stakeholders know about are identified, and second, stakeholder input ensures community buy-in needed to implement any resulting adaptation strategies or policy changes. Stakeholder involvement can be used in conjunction with other methods (case studies, indicators, etc.).

Downing and Patwardhan (2010) advocate a local-scale, grassroots process in which community stakeholders determine what they are vulnerable to (droughts, flood, rising input costs, etc.), what/who is vulnerable, how future vulnerability or resilience is shaped, and at what scales. Similar bottom-up, place-based and community-specific approaches have been advocated by Schroeter et al. (2008), Westerhoff and Smit (2010) and Ford et al. (2010).

The Canadian Centre for Community Renewal (CCCR) has developed a community resilience assessment method that incorporates both the use of generic resilience indicators and community participatory workshops. Community resilience is assessed using a comprehensive set of indicators, with data captured through 50 interviews with key community members. A community portrait is created from that assessment and then tested and refined in community planning workshops, where the community also determine what their priority risks are. The method ensures that robust indicators are used but that they are specific to the community (CCCR 2000). For the reasons outlined above, the research in this report adoped a contextual, bottom-up approach involving active multiscale stakeholder enagement.

3.1 Research methods

The research was conducted over a period of fourteen-months (Table 4). There was a 3-month delay to the original 1-year timeframe, owing to the unexpected departure of Dr Sue Peoples (AgResearch) during the intital stage of the project.

Table 4: Research strategy and time line

Project stage	Time	Purpose and activities
Project planning	April 2014-May 2014	Review literature
		Establish research links
Fieldwork preparation	June 2014-July 2014	Scoping visit to study area
		Establish contacts within community
		Prepare for fieldwork and data collection phases
		Design questionnaire
		Prepare and submit M1 report
Farmer interviews	August 2014-October 2014	Develop network of interviewees through purposive snowball sampling
		Semi-structured interviews (n = 17)
		Refine interview strategy
		Prepare and submit M2 report
Analysis	November 2014-January 2015	Transcribe interview data
		Code and analyse using QSR NVivo 10
		Review existing sustainability indicators
Stakeholder Workshops	February 2015-April 2015	Resilience workshops with stakeholders (n=3)
		Review and evaluate indicators
Final Reporting	May 2015-June 2015	Economic and farm systems modelling
		Prepare and submit final report

3.2 Research methods and objectives

Three main methods were used for data collection: (1) critical document review, including a literature review of previous studies on resilience and vulnerability, and analysis of existing indicators-based frameworks for agricultural, primary-sector and/or farm sustainability; (2) interviews and workshops with primary sector practitioners and other stakeholders; and (3) economic modelling using proposed indicators to develop narratives of likely responses to climate change impacts and implications. The selection of methods is consistent with other studies on socio-ecological resilience, agricultural research and adaptation to climate change, which emphasise the need for empirically grounded, place- and/or sector-specific analysis with the participation of affected stakeholders (van Aalst et al., 2008; Claessens et al., 2012; Tschakert, 2012; Hammond et al., 2013; Bardsley and Bardsley, 2014). The research methods and the overall objectives of the research are summarised in Table 5.

Table 5: Research methods as they relate to the research objectives

Objective	Methods
1. Characterise the resilience of sheep and beef land management systems, by obtaining insight into elements of resistance, latitude, and precariousness as they relate to climate change.	• Analysis of relevant literature to develop conceptual framework for study. • Develop a semi-structured interview format for a range of agricultural producers representing different farm types and geographical locations. • Semi-structured interviews with range of producers to determine current exposure sensitivity (climatic and non-climatic risks) and adaptive capacity.
2. Identify suitable surrogates and indicators that might be used to help characterise movement towards or away from system-critical thresholds within land management systems.	• Review of existing sustainability frameworks to identify potential indicators for linking to resilience surrogates. • Characterise resistance, latitude and precariousness and identify surrogates able to describe the stability of regional farming landscapes. • Workshops with primary producers and other stakeholders (agribusiness, research and consulting, government) in Hawke's Bay, Northland and Canterbury to determine climatic risks, decision making influences, timeframes, and barriers to adaptation, and to obtain feedback on proposed indicators. • Discussion and review of proposed indicators with stakeholders to determine suitability and value for on-farm decision making.
3. Apply the indicators through economic and farm-systems modelling to determine their suitability for informing on-farm decision-making and monitoring under anticipated changes in climatic conditions.	• Economic and farm systems modelling using scenarios of future climate change to demonstrate the value of proposed indicators and further assess their suitability. • Produce case study narratives that describe likely changes in farm operations under differing climate change scenarios, and anticipated impacts for management and production. • Assess resilience on the basis of current dimensions; compare with scenarios of changes in climatic conditions; insights from stakeholders regarding their views on climate change, potential risks and opportunities.

3.2.1 Objective 1: Resilience characteristics

We used an iterative process of exchange and collaboration with key informants, including stakeholders working in the agricultural sector, farmers, and representatives from local, regional and district-level government bodies. Data was collected using semi-structured interviews, stakeholder workshops, and an analysis of secondary sources. Our approach was underpinned by our understanding of the stability landscape model (Walker et al., 2004), and was epistemologically sympathetic to Robert Chambers' Rapid Rural Appraisal (Chambers 1983; Berardi, 2002). Our approach was also based on a close reading of the literature and a review of methods used elsewhere (Campbell and Beckford, 2009; Westerhoff and Smit, 2009; Sovacool, 2012; Vachon et al., 2013; Calgaro et al., 2014; Keskitalo et al., 2014).

Interviews

A total of seventeen interviews and three workshops provided the initial empirical basis for the study. Farmers were invited to participate in a semi-structured interview to provide information on the range of exposure sensitivities and adaptive capacities employed in the regional farming system.

Following Bernard (2005) and Bradshaw and Stratford (2005), purposeful snowball sampling methods were used to obtain an illustrative sample of size and spatial distribution of farms. A diverse selection of farmers (in terms of farm size, years in operation and age) in different locations were engaged. No incentives were used to engage participants; researchers relied on the participants' goodwill and interest. All initial contacts were made by telephone. In cases where an individual was busy, a message was left, or a repeat phone call was made several weeks later to follow up.

Farms were sampled over a wide geographic area, to ensure a diversity of farms with differing soil, climate, topography and other biophysical characteristics. The first round of fieldwork focused on Canterbury and Otago (South Island); and Hawke's Bay and Bay of Plenty on the North Island (Table 6).

Table 6: Approximate geographic distribution of farmers interviewed (n = 17)

Farm Type	Location	Number of farms
Extensive, High Country	Central Otago, N Canterbury	5
Extensive, Lowland	Hawke's Bay	3
Intensive, High Country	N Canterbury, Central Otago	4
Intensive, Lowland	Bay of Plenty	4
		17

Interviews were semi-structured and lasted just over an hour, on average. Interviews were conducted over coffee at the home or a small meal. Questions were developed in advance based on a close reading of previous work on agricultural risks, climate change, vulnerability and resilience (Smit and Skinner, 2002; Vásquez-León et al., 2003; Ziervogel et al., 2006; Hammond et al., 2014). An advantage of the semi-structured format was that it provided the flexibility to develop questions, pursue comments, and develop ideas as the conversation progressed (Dunn 2005). The generic nature of the interview format also allowed the interviewer to ask questions specific to particular farms, farmers, or management systems.

The interview was designed to identify the multiple climatic stressors to which producers are exposed and/or sensitive, as well as to establish the broader context in which production takes place. Questions sought input on a range of topics related to climatic risks, as well as other relevant non-climatic stressors (e.g. market risk, institutional risk, risk of personal injury, etc.). Interviewees were asked first about the general features of the farm (size, location, soil types, length of time in operation), and then about their experiences over the last ten years, and prospects for the future, including their characterisation of past good or bad years, and the farm management practices used in response. In several instances, farm owner-operators had grown up in the area or on the same property and taken over the business. In these cases, longer time periods were discussed. Conditions identified in good years were considered opportunities and those identified in bad years as risks (Belliveau et al., 2006; Faysse et al., 2012; Hammond et al., 2013; Mapfumo et al., 2013).

To minimise bias, producers were asked about all possible conditions that affected them, with a focus on those related to weather. This also provided a sense of where climate risks and climate change fitted into producers' multi-risk decision-making environment (Darnhofer et al., 2010a; Bardsley and Bardsley, 2014).

Twenty farmers were contacted; three declined because of scheduling conflicts or workload. Interviewees readily suggested other farmers that might be willing to participate. All participants were asked for permission to use a digital recording device during the interview. The advantage of using the recorder was that it enabled a more conversational and flexible interview style, as well as providing an important record (Dunn 2005). Following the interview, a brief summary was immediately written up.

Audio recordings were transcribed verbatim, yielding nearly 100 pages of transcript. Copies of individual transcripts were emailed to participants with an invitation to add additional comment or clarification if needed. Interviews were formatted and loaded into a qualitative data analysis software package (QSR NVivo 10) for analysis. The software was used mainly as an organisational tool, given the volume of transcription.

Interview data was coded and analysed by widely used methods outlined in Corbin and Strauss (2008). Data was scanned to identify common or recurring themes or processes related to the central components of latitude, resistance and precariousness and coded accordingly using QSR NVivo 10.

Transcription and repeated readings of transcripts ensured a high degree of familiarity with the data. Text was highlighted first using markers, and notes made in order to develop themes of resilience. For example, those climatic conditions which had an adverse influence on farming activities (i.e. increased resistance) were coded and organised according to relevant variables (e.g. climatic*:* precipitation, temperature, variability, etc.). Factors that increased the latitude of the farm (e.g. increased production or yield) and aspects related to precariousness were coded in a similar fashion. The identification of themes and connections in interview transcripts was facilitated by the underlying structure of the questions asked (Kitchin and Tate 2000; Walker et al., 2004).

The use of questionnaires can limit the amount and type of information obtained (Valentine, 1997), and there were limitations to the methods used in this study. While the aim of the research was to draw qualitative insights into resilience to identify suitable indicators, additional quantitative data may have been useful. Economic data in particular (e.g. costs associated with management systems or fertilizer inputs), as well as standard demographic information (e.g. age of farmer), might have helped to provide the basis for an analysis of correlations between different farm types. We also were constrained by the breadth of variation in drystock farms, which included extensive as well as intensive properties, and high country and lowland systems.

Workshops

Workshops provided an additional source of qualitative data. Three workshops were held in different regions between March and April, 2015 on both the North and South Islands. Workshop participants were recruited by the researchers. North Island meetings were held in Kerikeri, Northland, which is focused on intensive hill country farming, predominantly of beef cattle, and which has experienced a range of climatic hazard events in recent years; and Waipukurau, Central Hawkes Bay, which is focused on extensive sheep and beef operations. Two South Island workshops were originally scheduled. The first was in Oamaru, which drew participants from North Otago and South Canterbury. A second workshop was originally planned for Cheviot, North Canterbury;however, at the time we were conducting fieldwork, North Canterbury was experiencing an unprecedented drought and farmers were already faced with with high stress levels, and barely coping. We decided that to ask them to attend a workshop on farm resilience would not be appropriate and we were unable to organise a replacement workshop at short notice.

Farmers from each of the study sites experienced different threats and were selected based on size and type of operation and years of experience in farming to achieve the greatest possible range of perspectives. One-third of the participants had greater than twenty years' experience farming, and many of these had taken over an intergenerational family farm. One-sixth of the participants had between five and twenty years' experience. The emphasis on selecting from a range of farming experience allowed for better exploration of adaptive capacity, resulting not only from wisdom gained through practical experience, but also rapid and successful innovation resulting from knowledge from a variety of sources (Hudson, 2010; Nelson et al., 2010; Schwartz and Sharpe, 2006). One common threat farmers face in all three areas is vulnerability to climate change impacts. Northland is vulnerable to flooding and increasing pests; Central Hawkes Bay also has pest problems, as well as drought stress; and North Otago is vulnerable to drought as well as extremes of cold, and unseasonal snowfall events.

Preliminary participant lists were generated after consultation with farm agencies and organisations, as well as existing research networks. Agencies consulted were Federated Farmers, Landcare Trust, the network of Rural Support Trusts and Beef + Lamb New Zealand. Local and regional governments were also represented at all three workshops. Participation was solicited via email/internet contact and phone calls. A total of 24 farmers participated in the three workshops, allowing for concerted small-group discussion. The total number of participants reflected a significant commitment of time in a population that rarely takes time away from work. In studies similarly examining stakeholder perspectives on a particular issue, the total number of participants was comparable to or less than that of the present study (McCrum et al., 2009; Baird et al., 2014b). For example, Atwell et al. (2010) examined tradeoffs between ecosystem services and food and energy production through a participatory workshop and follow-up interviews with 14 leaders working in the Iowa agricultural sector.

Approximately two-thirds of the workshop participants were sheep and/or beef farmers, the remainder involved in local and regional government, industry or rural support services. Workshops were facilitated by the principal investigator and co-investigator, and audiovisually recorded. Both researchers also observed and took notes. Recordings were later professionally transcribed in full for analysis and interpretation.

Each workshop followed the same format. Researchers introduced the concept of resilience and discussed two case studies of farm and food vulnerabilities: 1) threats arising from salt water intrusion in the Goldburn-Broken Catchment (Walker and Salt, 2006), and 2) Hurricane Katrina impacts on gulf aquaculture (Buck, 2005) and Midwestern farming (Walker, 2005; Commodity Credit Corporation, 2006). In both examples, extreme events had weakened or permanently altered farms and agricultural communities. The case studies presented human- and naturally-induced threats, as well as slow- and rapid-onset events.

The participants were then introduced to the analytical framework and the stability landscape model: resistance, latitude, and precariousness. Depending on the size of the workshop, participants were divided into small groups of three to six participants or remained as a small group. In discussions, participants were asked to consider the characteristics of the region with respect to risks and exposures (resistance); opportunities and strategies for adaptation (latitude); and any significant social, economic, or ecological thresholds (precariousness). Each participant received a set of discussion prompts concerning challenges, needs, resources, and long-term impacts likely to affect adaptation, as well as resilience concept notes. Participants were encouraged to discuss resilience from their perspective, thus situating their farm system within the larger sector.

Each workshop concluded with a full group discussion of the commonalities between regions, especially ways in which farm vulnerabilities or adaptive capacity characteristics were similar across different contexts. The workshops lasted approximately six hours, and included lunch for the participants.

3.2.3 Objective 2: Surrogates and indicators for resilience

Objective 2 was to identify suitable surrogates and then indicators that might be used to help characterise movement towards or away from system-critical thresholds within sheep and beef land management systems. It drew on on the data collected in the interviews and workshops, as well as exisiting sustainability and monitoring and evaluation frameworks, and a review of the literature.

The following steps were followed to develop a short list of indicators:

1. Literature on indicators-based monitoring and evaluation frameworks was reviewed for relevance to New Zealand sheep and beef farming;
2. A framework was selected to group similar indicators together;
3. A shortlist of climate sensitive indicators was produced;
4. Indicators were compared with resilience surrogates for resistance, latitude and precariousness;
5. Indicators were workshopped with farmers and industry representatives and final suite of indicators was identified.

Literature review of indicators and surrogates

Resilience metrics are critically underdeveloped (Bennett et al., 2005; Carpenter et al., 2005; Cumming et al., 2005; Dakos et al., 2015). This is particularly true for research on agriculture and farming systems (Darnhofer et al., 2010b; Hinkel, 2011; Bélanger et al., 2012). The abstract and multi-dimensional nature of resilience makes it difficult to operationalise

(Cumming et al., 2005). Nevertheless, there have been various attempts to do so (Büchs, 2003; Gómez-Limón and Sanchez-Fernandez, 2010; Vári et al., 2013; Dakos et al., 2015).

Among the challenges to developing resilience metrics is its dependence on spatial and temporal context. New Zealand sheep and beef farms are very diverse in their farm systems, topography and climates. A system that is considered resilient today may not be considered so in 20 years, or in a few years, because the farm system or market conditions that it is embedded can and will change (Burton and Peoples, 2014). Change can happen suddenly (Holling 2001), as currently experienced in some regions in New Zealand that are undergoing land use change, production intensification, new irrigation development, increased frequency of droughts and floods, nutrient caps and increased environmental regulation (Barnett and Pauling, 2005). Compounding the difficulty is the fact that resilience in the short term may paradoxically reduce a system's resilience in the long term. Farming systems can become stuck in a cycle of environmental degradation that is resistant to transformation into a more positive configuration. In contrast, apparent instability today might build greater resilience for the future (Carpenter et al., 2001). "By its nature and because of our own limitations of comprehension, resilience defies measurement" (Cabell and Oelofse, 2012). Finally, a farm system is very dependent on the farmers' decisions and actions and not all farmers respond the same way to challenges, opportunities and risks (Leslie and McCabe, 2013). Often the difference between the best farmers and the average farmers is the ability to make good management decisions at the right time. This is difficult to measure.

While there are few examples of indicators for resilience, there are a number of existing frameworks to assess various aspects of farm sustainability, some of which may have some bearing on resilience (Darnhofer et al., 2010b; Bélanger et al., 2012; Kassie et al., 2013). Based on the review of relevant literature, we developed a list of indicators and surrogates, which, when identified in a farm system, suggested that it was resilient and endowed with the capacity for adaptation and transformation.

The first step in this objective, was to assess indicators currently used in Australia and New Zealand agriculture. A number of New Zealand farming organisations have developed a range of indicators to benchmark farmer performance. Indicators can be divided into three types: performance (e.g. key performance indicators or KPIs), practice (i.e. best practice), and context indicators (i.e. components of benchmarking or standards).

The selection of indicators was refined based on several criteria including: locally grounded, relevant to the New Zealand context, useful, and affordable for application in the sheep and beef sector. There are few examples of indicators developed for climate change in New Zealand and so the review was widened to include international research and examples of best practice from elsewhere.

Framework for grouping indicators

A wide range of indicators and their surrogates are used by various agricultural organisations to benchmark farmers and businesses. Triple bottom-line reporting (i.e. reporting on economic, environmental and social performance) is widely used in the commercial sector; however in New Zealand, most performance metrics – particularly for sheep and beef – have an economic or production focus. Beef+LambNZ have indicated that they are considering adding environmental and social indicators to their economic survey work (van Reenen, *personal communication*). Beef+LambNZ have also been actively encouraging their farmer levy payers to develop Land and Environment Plans (LEP) and in Canterbury, Farm

Environment Plans (FEP) that increase farmer awareness of environmental risk and include some simple indicators.

The Global Reporting Initiative (GRI) is the dominant tool used globally by business organisations and companies to report on their sustainability performance. GRI does provide some useful guidelines for reporting; however, Saunders et al. (2006a: 2) suggest that agribusinesses are different from other businesses because 1) they have a biological basis and hence are dependent on the 'natural environment and climate, and seasonality of production', 2) sheep and beef farms tend to be based around families and family labour, and 3) the sheep and beef sector is not homogeneous, with a wide range of farm systems, scale, regional and geographic differences.

Given the complexity of agricultural systems, it is important to use a structured framework to develop indicators. A framework provides a systemic approach by demonstrating links or relationships between the indicators. There are a number of international agricultural sustainability frameworks. The four frameworks we evaluated were:

- Sustainability Assessment of Food and Agriculture systems (SAFA)
- The Response-Inducing Sustainability Evaluation (RISE) tool
- The New Zealand Sustainability Dashboard
- The Prairie Climate Resilience Project

Selection criteria for indicator shortlist

A long list of indicators was identified based on the review, and then refined to include only those that would be considered climate sensitive; either to a change in climate or extreme weather events. Indicators were then compared with the surrogates for resistance, latitude and precariousness, in order to determine their correlation (in a qualitative sense) with resilience.

In addition, all indicators selected had to be:

- Understood by nearly all farmers;
- Measureable and time bound; and
- Using data that was readily available and affordable.

3.2.3 Objective 3: Empirical application and evaluation

Objective 3 was to apply the indicators to assess the insights to future change they provided. Economic modelling was used to determine the extent to which selected indicators could provide insight into future climate change impacts and potential responses.

Data was obtained from the Climate Cloud website[1] for pasture production in Northland, Hawkes Bay and Canterbury for the period 1980–1999 (taken to represent the present

[1] www.climatecloud.co.nz

situation) and under the influence of predicted climate change parameters for the period 2039–2049 (taken to represent the future climate change scenario).

A quantitative farm economic model, driven by feed production, was then constructed. This model was connected to a MS Excel add-on called @Risk, which determined the probable outcomes from a range of variable inputs that result from variable feed production and product price.

3.4 Ethics

Research was conducted in an ethical manner, seeking appropriate permissions, and respecting respondents' rights and opinions. Before all interviews and workshops participants were asked for permission to use a digital recorder. Participants were assured that no actual names would be used and that they would receive a copy of their transcript and/or summary of workshop findings. Current contact information was exchanged. During all interactions, researchers sought to maintain an open, non-judgemental approach to encourage participants to express themselves fully and respect their rights to express their own opinions (Mullings 1999; Dunn 2005).

3.5 Seasonality and research

While no single extreme event can be directly correlated to climate change, perceptions of the relative importance of climate-related exposures may be influenced by a particular season or climatic event (Vedwan and Rhoades, 2001; Meze-Hausken, 2004; Thomas et al., 2007; Battaglini et al., 2008). For example, pronounced interannual variability or extremes can influence producers' perceptions of rainfall change (Meze-Hausken, 2004; Deressa et al., 2011). The conceptual framework accounts for this, by recognising the dynamic nature of resilience and its characteristics. Resistance, latitude and precariousness vary spatially and temporally (Turner et al., 2003; Adger, 2006; Füssel, 2007; Wilbanks and Kates, 2010).

It should therefore be noted that the research findings may have been influenced by seasonality. Following on from record temperatures in the 2013/2014 summer (Harrington et al., 2014), much of the country again experienced severe summer drought conditions, affecting sheep and beef farmers in the regions studied. Producers therefore may have been more aware of climatic conditions, risks and potential impacts of climate change.

3.6 Triangulation

An important criterion for determining the rigour of qualitative research is triangulation (Baxter and Eyles, 1997) (Figure 6). Based on convergence, triangulation suggests that when multiple sources provide similar findings their credibility is considerably strengthened (Knafl and Breitmeyer, 1989; Krefting, 1990). The transcripts from interviews and farmer workshops showed a high level of agreement with respect to major risks, adaptation responses and key indicators, despite being conducted with different types of stakeholder (farmers, consultants, researchers, and policy- and planning-staff), in different modes, and in different locations. The semi-structured interview format, in combination with the facilitated workshop mode, achieved the goals of data collection and can therefore be considered methodologically appropriate (Elliott 1999).

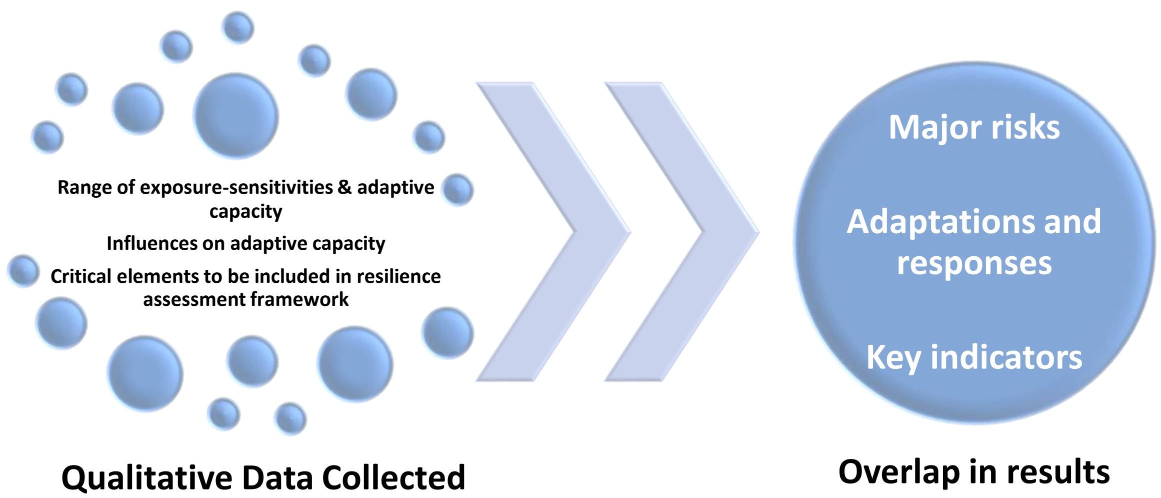


Figure 6: The triangulation process provided the basis for identifying key indicators, which can deliver insight into farm-level resilience, and support decision making under changing climatic conditions.

4 Resistance, Latitude and Precariousness

The first objective was to characterise the resilience of sheep and beef farms, drawing on insights from resilience thinking. The stability landscape model (Walker et al., 2004) was used to conceptualise and frame the analysis, and is used here to present findings. The first step in the analysis was to clarify the resilience 'of what, to what' (Carpenter et al., 2001), or the so-called 'specified resilience', as opposed to a broader resilience of the system as a whole (Walker et al., 2009). This step involves understanding the context of a farm, or farming systems in a region, and in particular, its subsystems. While reductionist to some extent, the disaggregation of the sheep and beef SES into subsystems, key units and processes is an important step towards understanding the resilience of the whole system. This approach is in line with an analysis (Walker et al., 2009) of social subsystems in the Goulburn-Broken Catchment, Australia.

The evaluation of the resilience of individual farms and their subsystems focused on three dimensions in relation to stakeholder-defined thresholds. Walker et al. (2004: 7) describe these in the following terms:

> *Social–ecological systems can be close to, or far away from, important thresholds (Pr). They can be easy or hard to change (R). The range of dynamics that can be accommodated while still retaining basically the same system can be large, or small (L).*

Findings from interviews with 17 sheep and beef farmers are presented, organised according to the conceptual and analytical resilience framework. Additional insights into the three dimensions of resilience – resistance (R), latitude (L) and precariousness (Pr) – were also obtained through stakeholder workshops, and are included in the discussion.

4.1 Understanding Resistance

Resistance relates to the 'depth of the basin' (refer to Figure 2), indicating the level of perturbation required to change the current state of the system. Producers identified the greatest sensitivity to climatic conditions that affect production and yield, and in turn, farm income. Climatic conditions to which producers are sensitive vary from farm to farm. Producers also reported sensitivity to a much broader range of climatic variables than average temperature and precipitation (the most widely modelled climatic conditions in typical scenario-based studies), in particular, to climatic variability and extremes. Producers also identified rising input costs and poor returns as factors that influence their resilience. These non-climatic pressures act independently, but can also increase sensitivity to climatic conditions. Stressors function synergistically to influence producers' overall resilience.

Without prompting, farmers most frequently identified climatic conditions (usually referred to as 'weather') as the greatest source of exposure for operations. Regardless of farm type, size or location, climatic conditions were seen as being integral to the long- and short-term success of their business. The main climatic exposures identified by producers were combinations of temperature and precipitation, and current climatic variability and extremes, including unseasonal snow events, drought and flood. Selected examples of climate-related stressors and farm-level impacts are shown in Table 7.

Table 7: Climatic conditions and related effects identified by producers

Weather	Farm-level impacts
Good weather (warm, timely precipitation)	Improved pasture growth and production
Excessive precipitation	Pugging
Drought conditions	Pasture growth slowed, halted
Cold, wet spring/Late spring	Animal reproduction
	Delayed grass growth in spring
High summer temperatures	Adverse effects on animal health (diet, reproduction, heat stress)
Flood conditions	Animal reproduction and mortality
	Halts/slows production
	Damage to farm infrastructure
Frost	Knocks back unwanted C4 grasses
	Lambing mortality
	Pasture slow to start growing in spring
Snow	Lambing mortality
Strong winds	Dries out pasture quickly

Combinations of temperature and precipitation were most frequently referred to by producers. For drystock farmers reliant on grass growth, warm temperatures with adequate precipitation are critical. In response to the question 'What makes a good season?' typical responses were: 'Lots of rain and sunshine. It's the climate that grows grass', and , 'A good season would be regular rain'. For these producers reliant on pasture, sufficient rainfall and warm temperatures are the basis of production (Verkerk, 2003; Morris, 2009). Drystock farms typically rely on natural grass growth and do not have irrigation to supplement natural rainfall.

Producers identified a greater sensitivity to changes in precipitation, than to changes in temperature. A decrease in precipitation is associated with a range of exposures including poor grass growth and certain pests, while excess precipitation can create problems with landslips on steeper terrain, floods, increased diseases and pests, and pugging, all of which have an adverse effect on production.

Extremes of cold and heat can represent both a risk and an opportunity for producers. Where invasive, temperate C4 grasses, such as paspalum and kikuyu, are problematic, cold winter temperatures can slow or halt their spread as certain *Paspalum* species are killed by winter frosts (Rumball, 1991; Radhakrishnan et al,. 2006; Crush and Rowarth, 2007). Where these grasses were less problematic, cold temperatures can be a negative influence, delaying spring growth. As one producer stated: ‘The cold just restricts your grass growth, winter obviously – if you get a cold winter, then it really knocks the grass back, frost after frost after frost. And you just have to wait for the warmer weather to get going again.’ High summer temperatures were cited as having negative effects on animal health and welfare, including heat stress, reduced diet and reduced reproduction.

In addition to combinations of temperature and precipitation, producers also described floods and droughts (extremes of both temperature and precipitation) as being serious climate-related exposures to which they were sensitive. The most severe impacts of flooding were animal mortality, direct impacts on animal health and physical damage to the farm, including erosion, and sometimes damage to farm infrastructure such as fences.

Drought conditions in New Zealand are typically related to ENSO/IPO (Rolland, 2002; Griffiths et al., 2003; Fowler and Adams, 2004; Ummenhofer and England, 2007), although there is growing evidence for anthropogenic influence on the most recent drought events (Harrington et al., 2014). Nearly all farmers interviewed described drought as a serious exposure for farm production. All had experienced dry conditions, though the dry periods that have marked recent seasons were often described as ‘exceptional’, ‘not normal’ and ‘unusual’ in their severity and duration. As one farmer described it:

> *Normally it starts getting dry after Christmas and you might have three months of fairly hot and dry, but then it will rain in April, and as long as all your lambs are gone, it doesn’t really matter, you get by, because you're not – your numbers of priority stock are low, so yeah, we think we’ve got the thing set up to cope with that scenario fairly well, but when you double that dry period – never had that before, this (2014/15) was exceptional, the drought covered the whole country.*

Drought conditions slow or halt grass growth; producers are also vulnerable to much higher input costs. Intensification in the dairy industry, which is also adversely affected during dry spells, can accelerate competition for supplemental feed and the carry-on effect of a prolonged dry spell can be much longer, further delaying recovery.

> *A flood can be up to there today and gone tomorrow, but a drought might last for two months. And you’re going to recover from the flood, generally the recovery is not too bad, from the average flood, but a drought can take a bit longer.*

The same farmer noted that in ‘normal’ drought conditions, it might be regional and so farmers are able to send out for grazing elsewhere, as part of a typical adaptive strategy. However, when the drought covers the whole country and no one has any grass, the ‘usual’ response is severely constrained.

A number of producers commented on an apparent trend towards more frequent and severe dry spells, and expressed concern about being able to handle severe droughts. Producers also noted that a drought was a source of exposure that was felt not only as a climatic or financial risk. As one farmer said, "'It's a lot of stress, walking the farm, wondering if another blade of grass is ever going to grow again."'

Seasonal to interannual climate fluctuations strongly affect the success of agriculture. Wratt and Matthews (1992) estimated year-to-year climatic variability is responsible for about NZ$600m in losses in New Zealand's agricultural production. Using a structured VAR business cycle model, Buckle et al. (2007) demonstrated a statistical relationship between soil moisture and GDP and exports in New Zealand. The dynamic relationship shown by the authors clearly implies that adverse climatic conditions will generate a recession. A rise in the number of days of soil moisture deficit results in an immediate and significant fall in domestic output that is sustained for nearly two years (Buckle et al., 2007:1007). Long-term climate change is likely to alter agricultural productivity in New Zealand (Clark et al., 2012; Kalaugher et al., 2013; Manning et al., 2014).

Climatic variability, independent of climate change, represents another source of risk and/or opportunity for producers and stakeholders. Lambing dates, for example, may be based on experience with a long-term mean. A lack of predictability or increased variability in weather patterns can make planning and strategic forecasting more difficult, and may ultimately require adjusting management decisions

In addition to direct risks, climatic conditions also represent an indirect source of risk for farmers and growers. Warmer conditions are favourable for the spread of tropical non-native grasses such as such as paspalum, johnsongrass *(Sorghum halepense)* and kikuyu. These non-native and non-commercial grass species have low nutritional value (Prestidge and Potter, 1990; Crush and Rowarth, 2007), reduce overall production and yield (Clark et al., 2011) and result in additional cost for producers to manage or eradicate these pests. Kikuyu, a tropical grass (Radhakrishnan et al., 2006), is increasingly prevalent in eastern regions, where it has spread after being introduced to Northland, where it flourished in the dry temperatures (Ballinger, 1962; Askew, 1965). Several farmers expressed concern that with the trend towards warmer and drier conditions, it would be an ever-increasing source of risk.

Facial eczema is also a serious climate-related exposure. The disease, which affects sheep and cattle, occurs during the late summer and autumn, and flourishes under warm, humid conditions, producing severe toxic effects in the liver of the animals. Loss of production and animal mortality are common. With the intensification of farming, and higher stocking rates, there is the potential for greater numbers of stock to be more exposed to outbreaks.

4.2 Understanding Latitude

To some extent, latitude is synonymous with adaptive capacity and adaptation. In the climate change literature, adaptation is used to describe 'adjustment in natural or human systems in response to actual or expected climatic stimuli or their effects' (Parry et al., 2007). Adaptation can be reactionary or anticipatory (Fankhauser et al., 1999; Smit et al., 2000). Successful adaptation is not inevitable (Engle, 2011), but is is a function of a system's adaptive capacity (Füssel and Klein, 2006). Adaptation as a property of any given system describes the ability to manage current or anticipated stresses or exposure, by utilising available resources. Adaptation influences the ultimate potential for implementing sustainable adaptation to climate change (Wall and Smit, 2005; Wilbanks, 2007). Adaptive capacity varies between systems and it is not equally distributed (Adger et al., 2007). Therefore, it is important to identify what enhances adaptive capacity and what prevents or limits adaptation (Adger et al., 2009; Moser and Ekstrom, 2010).

It is important to note also, that adaptive capacity is understood to be a component of resilience, and has the potential to link different assessment frameworks (Zhou et al., 2009; Adger and Brown, 2009; Nelson et al., 2010; Engle, 2011). In some resilience literature, adaptive capacity describes the capacity of actors in a socio-ecological system to enhance interaction between human and biophysical components of the system (Walker et al., 2004; Walker et al., 2006). The greater the adaptive capacity of a system, the more resilient it is to stress. The term is also used in reference to the ability of a system to transform or change state, following a disturbance. The more adaptable the system is, the more successful the transition to a new state is likely to be following a disturbance (Robards et al., 2011).

Analysing the adaptive responses of agricultural producers enables an understanding of the latitude of sheep and beef land management systems. By identifying the broad drivers of latitude, additional insight into the most suitable surrogates and indicators can be developed.

Producers identified a range of adaptive responses to climatic conditions. These ranged from short-term tactical responses to adverse growing conditions or a single flood event, to longer-term strategies for overcoming the limitations of the climate. Latitude is a function of several determinants, including the availability of financial resources, technology, and government policies. The producers' adaptive responses were affected by factors relating to farm operations and market or business operations at the farm level. Social and demographic factors – such as the age of the farmer, or social- and peer-networks – also had an influence on latitude. These factors are highly inter-related.

Farm operations

> *How do you manage a dry year? Self-preservation. It's total grief of trying to find grass, go and chop trees down, fence off bits. It's just a matter of hunt for feed. It's just a matter of farming.*

Pastoral farmers have developed a range of short- and long-term strategies for coping with soil moisture deficits. Supply and demand provides the basis for most adaptive strategies to drought according to interviewees. While they are not mutually exclusive, adaptations to drought can be broadly classified as either those that seek to ensure an adequate food supply or those that involve reducing demand to better match available feed.

The most common strategies were to match existing or available feed supply with demand (Table 8, overleaf). Producers reduced demand by lowering stocking rates, or shifting lambing dates to earlier in the season when grass growth is more reliable. Farmers also described adjustments in pasture management, using a longer rotation to allow animals to graze longer in each paddock, giving the remaining paddocks time to recover.

For most dry stock farmers, supplemental feed is prohibitively expensive and in many cases the only available strategy is to lower stocking rates. As one farmer put it:

> *Getting rid of all your priority stock, because if you've got stock that have to grow to give you a return, and you're not growing them, you've got to question why you've got them… It's just about recognizing how much feed you're likely to grow, what the quality*

of that feed is and matching it to the stock you've got, it's pretty simple really. Old story: you don't have a drought if you don't have any stock. We don't have a drought if we don't have any stock.

A small number of farmers described purchasing supplemental feed to make up for shortfalls of grass. This can be a short-term response, with farmers purchasing feed as needed, or part of a longer-term strategy, involving forward contracts or changing farm management practices. Purchasing supplemental feed is constrained both by farm income and the availability of feed. Recent droughts have been far more extensive than in previous years, often covering most or all the North Island (MAF, 2010), compounding feed shortages.

Table 8: Latitude with regard to managing drought in NZ pastoral farming systems

Ensure adequate supply of feed	Purchase supplemental feed (spot market)
	Purchase supplemental feed (6-12 month forward contract)
	Stored supplements
	Install irrigation system
	Switch on irrigation
	Plant fast growing fodder crop (e.g. Turnips)
	Switch to drought-tolerant grass species (e.g. lucerne)
	Shift from grass-based system to high-input system
	Purchase runoff
	Plant trees for fodder
	Replant, drought tolerant cultivar
Match feed supply with demand	Shift to a longer round (pasture management)
	Drop stock numbers
	Have proportion of animals ready for market
	Deferred grazing
	Earlier lambing/calving
	Run lower stocking rates
	Monitor grass growth
Other strategies	Improve soil quality
	Monitor soil nutrient levels
	Lease farm to someone else
	Diversify income streams

Recently recurring drought years, and the limitations of existing strategies has prompted some to look at longer-term, strategic anticipatory responses, including irrigation. Irrigation reduces exposure-sensitivity to dry periods but has other advantages as well. Exposure-sensitivity to climatic conditions is reduced by ensuring sufficient grass growth during dry periods (overcoming the limitations of climatic conditions), and in turn enables continued or increased production (overcoming market and financial risks). Increased production improves cash flow and permits expansion, or investment into the farm can enhance Latitude.

There are limitations to irrigation as a response to climatic extremes, including capital costs, as well as questions surrounding long-term sustainability, with growing pressure on existing water resources. Irrigation as a strategy for increasing Latitude also highlights the close interrelationship between climate, market forces and responses. The range of potential adaptive strategies producers' might adopt is strongly influenced by farm income (which in turn is influenced by climatic conditions, markets, and other stimuli) or an individuals' access to capital (Smit and Skinner 2002). Market forces can be a barrier to adaptation, limiting producers' capacity to respond.

Other adaptive strategies that were mentioned included planting fodder crops. In response to two dry years in a row, one farmer reported planting a fast-growing crop of turnips each season; others used trees as an emergency food source. Farmers had also changed cultivars in response to recent droughts, in one instance re-grassing affected portions of the farm with a hardier rye-grass that might better withstand drought conditions in the future. "It's not the best growing grass, but it's probably one of the toughest. We chose it based all on what we could grow on those dry areas". The neighbouring farm, similarly exposed to dry conditions, had experimented with growing more lucerne.

Finally, for those with the available capital – or access to it – purchasing or leasing a runoff in a 'summer safe' area, is another long-term adaptation to better manage drought, through secured access to an available food supply.

While the strategies above were used to deal with adverse conditions, producers also described opportunistic tactical responses to drought. By utilizing a higher stocking rate, some farmers maximized production before the dry conditions affected grass growth, and then simply lowered stock numbers to match pasture availability. Other farmers purchased supplemental feed at a higher cost, but this enabled them to maintain or even enhance stock condition. In this way, they sought to capitalise on an anticipated drop in stock going to the works, later in the season.

Most of the adaptive strategies for drought used by pastoral farmers are concurrent – i.e., they take place during exposure to the climatic risk – or post-risk. "Most of our responses are after the event really, rather than before", said one drystock farmer. Very few are anticipatory in nature. Often only in the middle of the drought are the climatic signals evident and why it is often referred to as a 'creeping' hazard (Glantz 1988; Hayes et al. 2004; Wisner et al. 2004; Smith and Petley 2009). This may be one reason why farmers identified very few anticipatory strategies. Producers did describe several strategies that differ from the responses described in their timing, for example noting that "the only one we could do before, which would be prudent I guess, would be having more feed on hand. Insure you a bit". Purchasing supplemental feed on a forward contract of several months, instead of on the spot market, also reduces exposure to market risks; highlighting the fact adaptation is often in response to more than climatic conditions alone.

Other anticipatory strategies include holding a percentage of stock that ready for sale if climatic conditions are detrimental. Producers also increased monitoring. "When you fall in a hole, you know you're in it; whereas with monitoring you tend to know you're going to fall in a hole – try and avoid the hole. It helps knowing". By closely monitoring soil fertility, not only is the farm better able to withstand dry conditions, but it also has reduced their exposure to a spike in input costs. "It's preventative... risk, all the things we do – whether it's fertilizer, our animal health is the same, the emphasis is on preventative care, it makes things a little bit more expensive along the way but the disasters are a lot fewer". Table 9 summarizes adaptive strategies to drought according to timing and duration of the response.

Table 9: Types of adaptations for managing drought (Source: Research findings)

Type of adaptation	Source of risk	Example of adaptation
Tactical, reactive	Drought	Purchase supplemental feed (spot market)
		Shift to a longer round (pasture management)
		Dry stock numbers
		Switch on irrigation
		"Grit teeth"
Tactical, anticipatory	Drought	Have % of animals ready for market
		Plant fast growing fodder crop (e.g. Turnips)
		Purchase supplemental feed (6-12 month forward contract)
		Deferred grazing
		Monitor grass growth
		Stored supplements
		Earlier lambing/earlier calving
Strategic, anticipatory	Drought	Install irrigation system
		Switch to drought-tolerant grass species (e.g. lucerne)
		Purchase runoff
		Run lower stocking rates
		Site selection
		Choice of cultivar
		Plant trees for fodder
		Earlier calving; earlier lambing
		Diversify income streams

Producers' ability to respond to these risks is closely related to market and financial forces, as well as the strictures of the Resource Management Act and local council regulations. For some, this has reduced their flexibility, making it more difficult to respond quickly. Other growers reported investing in long-term strategic adaptations, designed to reduce losses, and in some cases, also increase yield. As with other adaptive responses, motivations driving adaptations can be complicated as producers respond to multiple stressors or make opportunistic strategic adaptations to take advantage of opportunities at the same time as reducing exposure to climatic or market forces.

Producers and stakeholders have also developed strategies for responding effectively to pests, and several other exposures that affect a smaller range of producers than the ones already discussed. Pastoral farmers reported under-sowing rye grass, at great expense, a short-term strategy to control invasive grasses that may prove inadequate in the future, if present warming trends continue. Losses due to facial eczema have been sufficient for some producers to invest in a long-term adaptive response of breeding for resistance among sheep and cattle.

The other significant aspect of latitude is related to farm financial management. While producers did describe being exposed to market risks, there is a limited range of potential responses, suggesting that their capacity to adapt or respond effectively to these is much more constrained than for climate-related exposures.

Farm financial management

Farm financial management involves using farm income strategies to reduce the risk of climate-related income loss (Smit and Skinner, 2002). It can include decisions with respect to insurance, crop shares and futures, income stabilisation programs, and household income (Bryant et al., 2000; Wandel and Smit, 2000; Berg and Schmitz, 2008). Producers can also take advantage of market conditions, through opportunistic adaptive strategies to capitalise on favourable market conditions.

Poor returns – low meat or wool prices – have the biggest effect on latitude, because they often occur in conjunction with climatic risks. Returns are influenced by market conditions beyond farmers' control, including commodity prices and fluctuations in the value of the New Zealand dollar. Unlike weather-related exposures, for which producers have a range of adaptive strategies, farmers have little control over a financially poor year. An often described response to poor returns, was to stop spending or reduce inputs. 'We stop spending in the bad years', said one beef producer, 'and then in the good years play catch up'. Another drystock farmer echoed this statement, saying that in a bad financial year you simply 'cut your costs. If we thought it was going to be a low payout next year, we might cut our stock numbers so we didn't have to buy in so much feed'. Beyond reducing expenditures, little else was described by producers. Producers are able to weather poor returns by taking advantage of better returns in subsequent years.

There is also a close relationship between latitude and inputs. Inputs vary from farm to farm, and can include fertiliser inputs, supplementary feed, electricity and fuel costs, young stock and labour. In light of increasing variability in climate – including severe drought – and higher costs, several farmers described using forward contracts more than they had in the past as a way to increase their latitude. Forward contracts reduce the risk of purchasing inputs on the spot market, and can be considered a form of risk sharing (Wandel and Smit, 2000). As one farmer described his response for dealing with rising input costs for supplementary feed:

> *I think if you're forward thinking you can plan, and buy twelve months out. So we've actually purchased twenty hectares of grass silage from a maize grower. By forward managing that you get a better price, rather than "Oh hell we're getting a little low on feed", and you go out into the market and holy hell the price is gone through the roof. Do we buy it or don't we? It's very expensive, so we try and forward order.*

Other farmers described having a 'bit of supplement up [their] sleeves', rather than 'farming on a knife edge'. One dry stock farmer, whose main input is buying calves to rear, managed exposure to rising input costs by purchasing stock throughout the year, and from several different sources. This diversification not only shared the risk in terms of feed, but increased latitude through supplemental income, to offset climate-related losses.

Household income strategies have long been important adaptation options in agriculture. Such financial decisions may also represent a means of dealing with economic losses or risks associated with climate change. Diversification of income sources has been identified as an adaptation option, including off-farm employment and 'pluriactivity', which has the potential to reduce vulnerability to climate-related income loss (Brklacich et al., 1997; Smithers and Smit, 1997). The term pluriactivity is used by MacKinnon et al. (1991:59) to describe the phenomenon of 'farming in conjunction with other gainful activity whether on or off farm'. While activities such as agri-food tourism receive a lot of attention in both academic and popular circles, the most common and least glamorous pluriactivity is off-farm work.

Diversifying household incomes is unlikely to be undertaken directly in response to climatic perturbations alone (Le Heron et al., 1994; Bradshaw et al., 1998), but was described in interviews and workshops as a factor that enhanced respondents' latitude. When asked the difference between a good year and a bad year, one farmer simply said 'my wife working'. The extra income helped them to get through the years when production was particularly low.

Farmers have also used diversification of production as a way to increase latitude. For some, the motivation to diversify was strictly in response to market and financial pressures, while for others, a mix of climatic stressors and market forces. Changes have also been driven by intensification in the dairy industry. Dairy farmers have increasingly sought to free up the milking platform and so send calves and heifers to graze on neighbouring farms. Because many dry stock farms are located on a mixture of terrain, they are often well suited to supporting a variety of stock. Many drystock farms now include dairy grazers, as well as fewer sheep and more beef cattle. Farmers have also changed land uses. Such diversification reduces exposure to some climatic events, as well as provides some flexibility to take advantage of favourable market conditions.

> *Within my system I've built in really, a space around three corners – thirds of risk factors if you like. I've got three different enterprises and not very often is one, or the whole lot of them, down at one time, and history is proven that to be a fact – if you go back years, lamb might have been bad, but wool was good; beef cattle were bad but the dairy side of my business was good; when I was in bulls, the beef side of that was good, and dairying possibly, might not have been so good.*

In addition to running a varied range of stock on their farms, some dry stock farmers also described expanding into horticulture, planting kiwifruit on a section of the property; expanding into forestry; one drystock farmer had added a farm-stay that earned more in the year than raising lambs; and another farm started hosting enduro motorcycle events once a month to earn extra income from the property.

Producers' latitude can also be enhanced by making the most of opportunities. By taking advantage of premiums offered by supplying the shoulder season, producers can offset the climate risk, or minimise the danger of running out of feed later in the year, when supplies are short. For sheep and beef farmers, this means supplying different parts of the market at different times, taking advantage of the early sales, and setting themselves up for the following year's production. By taking advantage of such opportunities, producers are able to capitalize on production or payout, re-invest into the farm, and increase their ability to weather the next downturn or the next climatic extreme.

> *There's no insurance for drought, back in the days of subsidies, the government would have jumped in, and probably doubled our payout, or given us feed for cheap. Those days are gone. If we get a few droughts, it takes a lot of catching up from those.*

An important strategy for getting through the bad years then, is to have the odd good one.

4.3 Understanding Precariousness

The precariousness of a system denotes how close it is to a limit beyond which it is likely to move into a new state space. In other words, it describes how marginal a farm is under current and future conditions. The interviews and workshops highlighted that some farms are currently operating quite closely to their limits. Several farmers indicated that the current dry conditions are having a significant impact on their operations. With higher temperatures and lower rainfall projected for much of New Zealand under climate change, it is likely that in a number of regions, climatic conditions will move sheep and beef land management systems even closer to the edge (Table 10 and Table 11).

Table 10: Summary of climate change for eastern New Zealand (Clark et al. 2012)

Climate variable	Direction of change (* = confidence)	Magnitude of change
Mean temperature	Increase (****)	>0.9 °C by 2040 >2.1 °C by 2090
Mean rainfall	Annual decrease (**)	<5% by 2040 <6% by 2090
Extreme rainfall	Heavier and/or more frequent rainfalls (**)	High intensity rainfall with probability of 50-yr return >10% by 2040 >18% to 34% by 2090
Major drought	Increase in all areas that are currently prone to drought (***)	Major drought events with probability of 20-yr return >10% additional time spent in drought
Wind (average)	Increase in the annual mean component of wind flow across NZ (**)	Appx 10% increase in mean annual westerly flow
Strong winds	Increase in severe wind risk (**)	Up to 10% increase in strong winds (>10m/s) by 2090
Storms	More storminess possible (*)	-
Sea level	Increase (****)	At least 18-59 cm (1990-2100)
Storm surge	Assume tide elevation rises with MSL (**)	-

Precariousness is harder to assess than aspects of resistance and latitude, especially when contested factors, such as climate change, are likely to drive a subsystem towards a limit. This was reflected in the interviews, where little controversy was evident on how weather and climate affect farm operations, and what land managers typically do in response to these risks, but assessments on the precariousness of the farm system were less clear-cut. For example, interviewees were not in agreement on how seriously they should take climate change, and the prospect of more frequent and/or severe droughts was met with some scepticism. Several farmers expressed great confidence in the fact that farming will always be a major economic activity in their respective regions, regardless of any changes in climate, as 'people are always going to need to eat'. While for some this reflected pure confidence in their adaptive capacity (no matter what change), for others it was clear that they were unable to imagine anything other than the status quo. The latter attitude denied the possibility that sheep and beef land managers might find themselves in alternative state spaces, and perhaps represented the most obvious contradiction between the theoretical model and practitioners' perceptions.

Table 11: Summary of the projected impacts of climate change for New Zealand (IPCC 2014)

The regional climate is changing
Long term trends are towards higher air and sea-surface temperatures, more hot extremes and fewer cold extremes, and changed rainfall patterns.
Warming is projected to continue through the 21st century.
Warming is expected to be associated with rising snow lines, more frequent hot extremes, less frequent cold extremes, and increasing extreme rainfall related to flood risk in many locations. Annual average rainfall is expected to decrease in the north-east South Island, northern and eastern North Island, and to increase in other parts of New Zealand. Fire risk is projected to increase in many parts of New Zealand. Regional sea level rise will very likely exceed the historical rate (1971–2010).
Uncertainty in projected rainfall changes remains large for New Zealand.
Precipitation changes are projected to lead to increased runoff in the west and south of the South Island and reduced runoff in the north-east of the South Island, and the east and north of the North Island. Annual flows of eastward flowing rivers with headwaters in the Southern Alps (Clutha, Waimakariri, Rakaia, and Rangitata) are projected to increase by 5–10% in response to higher alpine precipitation. Most of the increases occur in winter and spring, as more precipitation falls as rain and snow melts earlier.
Recent extreme climatic events show significant vulnerability of some ecosystems and agriculture to current climate variability
The frequency and/or intensity of such events is projected to increase in many locations. Recent floods caused severe damage to infrastructure, farms and houses. Widespread drought in many parts of New Zealand (2007–2009; 2012–13) resulted in substantial economic losses of NZ$3.6b in direct and off-farm output in 2007–09.
Without adaptation, further changes in climate, atmospheric CO_2 and ocean acidity are projected to have substantial impacts on water resources, coastal ecosystems, infrastructure, health, agriculture and biodiversity.
Freshwater resources are projected to decline for rivers originating in the north-east of the South Island and east and north of the North Island. Rising sea levels and increasing heavy rainfall are projected to increase erosion, with consequent damage to many low-lying ecosystems, infrastructure and housing; increasing heat waves will increase risks to human health; rainfall changes and rising temperatures will shift agricultural production zones; and many native species will suffer from range contractions and some may face local or even global extinction.
Some sectors in some locations have the potential to benefit from projected changes in climate and increasing atmospheric CO_2.
Examples include reduced energy demand for winter heating and forest growth in cooler regions, except where soil nutrients or rainfall are limiting. Spring pasture growth in cooler regions would also increase and be beneficial for animal production.

4.4 Resilience Surrogates

Based on the results presented above, 20 resilience surrogates are proposed to describe the stability landscape of sheep and beef farming in the face of climate variability and change (Table 12). For the particular stress factor of climatic impacts, three surrogates for resistance were found to sufficiently capture the system dynamics. The largest number of surrogates relates to latitude (i.e. the width of the state space). Latitude reflects opportunities for flexibility or diversity that allow a system to take different configurations and still fulfil its essential functions. Precariousness can be described by four surrogates; three reflecting the occurrence of marginal conditions under present-day weather conditions, and the other relating to the systems’ response to climate changes.

Table 12: Resilience surrogates for resistance, latitude and precariousness

Stability landscape aspect	Surrogate	Description
Resistance	Exposure	Extent to which farming system is exposed to adverse climatic conditions (e.g. location, aspect, etc.).
	Sensitivity	The degree to which the farming system is sensitive to adverse climatic conditions.
	Coping range	Level of critical threshold above or beyond which, normal operation is not possible.
Latitude	Age	Degree to which capacity to absorb losses or respond to adverse events is influenced by age of farmer.
	Debt	Degree to which flexiblity and responses are constrained by debt levels.
	Information	Climatic and farm management information that is used in decision making.
	Communication	Access to reliable communication.
	Access	Dependence on a particular resource or location.
	Product	Diversity of products produced on the farm.
	Markets	Diversity of market segments (e.g. early season) or segments a farm is producing for.
	Productivity	Amount/total yield of products produced on the farm.
	Suppliers	Diversity of suppliers for inputs (e.g. lambs, feed, fuel).
	Processors	Diversity of processors that the farm is able to supply.
	Networks	Connectedness of the farm and its activities, within and across a region to allow for greater diversification in the face of adverse conditions (e.g. neighbors assisting in flood events)
	Pluriactivity	Access to off-farm income, not affected by adverse climate.
	Health and well-being	Physical and emotional well-being of farmer/staff and family.
Precariousness	Frequency	Extent to which activities on the farm are disrupted under current climate conditions.
	Severity	Degree to which activities are affected under current climate conditions.
	Recurrence interval	Frequency with which farm is affected under current climate conditions.
	Climate change	Extent to which climate change will exacerbate climatic impacts for farm.

We use the example of drought on a low-input, or pasture based farm to illustrate briefly how the surrogates can be contextualised. Pasture based farming is highly sensitive to a range of weather conditions including too little rain, too much rain (risk of pugging), snowstorms, and combinations of high temperatures and/or humidity. While no specific thresholds were identified for amount of rainfall, an economic threshold was specified by interviewees: two drought years in three would make the farm no longer viable. Overall, the resistance to climatic disturbances of pasture-based farming appears to be relatively low.

The limited range of options for farmers in the event of a drought similiarly restricts their latitude. Pasture based farmers may not have access to the same networks as more intensive producers, and thus may find it difficult to secure additional feed, especially on short notice. Farmers are able to drop stock, but will receive a lower price in a depressed market. Much sheep and beef farming is on land that is not suitable for dairying (hill country or steep terrain, marginal soils or lower grass growth) and so the choice of alternative land uses may be limited. The quality and type of land negatively affects the number or type of states the farm can take. Farmers can reduce exposure to adverse climate through diversification of income. Off-farm income has a positive effect on latitude. Latitude can be increased by working outside the farm in an industry or sector not affected by climate, or by diversifiying on-farm activities (e.g. farm stays). Latitude could also be increased by targeting new markets or segments, such as spring lambs. Finding and retaining quality staff is a significant challenge, related to communication and access to information. As one farmer said, "No one under twenty-five wants to work on a farm if there isn't cell phone coverage." Others described the challenges of rural internet access; being unable to access it, high costs, and slow speeds that may make it difficult to locate resources or download useful information.

Networks and the level of connectivity between farmers is also a crucial component of latitude. In the event of flood or drought, farmers described support from the local community that included stock transportation, financial and emotional support, and assistance with recovery. Farmers new to an area, new to the industry, or employed as seasonal or migrant workers may have less developed social networks and therefore have less latitude.

Access to the natural resource of grass is fixed. Farms and infrastructure cannot be moved, further reducing latitude. Use of climate information, including longer-term seasonal forecasts, may increase latitude of on-farm decision-making. Several farmers did note their use of long-term seasonal forecasts as well as daily reports. In some rural areas – particularly Northland – the consensus was that farming was not well connected. Road and rail access, in particular, were described as problematic. Road closures were frequent, making it difficult to get stock to market.

Pasture based farming systems can be described as being close to the edge of the state space and precariousness is currently high. Under current climate variability, the weather conditions are already affecting day-to-day operations quite frequently. Climate change projections predict warmer temperatures, decreased rainfall and greater variability and extremes, all of which will affect the industry. Importantly, climate change is expected to exacerbate these factors, for example increase the frequency or severity of drought, and move the system closer to the edge, thus increasing precariousness.

5 Resilience indicators

The second objective was to use the data from interviews and workshops and the surrogates for resilience to describe the stability landscape of sheep and beef land management in New Zealand, and then link these surrogates with appropriate indicators to support decision-making.

Businesses commonly report on their sustainability initiatives, variously named sustainability, sustainable development, corporate social responsibility, corporate responsibility, triple bottom line and accountability. While such reporting is usually voluntary, many guidelines have been produced, the most commonly used being the Global Reporting Initiative (GRI, 2006). The GRI is a non-profit organisation promoting economic, environmental and social sustainability. It works towards a sustainable global economy aiming to combine long-term profitability with social justice and environmental care. GRI reporting on sustainability covers the key areas of economic, environmental, social and governance performance. Such reports can be used for benchmarking and comparing sustainability performance within and between businesses over time. The following section reviews a number of indicators-based monitoring and evaluation frameworks related to farm sustainability. This provides the basis for further development of the resilience surrogates and indicators to support on-farm decision-making.

5.1 Agricultural sustainability reporting

Four international agricultural sustainability frameworks were evaluated as part of this project:

- Sustainability Assessment of Food and Agriculture systems (SAFA)
- The Response-Inducing Sustainability Evaluation (RISE) tool
- The New Zealand Sustainability Dashboard
- The Prairie Climate Resilience Project

Sustainability Assessment of Food and Agriculture systems (SAFA)

The United Nations Food and Agriculture Organisation (FAO) built on other frameworks to develop a framework for Sustainability Assessment of Food and Agriculture (SAFA). SAFA provides a tool for assessing sustainability along food and agriculture value chains. SAFA is structured along four dimensions of sustainability: good governance (G), environmental integrity (E), economic resilience (C), and social well-being (S). Each of these dimensions is broken into four or more themes (Table 13), then each of these into sub-themes have indicators attached to them. SAFA does not treat themes as discrete entities and provides a diagram showing how the themes are linked (Figure 7).

Table 13: Dimensions, themes and subthemes in the SAFA structure (SAFA 2012)

Dimension	Theme	Sub-theme
Good governance	G1 Governance structure	G1.2 Corporate ethics
		G1.2 Due diligence
	G2 Accountability	G2.1 Holistic audits
		G2.2 Responsibility
	G3 Participation	G3.3 Stake-holder dialogue
		G3.2 Grievance procedures
		G3.3 Conflict resolution
	G4 Rule of law	G4.1 Commitment to fairness and legitimacy
		G4.2 Remedy, restoration and prevention
		G4.3 Co-responsibility
		G4.4 Resource appropriation
	G5 Holistic management	G5.1 Sustainability in quality management
		G5.2 Certified production and sourcing
		G5.3 Full-cost accounting
Environmental integrity	E1 Atmosphere	E1.1 Greenhouse gases
		E1.2 Air pollution
	E2 Freshwater	E2.1 Water quantity
		E2.2 Water quality
	E3 Land	E3.1 Organic matter
		E3.2 Physical structure
		E3.3 Chemical quality

		E3.4 Land degradation and desertification
	E4 Biodiversity	E4.1 Habitat diversity and connectivity
		E4.2 Ecosystem integrity
		E4.3 Wild biodiversity
		E4.4 Agricultural biodiversity
		E4.5 Threatened species
	E5 Materials and energy	E5.1 Non-renewable resources
		E5.2 Energy supply
		E5.3 Eco-efficiency
		E5.4 Waste disposal
	E6 Animal welfare	E6.1 Freedom from stress
		E6.2 Species appropriate conditions
Economic resilience (C)	C1 Investment	C1.1 Internal investment
		C1.2 Community investment
		C1.3 Long-ranging investment
	C2 Vulnerability	C2.1 Stability of supply
		C2.2 Stability of marketing
		C2.3 Liquidity and insurance
		C2.4 Employment
		C2.5 Stability of production
	C3 Product safety and quality	C3.1 Product information
		C3.2 Traceability
		C3.3 Food safety
		C3.4 Food quality
	C4 Local economy	C4.1 Value creation
		C4.2 Local procurement
Social well-being	S1 Decent livelihood	S1.1 Wage level
		S1.2 Capacity building
	S2 Labour rights	S2.1 Employment relations
		S2.2 Forced labour
		S2.3 Child labour
		S2.4 Freedom of association and bargaining
		S2.5 Working hours
	S3 Equity	S3.1 Non-discrimination
		S3.2 Gender equality
		S3.3 Support to vulnerable people
	S4 Human health and safety	S4.1 Physical and psycho-social health
		S4.2 Health resources
		S4.3 Food security
	S5 Cultural diversity	S5.1 Indigenous knowledge
		S5.2 Food sovereignty

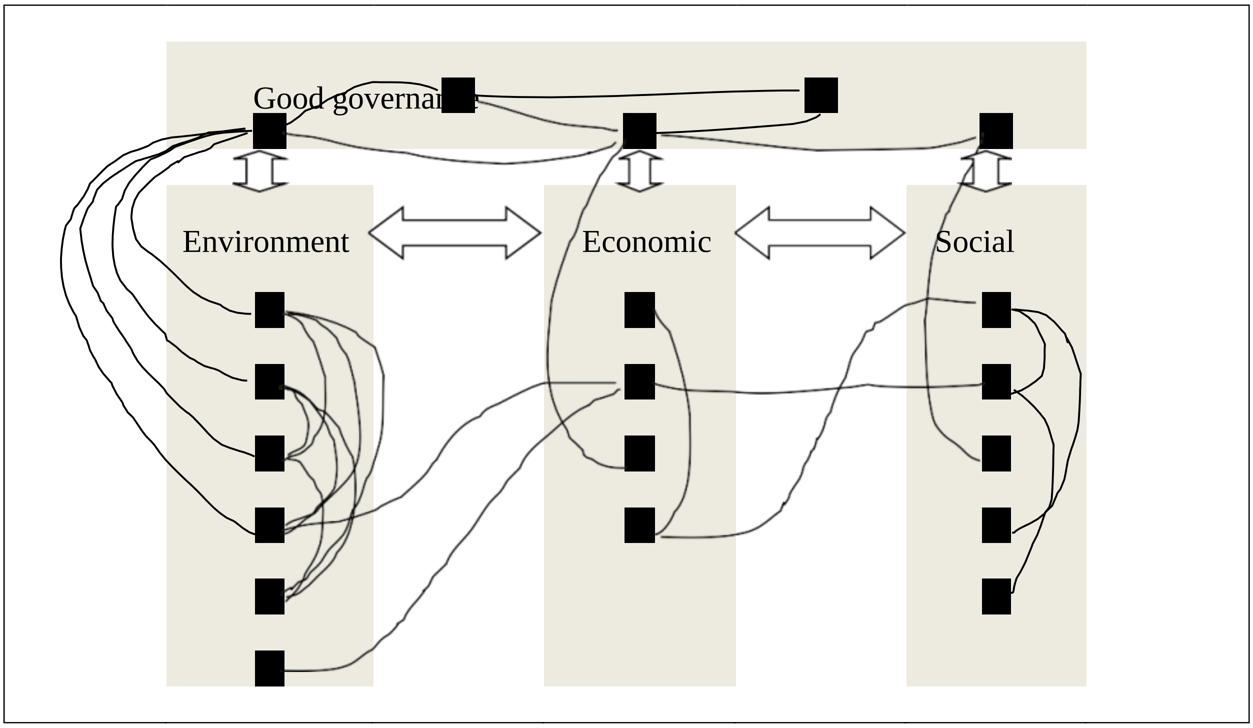


Figure 7: Interrelations between SAFA sustainability dimensions and themes
Lines indicate strong, direct interrelations between one or more sub-themes. Theme numbers as per Table 9 (SAFA 2012: 39)

RISE framework

The Response-Inducing Sustainability Evaluation (RISE) tool is a farm-level, system-oriented approach developed in Switzerland. RISE covers ecological, economic and social aspects of sustainability by defining 10 indicators for energy and climate, water use, nutrient flows, soil use, animal husbandry, plant protection and biodiversity, farm management, economic viability, working conditions, quality of life. These are calculated from 54 parameters collected in an interview. Indicator measures are normalised to give a measure of the degree of sustainability, resulting in a number between 0 (completely unsustainable) and 100 (completely sustainable).

The RISE tool is used by many large global companies, such as Nestlé, Fonterra and Syngenta, and it has support from international organisations, including the FAO (RISE, n.d.). Although RISE employs an interview-based methodology for assessing farm sustainability, it is delivered using a fee-for-service model, and so was regarded as less suitable for this project than some of the other, more accessible frameworks.

New Zealand Sustainability Dashboard (NZSD)

The New Zealand Sustainability Dashboard (NZSD) is project funded by the Ministry for Business, Innovation and Employment (MBIE). It provides a generic sustainability framework and indicators that can be used by different land-based production sectors at different levels (farm/orchard business, associated agribusiness, sector organisation). The NZSD is based on the SAFA framework, providing sustainability reporting for economics, environmental and social indicators. A fourth dimension – governance – has been added. NZSD is being used in the wine and kiwifruit sectors and will be extended to the horticulture and forestry sectors. It also has Ngai Tahu as a partner so will be trialled on their corporate dairy farms.

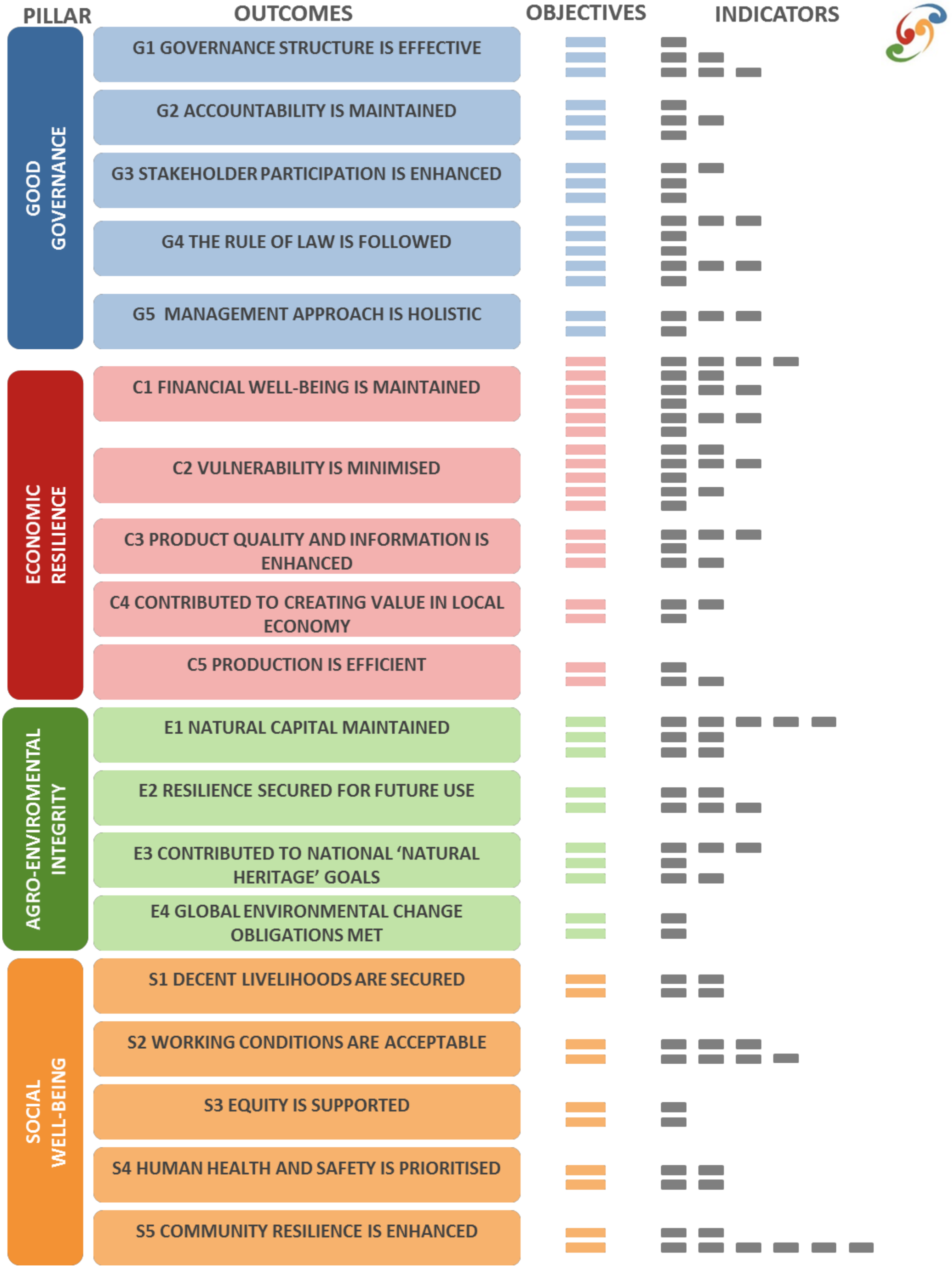
Internationally recognised frameworks and their key generic sustainability performance indicators (KPIs) are included in the design to ensure that overseas consumers can benchmark and verify the sustainability credentials of New Zealand's export products. The NZSD provides a four-pillar framework to assess progress towards achieving sustainability goals, outcome focused objectives and aligned indicators. The four pillars are:

- Measuring the governance of New Zealand's primary-based industries
- Measuring the economic resilience of New Zealand's primary-based industries
- Measuring to secure agro-environmental integrity in New Zealand
- Measuring the contribution of primary-based industries to social well-being in New Zealand

Under each pillar there are goals and outcomes, with objectives given for each outcome. The achievement or movement towards the objectives is shown by indicators for which measurements can be developed by each end-user of the Dashboard in consultation with the Dashboard team and other stakeholders (Figure 8).

The New Zealand Sustainability Dashboard will incorporate New Zealand KPIs and develop capacity for more regular sustainability reporting to New Zealand's regional and national agencies and the farmers/growers involved (Manhire et al., 2012). Given that the framework has been adapted for use in New Zealand primary sectors, it was the most relevant framework for this project.

Figure 8: Outline of NZSD framework structure (Hunt 2013)

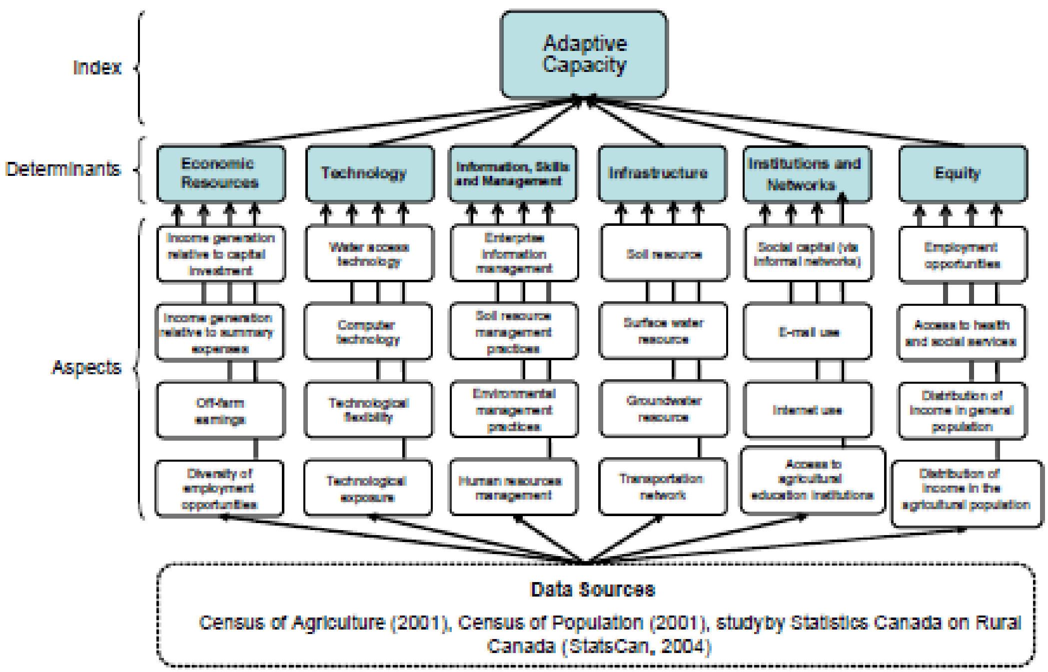


Prairie Climate Resilience project

The Prairie Climate Resilience project was also reviewed as it is one of the few well-developed indicators frameworks designed specifically for agriculture. This project was designed to measure adaptive capacity in relation to climate change for Prairie Regions, Canada. The project developed a geographic information system (GIS) based indicator of the adaptive capacity of agriculturally based communities using the 2001 agricultural census and the population census. A series of 17 indicators were organised into six themes: 1) Economic resources, 2) Technology, 3) Infrastructure, 4) Information, skills and management, 5) Institutions and networks, and 6) Equity. Each indicator was specific, measureable and time bound (Swanson et al., 2007).

The project identified a number of indicators – termed 'aspects' in the framework – that could provide insight into a farm's adaptive capacity (Figure 9). Examples include access to secure water resources, computer and communication access and use, and health services. As with other indicators frameworks, many of the aspects are context-dependent, such as the suggestion that smaller, rather than larger, tractors enhance options to initiate time-sensitive seasonal field activities.

Figure 9: Framework for adaptive capacity used in the Prairie Project (Swanson et al.2007)



Some of the indicators in the Prairie Climate Resilience project were identified by the researchers as having potential application for New Zealand, and were included in the original long list (Tables 25 to 28, Appendix 2). These included: ratio of income to expenses, roading quality, area of no till or minimum till vs. full cultivation, ground water resources, use of technology, use of computers on farm, use of internet, distances to services and education, and access to health and social services (Figure 10). In some cases the indicators were renamed to fit within the NZSD framework and a selection of indicators was trialled with stakeholders in workshops.

Figure 10: Selected indicators from the Prairie Climate Resilience project stakeholders identified as useful for application in the New Zealand context

Theme	Outcomes	Objectives	Indicator	Measure
Economic	Financial well being is maintained	C1.4 Performing efficiently	**Efficiency**	FWE/GFR as a percent
	Vulnerability is minimised	C2.2 Ensuring stability of supply	**transportation infrastructure**	roading quality (both on farm and in district)
Environment	E1 Natural capital maintained	E1.1 Maintaining ecosystem processes	**Soil Status**	area of 'no or minimal till' vs cultivation
			Water yield	groundwater resources
Social	S5 Community resilience is enhanced	S5.2 Recognising stakeholder values & choices	**Human capital**	use of technology
				use of computers on farms
			Infrastructure /isolation	use of internet and email (good broadband access)
				distance to services & education
				access to health and social …

5.2 Linking resilience surrogates to selection and development of indicators

A long-list of candidate indicators was chosen according to the key criteria: locally grounded and in most cases currently used in New Zealand; relevant, useful and affordable to the sheep and beef sector; and broadly accepted by policymakers, major stakeholders and users. The indicators are presented according to the four domains affected: economic, social, ecological and governance. The indicators are conceptually based on the the resilience surrogates, developed in the empirical work with stakeholders (Table 14*).*

Table 14: Surrogates for Resistance, Latitude and Precariousness and linked indicators

Stability landscape aspect	Resilience Surrogates	Proposed Indicator	Measure
Resistance	Exposure	Liquidity	Debt to equity ratio
		Biodiversity	Protection of endemic species
		Land	Flood prone
			Erosion prone
			Drought prone
			Weeds
		Water quality	P and sediment runoff
			Biological health of rivers and streams
		Animal Welfare	Shelter and shade for stock
	Sensitivity	Land	Erosion control
		Soils	Soil fertility levels
			Area of 'no till' or 'minimal till' vs. cultivation
		Water quality	Nitrogen conversion % efficiency
			Active nutrient management budget/plan
	Coping range	Water yield	Groundwater resources
			Reticulated stock water
			Water storage/harvesting
		Risk Management	Attitude to risk
			Managing risks effectively
			Stored feed on hand
Latitude	Age	Family	Scope for farm succession
			Number of generations involved in the business
			Time for family, balanced life
	Financial position		Cashflow
	Information	Knowledge and skills	Skills enhancement
			Educational attainment of farmers and staff
			Use of technology
			Use of computers on farm
		Decision making	Making good decisions at the right time
			Use of advisers
			Benchmarking
			Effective governance

			Written agreements
		Internal communication	Operating procedures
			Good communication with partners, staff
	Communication	Infrastructure/ isolation	Use of internet and email (good broadband access)
			Good cell phone reception
	Access		Transportation infrastructure
			Distance to services and education
		Animal welfare	Stock condition
	Markets	Diversification	Product diversification
			Market diversification
			Price premiums available
	Pluriactivity		Off-farm income
	Networks	Community Health	Counselling services available
			Access to health and social services
			Involvement in the community
	Health and well-being		Working hours/work-life balance
			Rural Support/Task Force Green
		Employee working conditions	Staff retention/Employee turnover
			Lost time injury/frequency ACC claims/sick days
Precariousness	Frequency		
	Severity		
	Recurrence Interval		
	Climate change		

Economic indicators

Benchmarking of economic indicators is well developed in New Zealand agriculture. Historical agricultural statistics for New Zealand are available from 1861.

The use of physical and financial performance indicators and benchmarking for the financial analysis of businesses is a widespread practice throughout the New Zealand primary sector. Benchmarking involves the comparison of a performance indicator derived for one business with the same performance indicator derived for one or more other businesses (Shadbolt and Bywater, 2005). Benchmarking therefore focuses on the key variables influencing productivity, profitability, liquidity and solvency. Through benchmarking a farm business manager would:

- measure current physical, ecosystem, social and financial performance;
- identify areas of performance where improvement needs to be made;
- identify changes which can be made to current husbandry and business management processes and practices in order to improve enterprise and/or whole farm performance.

‘A manager may use a range of key performance indicators that are an index of a set of performance measures to provide an indication of the overall performance of the business.

These measures must be tightly linked to the farmer's goals' (Gray, 2005: 51). Factors can be measured objectively using some form of instrument (e.g., scales, refractometer for fruit sugar) or subjectively using visual assessment. Monitoring frequency is an important consideration. 'Factors must be monitored at a frequency that allows the farmer time to take effective corrective action. The frequency for any particular factor will be dependent on the factor and the nature of the production cycle' (Gray, 2005: 51). Too frequent monitoring can become costly.

Increasingly, information has to be collected to meet compliance requirements and quality assurance for products. Farm managers also find they can use this information for benchmarking to achieve continuous improvement in their business management systems (Shadbolt and Bywater, 2005). All properties have annual accounts with additional information on production inputs and outputs.

MPI's farm monitoring programme models the production and financial status of farms, orchards and vineyards throughout New Zealand. The MPI farm monitoring publications contain:

- Models of major farm, orchard and vineyard types;
- Analysis of the relationship between financial results and the sustainability, productivity and adaptability of the different sectors;
- Discussion about issues facing the sectors and how the sectors are collectively and individually dealing with these issues.

Beef+Lamb New Zealand provide annual national survey data from 520 sheep and beef farms grouped by farm class. This information is provided to allow farmers to benchmark their farm, provide price trends, key annual prices and industry production trends. This information predominantly provides economic performance indicators with some context indicators used for benchmarking.

Table 15 shows the proposed economic indicators, based on the resilience surrogates, review of current frameworks and workshops with stakeholders.

Table 15: Proposed economic indicators

	Objective	Indicator	Measure	Threshold	Workshop comments
C1 Financial well being is maintained	C1.4 Performing efficiently	**Efficiency**	FWE/GFR as a percent	Comfort zone 40–60%	
	C1.6 Balancing liabilities and assets	**Liquidity**	Debt to equity ratio	Less debt better	
		Cashflow	Bills paid on time	Family has a living wage	
C5 Production is efficient	C5.1 Enhancing production	**Farm Productivity**	Kg meat/ha, product/ha		
C2 Vulnerability is minimised	C2.2 Ensuring stability of supply	**Transportation infrastructure**	Roading quality (both on-farm and in district)		Poor roading limits ability to diversify and get farm staff, also increases time cut off following storm events and transport costs

	C2.4 Managing liquidity	**Cashflow**		Bills paid on time, family has a living wage	
	C2.5 Managing risk	**Diversification**	Product diversification		
			Market diversification		
			Land diversification		Different rainfall zone, elevation, aspect, soils
			Off-farm income		
		Risk Strategies	Pasture as % of feed consumed	Varies with region and farm type	
			Stocking rate flexibility	More trading stock is better	
			Stored feed on hand	Tonnes DM stored (ranged 6 weeks to 18 months of stored feed)	
C3 Product quality and information is enhanced	C3.2 Enhancing food quality	**Product quality**	Price premiums available		

Environmental indicators

Benchmarking of environmental indicators in the New Zealand production landscape is more recent than benchmarking of economic indicators. A range of indicators is used by the Department of Conservation, Regional Councils and Statistics New Zealand to measure progress towards achieving environmental objectives at the regional and national levels. Environmental indicators have also been developed in a number of projects focusing on improving on farm practices to improve water quality at a catchment level, for examples in the Rotorua and Taupo Lakes areas. Internationally, there are a large number of ecological indicators.

In recent years, the agricultural industry organisations and companies have encouraged their farmer levy payers and suppliers to monitor their environmental footprints. A range of indicators has been developed as part of the programmes run by Fonterra, DairyNZ (Sustainable Milk Plan) and Beef+Lamb New Zealand (Land and Environment Plan). Uptake by farmers of environmental indicators is still in the very early stages.

A number of the environmental indicators impact at a catchment or regional level, particularly for the soil, land and water quality indicators. These involve farm management practices to meet compliance requirements; however, in many cases they are beyond compliance so are considered 'good practice'. The benefits of good proactice/ cost of poor practice are experienced at a community level, for example, the impact of high levels of nutrients, sediment and bacteria entering waterways. Indicators that provide context include the land indicators of 'drought prone', 'flood prone' and 'erosion prone'. These are a function of soil type and typography rather than farm management, although how the farmers manage these risks is vital for resilience.

Environmental indicators identified as important by the stakeholders in workshops are given in Table 16. These are not seen as a complete list of environmental indicators that could be used. For example, greenhouse gas emissions as an indicator was discussed, but not seen as a priority by the stakeholders under the current New Zealand regulatory environment, but this could change with a change in government policy.

Table 16: Proposed Environmental Indicators

	Objective	Indicator	Measure	Threshold	Workshop comments
Environmental	E1 Natural capital maintained	E1.1 Maintaining ecosystem processes	**Biodiversity**	Protection of endemic species	Ha of fenced-off/protected areas
			Land	Erosion prone/ erosion control	Loss of productive land
				Flood prone	Days under water
				Weeds	% Cover, new weed invasions, pugging, drainage, drought leading to increased weeds
			Soils	Good soil fertility levels	Olsen P and pH at agronomic optimal levels
				Area of 'no or minimal till' vs cultivation	More is better if erosion prone
				Nitrogen conversion efficiency %	
			Water quality	Biological health of rivers and streams	Reduced Algae blooms
				Biological health of rivers and streams	km of fenced waterways, fish and invertebrate numbers
				Phosphorous runoff	Meet local council regulatory water quality requirements, depends on catchment and soil type
				Nitrogen loss to water	Threshold depends on soil type and farm class
				Sediment into waterway	Streams maintain stony bottom (not covered in silt)
				Have active nutrient budget/ management plan	Nutrient budget used in decision making and revised regularly
			Water yield	Groundwater resources	No. and/or yield of wells
				Reticulated stock water	Days storage (100 days in drought prone region)
				Water storage/ harvesting	Water reliability

Social indicators

Social sustainability, or social well-being, as it is called in the SAFA (2013b) framework, only emerged with the so-called Brundtland definition of sustainability in the late 1990s (Colantonio, 2011), and is associated with the need for a country or an enterprise to ensure that basic human needs are met and that people have the right and the freedom to pursue and achieve their own aspirations for a better life (WCED, 1987).

To be sustainable, an enterprise would employ the most suitable people to do the required work, and would maintain good relationships and conditions for these employees so that they continue to work for the enterprise. In other words, a business is dependent on the people it employs and the work that they do. Therefore, the ‘people’ side of sustainability and resilience is a theme which could appear in both the economic and social dimensions. SAFA (2013b) and GRI (G4) place this aspect – employee working environment – in the social dimension.

Climate extremes already have a demonstrated effect on productivity on sheep and beef farms, with flow-on impacts for well-being. High intensity rainfall with a probability of 50-year return is projected to increase by 10% by 2040, increasing the risk of floods. Drought time is also projected to increase by 10%. Droughts, floods and other extreme weather events challenge the resilience of individual farmers and rural communities and depression is an increasing issue for rural communities. Ministry of Health data show there is a significantly higher rate of suicide in rural areas than in urban areas for 2009 to 2011. Managing climatic extremes is one of the factors Federated Farmers of New Zealand has identified as contributing to this higher suicide rate, along with poor or variable financial returns, increasing compliance costs and other causes of stress. Social indicators and thresholds may enable identification of the more vulnerable and the more resilient enterprises and farmers.

There are very few social indicators in common use in New Zealand agriculture. Table 17 shows social indicators proposed by workshop farmers and stakeholders. The majority of these social indicators (and those listed in Appendix 2) are used at a national level by Statistics New Zealand or have been developed by Sustainable Business NZ for a wide range of business enterprises. The framework below, describing the outcomes, objectives and indicators, is from the New Zealand Sustainability Dashboard project (Hunt et al., 2014) and is derived from a SAFA framework. Some researchers have suggested that community response is critical to drought adaptation (Stehlik, 2003a ; Burton and Peoples, 2008). Those workshop attendees that had either experienced drought or severe floods strongly reinforced this.

Table 17: Proposed Social indicators

	Objectives	Indicator	Measure	Threshold	Workshop comments
Social	S2 Working conditions are acceptable	S2.2 Maintaining high quality working conditions	**Employee working conditions**	Staff retention /employee turnover	Want high staff retention but occasional changes to get new ideas
				Working hours/work-life balance	Max of 55–60 hours per week
				Lost time injury frequency/ACC claims/sick days	Rate of frequency per thousand hours worked
	S4 Human health and safety is prioritised	S4.2 Improving facilities to meet basic human needs	**Community health**	Counselling services available	Time for help to be available
				Rural support, Task force green	Help available following extreme weather
	S5 Community resilience is enhanced	S5.2 Recognising stakeholder values & choices	**Family**	Scope for farm succession	Does farm have income/scope for succession
				Number of generations involved in business	Having more generations involved increases resilience
				Time for family, balanced life	Work less than 70 hours per week (owner), Dad has time for the kids
			Knowledge and skills	Use of technology	
				Use of computers on farms	Farm recording, Farm mapping,
				Skills enhancement	Attend discussion group, field day, industry events
				Educational attainment of farmers and staff	Some tertiary education (ITO, diploma etc)
			Infrastructure /isolation	Use of internet and email (good broadband access)	Needed to attract staff as well as communication, services
				Distance to services & education	Distance to schools/ tertiary education, options, affordability
				Access to health and social services	

	S4 Human health and safety is prioritised	S4.1 Maintaining safe, hygienic & healthy environment	**Interaction with community**	Involvement in community	Hours voluntary time

Governance indicators

'Governance means the process of decision-making and the process by which decisions are implemented (or not implemented).' (UNESCAP, 2009: 1). It is increasingly being used in a business setting where governance 'defines the rights of stakeholders, provides the separation of powers between management and a supervisory board, and seeks to insure responsible leadership in all dimensions of an enterprise' (FAO, 2012a: 10). It is believed that it is only through good governance that the challenge of meeting the environmental, economic and social dimensions of sustainability can be achieved (FAO, 2012a: 16). Figure 11 displays the attributes of good governance according to UNESCAP.

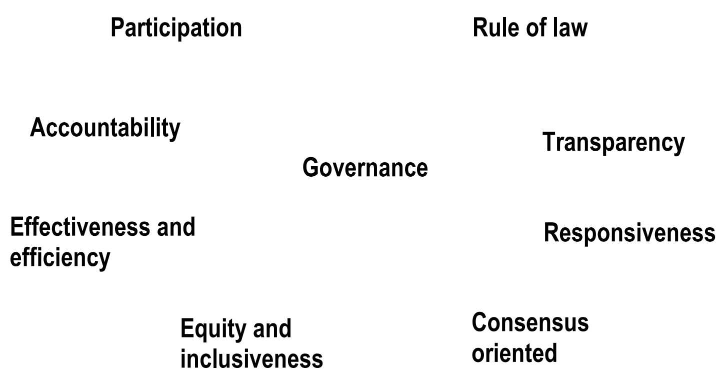


Figure 11: Good governance (UNESCAP 2009: 3)

The UN introduced institutional sustainability (Spangenberg, 2002), into a framework in 2001. Institutional sustainability uses the sociological meaning as the socially accepted rules or norms that can govern 'good' behaviour in any given society (Abercrombie et al., 1988). Institutional sustainability was seen as providing the means of integrating the three pillars. While this wording is still used in some sustainability frameworks, it has often been replaced by the word 'governance', which has greater implications for the processes of politics and rule-making, not only within a society but within organisations.

According to Keeble et al. (2003: 149):

- Investors are looking for evidence of good corporate governance, particularly sound business strategy and effective management of risk.
- Customers are asking about the origins of products, who made them and what they contain.

- Employees are looking to work for companies that visibly account for their responsibilities to society and the environment.
- Governments and civil society are increasingly placing pressure on businesses to report on social and environmental performance.
- Good governance links all these aspects and makes sure systems and capabilities are in place to ensure that they happen.

There are a variety of governance structures within New Zealand’s primary based industries. In 2005, it was estimated that 97% of farms were family owned and managed businesses (Shadbolt and Bywater, 2005: 27). They may be sole traders, partnerships, companies or trusts, and in some cases they have multiple business structures. For example, a family trust owns the land and a partnership managemes the business and stock. These businesses are usually based on the family unit, with the owners providing the combined roles of directors, managers and labour. Due to long working hours and personal involvement, decisions may be made without relevant information and adequate time given to the implications of these decisions. Also, there are a growing number of family businesses that own more than one property or properties that have more than one family as owners. There are also a small number of farms, orchards and vineyards owned by corporates. As the size of the business increases, the management is less and less hands-on. These businesses require performance indicators for leadership, including the ability to delegate.

Good decision making and communication with all stakeholders is becoming increasingly important as the scale of properties increases and in an environment of increasing variability. Good governance ensures sound decision making and implementation. Two key indicators developed from work in Northland in 2010 (Landcare Trust, 2010) were:

- Early risk assessment and decision making is vital
- Planning is essential for long term farm resilience

These indicators also were reported as key responses by Canterbury and Otago farms to manage drought (Burton and Peoples, 2008) and by workshop participants. One example from the workshop was of a South Canterbury farm that had a written plan to manage a snow event; the owners were on holiday in Europe when a severe snow storm hit, and the farm workers had all the information they needed to farm their way through the adverse event. Other examples of the benefits of written agreements, plans and operating procedures included being able to manage when the farmer has an accident or health problem.

From the workshops, the participants selected the following indicators as a priority for strong goverance:

- **Decision making and implementation procesess**, measured by having a governance team and having written agreements for employment, feed supply, and significant expenditure. A governance team may involve a few family members or a more formal board structure to improve decision making. Making good decisions at the right time has been included, however measuring this is difficult.
- **Methodology and tools to monitor and implement sustainability.** In order for a farm to be resilient and make good decisions it needs to have ways of measuring,

collecting and analysing data. Increasingly farmers are having to do this for compliance but the better farmers are also actively using their farm data for decision making and to benchmark the farm performance between seasons and against other farms. Farms that regularly weigh or score stock condition and monitor pasture growth /feed tend to make decisions earlier to manage risks and take advantage of good seasons. The use of advisers was also seen as important.

- **Risk Management** under the goverance theme is the process to assess how a business can achieve its objectives, given information about, for example, the likelihood of drought, disease or flood (SAFA 2013a). The metrics for this would include evidence that responsibility is taken for risk management. The level of risk taken varies greatly between farms, depending on farmers' attitude to risk and the land managers' experience with the variability of climate and production. An example of this from the workshops was the stated threshold needed for stored supplementary feed, which ranged from 2 years' worth (for an older farmer who had experienced extreme droughts and was risk averse) to 2 months' worth (for a farmer newer to the district and more willing to take risks)**.**

- **Internal communication** within the farming team was also seen to be key to a resilient farming business; this includes communication between family members and farm staff. Some measures of internal communication are that staff (including family members) are actively informed, and staff have sufficient information to to effectively take part in discussion about the farming operations (Hunt et al., 2014).

- **Animal welfare** was identified by those involved in the Rural Support Trust and Federated Farmers New Zealand as showing how close the farm was to its threshold point. Thin or dead stock in paddocks show that a farmer is not coping or has poor decision making skills. As we experience more extreme weather, trees for shelter and shade will become increasingly important. Regional climate change predictions from 1980–1999 to 2039 –2049 show an increase in the number of days over 25 °C (Clark et al., 2012)and this is likely to increase heat stress in animals. A recent study in the Waikato showed cattle graze longer when they have access to shelter and shade in summer, resulting in a 3% increase in milk production (Bluett et al., 2000).

Table 18 shows the proposed indicators for governance, based on the resilience surrogates, the review of current frameworks and the workshops with stakeholders.

Table 18: Proposed Governance indicators

	Outcome	Objective	Indicator	Measure	Threshold
Governance	G1 Governance structure is effective	G1.1 Maintaining transparent decision making processes	**Decision making and implementation processes**	Effective governance culture	Governance team
				Written agreements	Feed supply agreements, employment agreements
				Making good decisions at right time	
	G1 Governance structure is effective	G1.3 Practicing due diligence	**Methodology and tools to monitor and implement sustainability**	Benchmarking	Uses benchmarking software or service
				Use of advisors	
	G2 Accountability is maintained	G2.2 Management actions are responsible	**Risk management**	Attitude to risk	
				Managing risks effectively	
	G3 Stakeholder participation is enhanced	G3.1 Maintaining effective stakeholder dialogue	**Internal communication**		Staff turnover, partnership relationship quality, have operating procedures or written guidelines for staff
	G4 The rule of law is followed	G4.5 Maintaining compliance with animal welfare legislation	**Animal welfare**	Stock condition	Thin stock, dead stock
				Shelter & shade	Km of shelter belts, lambing cover

6 Application of indicators framework

The final objective was to empirically examine the value of the proposed indicators for decision making. In stakeholder workshops, participants were presented with five resilience surrogates (efficiency, liquidity, productivity, risk management and product quality) and asked to nominate what they thought were the most important quantitative measures for each. Results are shown in Table 19.

Table 19: Responses to economic classifications from focus groups.

Resilience surrogate	Stakeholder recommended measures
Efficiency	Farm working expenditure / net cash income
	Farm working expenditure / gross farm revenue
	Effective farm surplus
	EBIT
Liquidity	Debt to equity ratio
	Cash flow
Farm Productivity	Kg meat / ha
	Stocking rate
	N use efficiency
	Kg DM / ha
Risk Management	Stocking rate flexibility
	Trading vs breeding stock.
	Stored feed on hand
Product Quality	Average c / kg meat

The methodology used was to construct a quantitative farm economic model which is driven by feed production. This model in turn was then constructed in an Excel add-on called @Risk which was able to determine the probable outcomes that would result from varying a range of variable inputs that result from variable feed production and product price parameters.

Data was obtained from the Climate Cloud website which was able to simulate the pasture production in Northland, Hawkes Bay and Canterbury for the period 1980 – 1999 (which was taken to represent the present situation) and then under the influence of predicted climate change parameters for the period from 2039 to 2049 (which is taken to represent the future climate change scenario).

The quantitative farm economic model created to test indicators calculated efficiency measures as a function of Farm Working Expenses / Gross Farm Revenue.

The liquidity measure of the debt to equity ratio was relatively easy to report from the financial models derived. The cash flow derived measure is difficult to report from the model produced, but it is able to be discussed according to whether there is an effective farm surplus.

The farm productivity measures of kg meat /ha, stocking rate and kg dry matter /ha can be compared, but the measure of N use efficiency cannot be reported because that is derived from an Overseer modelling exercise.

The risk management measures of stocking rate flexibility and trading versus breeding stock can both be commented on, while the proportion of stored feed on hand cannot.

The product quality measure of average cents per kilogram of meat can be commented on, but only in the context of its impact on the efficiency measures and not in relation to a measure of the quality of the farm production.

The three sheep and beef farm financial models used were the Northland, Hawkes Bay/Wairapapa and Canterbury/Marlborough Hill Country models from the MPI Farm Monitoring series last published in 2012.

Northland Sheep and Beef farm model.

The current farm model is modelled exactly the same as the way that it is described in the Farm Monitoring report. The Northland sheep and beef farm model represents 950 hill country and intensive finishing farms, located between Auckland and points North. Cattle make up about 75% of total stock units. The model runs a breeding flock with 25 to 30% ewe hogget replacements. A cross-bred breeding herd was run but is now mated to beef bulls, and replacement heifers are no longer bought in. The surplus heifer calves are sold as weaners and replaced with dairy beef bulls. Surplus heifers are mainly sold as prime rising 24 to 36 month heifers to the local trade market. The majority of steers are wintered over and sold on the spring grass market or carried through to slaughter from 22 to 30 months of age. Around 200 bull calves are purchased during the spring as weaners and sold as 24 to 36 month bulls.

Hawkes Bay / Wairarapa Sheep and Beef model

The Hawkes Bay model represents a wide range of country and climatic zones. Because the climate cloud data was for a medium rainfall (880 mm), it was assumed that the property was in the lower hill country and so the model was adapted to reflect the farming systems that would be used in that area. This model represents around 2000 farms south of the Napier–Taupo highway in the Hawke’s Bay, Tararua and Wairarapa regions. The model comprises mainly sheep and cattle breeding and finishing farms, with most of the cropping done for grazing livestock.

The farm model is 570 effective hectares and covers a range of environments: from the hill country in the western foothills of the main central mountain range, the dry central belt, to the coastal hills in the east. As a result, average rainfall ranges from 2000 mm p.a.to 500 mm p.a.

The terrain is easy to medium hill, but most properties have some ‘flats’, typically used for more intensive farming practices, and some steeper country that is potentially erosion prone.

The sheep system is a breeding ewe flock, breeding its own ewe replacements with, depending on the season, three-quarters of the lamb progeny being finished to slaughter weights and the rest sold store. Most of these store lambs stay within the region. The model has a 100-head mixed-age cow herd. Heifers are mated as rising two-year olds. The model finishes both steers and bull beef and, depending on the season, will buy in around 30 weaner bulls, 30 older bulls and 30 older beef cattle to finish.

Canterbury / Marlborough Hill Country model

The Climate Cloud model for Canterbury was based on a model which best represented the productivity of the Hill Country model rather than the Canterbury Breeding and Finishing model. This model represents 425 hill country farms in Canterbury and Marlborough. Farms have a proportion of land that is in tussock or too steep to be cultivated by two-wheeled tractors. They run mid-micron or crossbred sheep according to the class of country and farmer preference. They run breeding flocks and herds and produce a higher proportion of store stock than finished animals.

Productivity parameters for the current situation were taken as the average of the last six years’ productivity data as published in the latest available report. Expenditure items were taken as the average of the last year’s actual figures and the forecast years’ predicted data.

For the future scenarios, the numbers of breeding livestock remain the same but their reproductive performance was increased by 1% p.a. for the sheep lambing percentage and 0.33% p.a. for the calving percentage. This meant that the effective stocking rate increased by the amount of feed required to feed the increased breeding stock but the base numbers of stock did not change. The additional feed grown went into finishing the additional stock born on the farm. In those farm models where livestock were purchased from outside the farm for finishing, the numbers of those animals increased to consume the additional feed not taken up by the base breeding stock.

The Variable Parameters

The risk analysis application @RISK (pronounced at risk) uses Monte Carlo simulation to show many possible outcomes and their likelihood of occurrence, and the probabilities and risks associated with each outcome. Monte Carlo simulation is based on a number of runs of the data using the variability in the individual outcomes possible, which are set up in the input data randomly (in this case 1,000 runs) from which the results are presented in a figure which not only shows the average result which is expected but also displays the possible variability which can result from the variable input factors. In this way it is able to factor in the potential for considerable variability in both product prices and the range of possible outcomes of Dry Matter Production.

It was used in this instance to compute the likely range of possible outcomes under the twin uncertainties of changes in grass production and product price parameters. From the resultant charts we were able to describe the likelihood of a negative event occurring in any of the financial parameters.

Dry Matter Production

The variability of monthly dry matter production was charted in the Climate Cloud data. From this we were able to estimate the total variability of grass production in the model area. The parameters used are shown in Table 20.

Table 20: Average Grass Production and the Variability Range (kg DM / ha / annum)

	Present Average	Present Variability	Future Average	Future Variability
Northland	8752	1750	9627	1925
Hawkes Bay	7233	1808	7590	1898
Canterbury	5178	1553	6086	1825

Input Price Parameters

The financial parameters were driven by the adoption of an average figure from the MPI Situation and Outlook for New Zealand Agriculture and Forestry (MPI, 2015). This figure is an average of the last four years financial performance and the next four years predictions. The prices used are shown in Table 21**.**

Table 21: Average grass production and the variability range (kg DM / ha / annum)

	Low Price	Average	High Price
Lamb ($ / kg of carcass)	4.77	5.68	6.37
Beef ($ / kg of carcass).	4.00	4.41	4.77
Wool ($ / kg of wool)	2.70	3.29	3.85

6.1 Results of climate modelling

A brief summary of the results of the climate change modelling follows.

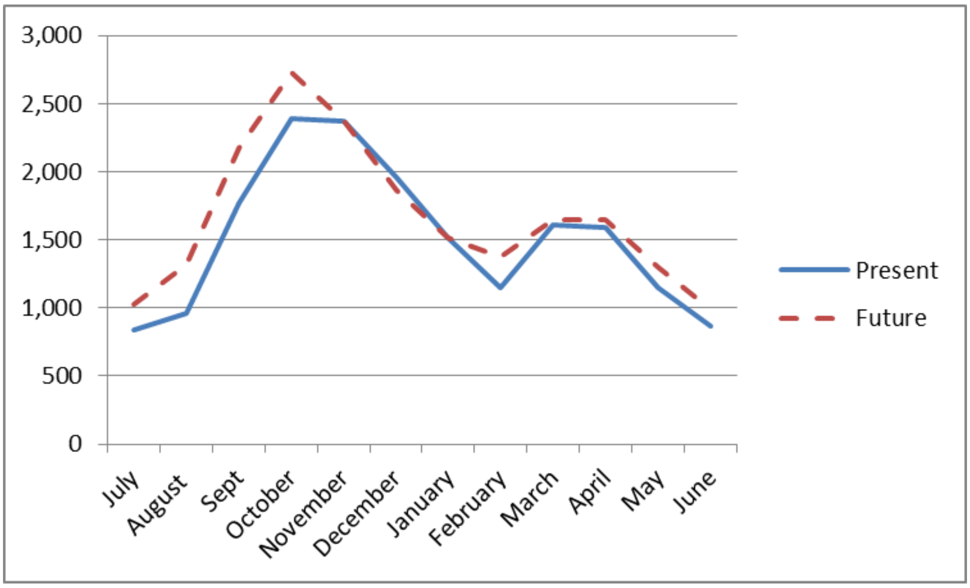
Northland

The number of days when the maximum temperature is greater than 25˚C doubles to 66 days. The number of days when the minimum temperature is less than 5˚C almost halves to 16 days. The first day of spring, which is taken as the start of a period where the running ten day average pasture growth rate exceeds 20 kg DM/ha/day, doesn't change. The mean temperature increases by 1.3°C , a relatively consistent increase apart from a slightly higher temperature increase in the summer. The total annual rainfall decreases by 52 mm to 1788 mm.

Modelled dry matter production increases by 10% to 9627 kg DM/ha/annum. The climate cloud data was modelled in Northland for a dairy farm so for this exercise it was adjusted to reflect the amount of grass production required to match a sheep and beef property with the same proportionate increase in DM production. In this exercise we did not allow for any changes that would result from a change to C3 pastures, which is predicted to occur in Northland.

The seasonal change in pasture production is shown in Figure 12. Monthly growth increases from August to a peak in October, a month earlier than the current peak, and then follows the same seasonal pattern for the rest of the year apart from considerably higher growth in February. Variability in year to year productivity did not change significantly from the current 10% variability. Note this seasonal growth pattern is unlikely to reflect the impact of extremely heavy rainfall events that result in localised flooding.

Figure 12: Seasonal Growth Pattern Changes in Northland (kg Dry Matter/ha/month)



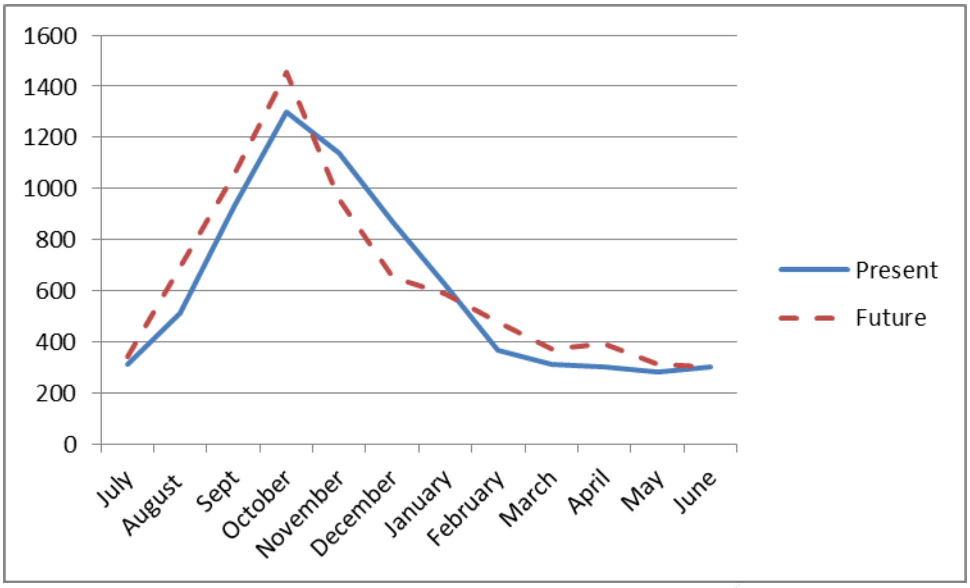
Hawkes Bay

The number of days when the maximum temperature is greater than 25°C increases by approximately 50% to 46 days. The number of days when the minimum temperature is less than 5°C reduces by approximately 20% to 88 days. The first day of spring, which is taken as the start of a period where the running ten day average pasture growth rate exceeds 20 kg DM/ha/day, advances by 17 days. The mean temperature increases by 1.0°C, a relatively consistent increase apart from a slightly higher increase in the summer temperature. The total rainfall stays the same at 880 mm.

Modelled dry matter production increases by 5% to 7590 kg DM/ha/annum.

The seasonal pattern change is shown in Figure 13. The increase in monthly production occurs during the peak spring months of September to November and after that monthly grass growth matches the current situation. Variability in year to year productivity does not change significantly from the current 25% variability.

Figure 13: Seasonal Growth Pattern Changes in Hawkes Bay (kg Dry Matter/ha/month)



Canterbury

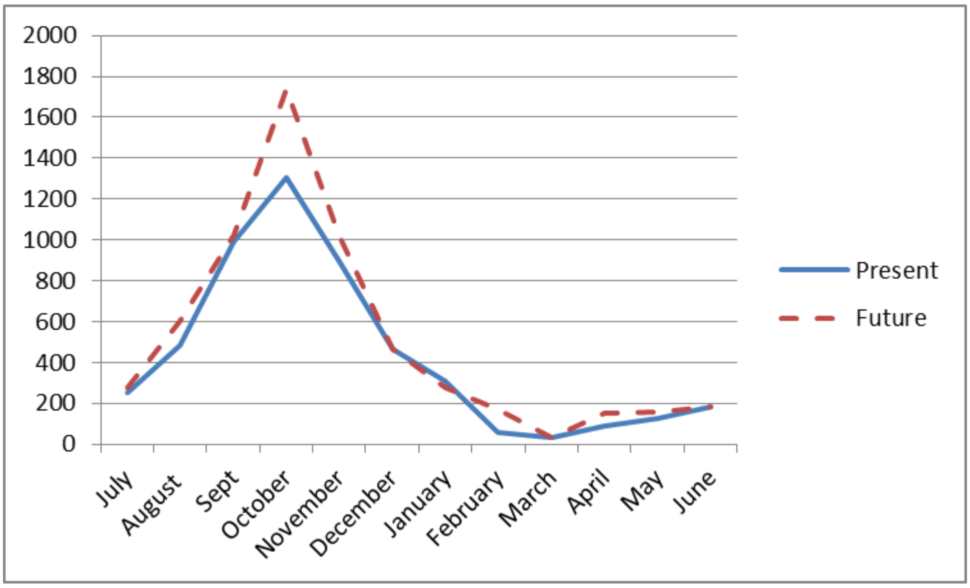
The number of days when the maximum temperature is greater than 25˚C increases by approximately 30% to 45 days. The number of days when the minimum temperature is less than 5˚C reduces by approximately 25% to 100 days. The first day of spring, which is taken as the start of a period where the running ten day average pasture growth rate exceeds 20 kg DM/ha/day advances by 14 days. The mean temperature increases by 1.3˚C and is a relatively consistent increase apart from a slightly higher increase in the autumn and winter temperatures. The total rainfall increases slightly by 23 mm to 755 mm.

Modelled dry matter production increases by 17% to 6086 kg DM/ha/annum.

The seasonal growth pattern change is shown in Figure 14 (overleaf). Monthly pasture production increases slightly from August until the peak month in October, then considerably reduces through to the end of January and then considerably increases from February to May.

On Canterbury dryland farms variability in year to year pasture production did not change significantly from the current 30% variability.

Figure 14: Seasonal Growth Pattern Changes in Canterbury (kg Dry Matter/ha/month)



6.2 Modelling results and workshop findings

The results of the modelling are reported against the choices made by the focus groups as to the important measures.

Northland

The extra growth in the Northland model predominantly occurs in the months of July to a much higher peak of grass growth in October. Thereafter, it is the same as or slightly higher than the current grass growth. This means that the best adaptation techniques is to increase the stocking rate by an increase in reproductive performance and by an increase in the number of calves purchased. The sheep to cattle ratio stays the same. Lambing and calving stay at the same date but the increased performance of both, and the fact that there is a considerable amount of rising one and two year cattle on hand, means that the additional feed produced in those months is able to be consumed satisfactorily (Table 22).

Table 22: Results of economic measures for Northland

	Measure	Current	Future	Percentage Change
Efficiency	FWE / GFR	64%	63%	-1%
	EBIT ($)	142 359	159 530	12%
	Effective farm surplus ($)	1838	16 176	780%
Liquidity	Debt to equity ratio	15%		

Farm Productivity	Grass production (kg DM / ha)	8752	9672	11%
	Stocking rate (Stock Units / ha)	12.7	14.0	10%
Kg meat / ha	Sheep	67	73	9%
	Beef	183	201	10%
Risk Management	Breeding vs trading	33%	33%	0%

Points to note from the Northland results are:

- There is very little change in the Farm working expenses / Gross farm revenue measure. This is primarily driven by the the low proportion of breeding stock in this model.
- There is a pleasing 12% lift in the EBIT and a substantial lift in the EFS.
- The debt to equity ratio is fairly low at the start at 15% and can be improved substantially if the improved EFS is expanded on further debt reduction.
- The stocking rate rises by 10% and the measures of sheep and beef output both rise by a similar amount.
- There is no change in the breeding versus trading measure, which is relatively low at the start.
- Based on the modelling results, the Northland farm model will be better off as a result of climate change.

Hawkes Bay

The future grass growth in the Hawkes Bay model is higher than current growth from August to a higher peak in October but is then lower from November to January, and then higher through to May. To counter this drop-off in summer production, the lambing and calving dates can both be brought forward by 2 ½ weeks. This means that most of the extra feed that will be grown can be consumed by the lambs, which can be killed or sold store before Christmas. In the model we transferred some of the feed crop grown for the winter to a finishing feed crop for feeding from December to January to allow the finishing of most of the lambs. By accelerating the finishing of the lambs, we increased the cattle retained for the autumn and winter by a small proportion.

As shown in Table 23, significant results to be noted from the Hawkes Bay model are:

- There is a pleasing drop in the Farm working expenses to Gross farm revenue measure, which flows through to the remainder of the efficiency results.

- EBIT lifts by a substantial 24% and the EFS also has a very substantial lift albeit starting from a break even position so the percentage change is quite substantial.
- The debt to equity measure starts off at a relatively conservative figure and, if the EBIT is used for debt reduction, it can be reduced further.
- Stocking rate lifts by 5% and the measures of sheep and beef productivity lift by 14%.
- The measure of breeding versus trading stock improves significantly, reducing the farm risk exposure.
- Economic impacts for the Hawkes Bay model farm are positive.

Table 23: Results of economic measures for Hawkes Bay

	Measure	Current	Future	Percentage Change
Efficiency	FWE / GFR	67%	63%	-6%
	EBIT ($)	157 380	195 611	24%
	Effective farm surplus ($)	812	32 735	3932%
Liquidity	Debt to equity ratio	22%		
Farm Productivity	Grass production (kg DM / ha)	7233	7590	5%
	Stocking rate (Stock Units / ha)	10.5	11.0	5%
Kg meat / ha	Sheep	85	97	14%
	Beef	39	44	14%
Risk Management	Breeding vs trading	66%	63%	-5%

Canterbury

The increased future growth in the Canterbury model is almost all produced in September to February. For the remainder of the year, the growth pattern matches the current growth pattern, albeit at slightly higher levels. The average lambing date can be brought forward by 2 weeks. This means that the additional growth pattern perfectly fits the demand pattern of a breeding and selling of store stock operation. So the stocking rate is increased, by increasing the reproductive performance of the sheep and cattle, and most of the progeny are sold before Christmas. Table 24 shows results from the Canterbury model. It should be noted that:

- There is considerable improvement in the measure of Farm working expenses to Gross farm revenue, which then flows through to the other measures of efficiency.
- EBIT rises by 78% and there is a large rise in the EFS.
- The debt to equity measure starts relatively low and could be further reduced reasonably rapidly if the EFS is used for debt reduction.
- Stocking rate increases by a substantial 18% and sheep and beef outputs both increase by 31%. It should be noted that in this model the sheep and beef output measures store stock production, not carcass weight.
- The risk exposure of this farm is reduced significantly as a result of an improved breeding versus trading measure.
- Overall effect of climate change on the Canterbury model farm is very positive.

Table 24: Results of economic measures for Canterbury

	Measure	Current	Future	Percentage Change
Efficiency	FWE / GFR	66%	52%	-21%
	EBIT ($)	212 787	378 415	78%
	Effective farm surplus ($)	25 928	214 188	726%
Liquidity	Debt to equity ratio	14%		
Farm Productivity	Grass production (kg DM / ha)	5178	6086	18%
	Stocking rate (Stock Units / ha)	7.5	8.9	18%
Kg meat / ha	Sheep	100	132	31%
	Beef	46	60	31%
Risk Management	Breeding vs trading	43%	37%	-15%

6.3 Dealing with the Non-Average Situation.

The analysis provided to date has been based on the average property, in terms of performance and debt structure. In all farming systems there is considerable variation in both farm performance and debt structure across the farm types. The range of farm types – relative to performance and debt structure – is shown in Figure 15, the colour intensity increases with increasing likelihood of a poorer financial outcome.

The vulnerability of any one of these operations to business failure is entirely determined by the EFS in an average year. The greater the EFS, the less vulnerable the operation. The measure of the impact of climate change therefore is the EFS more positive as a result of the change that will occur.

Figure 15: Financial Performance of Different Farm performance and Debt Structure Combinations.

	Low Performance	Medium Performance	High Performance
Low Debt			
Medium Debt			
High Debt			

In the Northland model, EFS indicates a relatively high degree of vulnerability to business failure at present (i.e. basically a break-even situation), with a positive improvement in the future. In the Hawkes Bay model property, EFS indicates a very vulnerable situation at present, with a significant improvement in the future. In the Canterbury property, there is a considerable improvement from a satisfactory current position to a very strong future position.

At the three workshops we discussed threshold and tipping points; however, farmers and industry representatives found it was difficult to define the level or range for most indicators as they varied from property to property and there were cumulative effects. Feedback showing weak sustainability performance is probably not enough on its own to trigger change amongst growers or industry stakeholders (Manhire et al., 2013).

Work by AgResearch in Northland, as part of a Sustainable Farming Fund project, identified that perceived threat to farming businesses of a drought or storm event was greater in years of low product price than in normal years (Payne et al., 2010).

Workshops also discussed how to deal with the ‘perfect storm’ of of low productivity, perhaps brought on by drought or poor animal health, combined with low product prices at the same time.

In the Northland workshop, participants defined a perfect storm as when a farm was mostly likely to reach its tipping point. A combination of low product returns, high debt levels, two droughts or floods in sucession and family stress would severely challenge a farming family business and may result in the sale of the farm. They were also aware that a number of Northland farms are small, resulting in significantly lower EBITs than shown in the MPI Farm monitoring modelling. These farms are far more vulnerable to the impacts of low product prices and poor climatic seasons.

The best way to measure this vulnerability is by EBIT, as this is the money available to pay interest, tax and any additional items, such as capital repayments, all of which can be deferred to allow the property to survive such an event.

The Monte Carlo analysis performed by @Risk determined the probability of a negative result for EBIT occurring. For the Northland property, a negative result did not occur for either the current situation or the future scenario. For the Hawkes Bay property, the likelihood of a negative result for EBIT improved from 35% currently to 20% in the future. For the Canterbury property, the likelihood of a negative EBIT improved from 20% currently to 15% in the future. We can assume from these results that the chances of suffering a perfect storm improve with climate change.

There was also discussion around the increased likelihood of suffering natural disasters, such as extreme rain storm events, as a result of climate change. The likelihood of this happening is not factored into the climate cloud results, although we expect that the likelihood of drought is factored into the assessment of increased variability. In our opinion, the best way to prepare a farming venture to withstand the negative financial impacts of such an event is to both create more profit and reduce the amount of farm debt All of the three properties modelled here were able to increase their profit as a result of climate change. The issue of how much debt to carry is ultimately the decision of farmers and the banks.

7 Conclusions and recommended next steps

This research has characterised resilience of sheep and beef farming in New Zealand, applying the stability landscape model (Walker et al., 2004) to identify elements of resistance, latitude and precariousness. A farm’s resistance was shown to be a function of the degree to which the operation is exposed to climate risks, and its coping range. Latitude described the capacity of the farm to respond to climate shocks using a mix of adaptive strategies, including the factors that enhanced or constrained that capacity. Two main factors were identified, relating to farm management and operations, and farm financial management. Not surprisingly, latitude was enhanced with profitability, and reduced when expenses were highest and income lowest, making the operation more vulnerable to climate stressors. Precariousness relates to critical thresholds or tipping points within the farm; for example, two drought years in a row was identified by stakeholders as a ‘game changer’, from which it would be difficult – but not impossible – to recover. However, some large thresholds, if crossed, would be sufficient to change the state of the farm.

While it is impossible to measure resilience directly, sixteen proxies or ‘resilience surrogates’ were proposed, based on the characterisation of the stability landscape. Together, they provide insight into the capacity of farming enterprises to respond to changes in climate. These proxies were then compared to existing sustainability monitoring and evaluation frameworks to identify quantiative indicators that can support decision-making. In keeping with the four domains of sustainability used by other frameworks, indicators relevant to sheep and beef land management in New Zealand were identified across economic, social, ecological and governance domains. The indicators correspond to resilience surrogates, and can provide a quantitative measure of important elements related to the resilience of farm systems. A key criterion in the selection of indicators was that they were measurable and that measurement data was readily available.

Economic modelling was used to determine the validity of the proposed indicators, by investigating farm efficiency under a climate change scenario. While model and methodology were constrained by project resources, valuable insight was obtained into the relationship between debt and farm performance.

The research demonstrates the feasability of using the stability landscape model to characterise resilience, identify surrogates and use these as the basis for identifying quantitative metrics, which can form the basis of monitoring and evaluations programs.

The resilience indicators identified in this study were characterised first as aspects of resilience, and then linked to quantitative indicators, successfully tested and reviewed with stakeholders, and applied using economic modelling. The central focus of study was on farm-level resilience, as opposed to regional economic resilience. As a result, most of the identified indicators measure aspects at the farm level. However, a farm is only as resilient as the resources, processes and people on which it depends, and the research identified the importance of factors at the sub-regional and national/global levels. This study, therefore, further validates the findings of socio-ecological resilience studies, which have found that resilience dynamics need to be assessed across multiple spatial scales and across a range of indicator types.

The assessment framework developed and presented here provides a robust methodology to determine which farm system components influence the farms’ resilience to a range of risks and which are critical for specific risks. This framework can help the sheep and beef sector identify system vulnerabilities and risks, and develop and support specific adaptation or resilience-building strategies.

Key findings from the research include:

- *Indicator selection is enhanced by the participation of affected stakeholders.* Planning processes are strongest when they are participatory and inclusive. Wide consultation with stakeholders can and should inform the indicator selection process. Doing so can (1) contribute to establishing the focus for the indicators, (2) clarify the methods of data collection and evaluation, (3) frame what success looks like according to beneficiaries, and (4) promote shared ownership and transparency. Stakeholder involvement can also bring a critical perspective on how to define appropriate steps toward the achievement of future outcomes (Sniffer 2012).

- *Both qualitative and quantitative indicators and data are required.* Indicators can be either qualitatively or quantitatively defined. *Quantitative indicators* express numerical information (e.g., percentage increase/ decrease), while *qualitative indicators* are descriptive observations or assessments (e.g., results of an open-structured interview). Usually, one type of indicator is not sufficient to provide all of the information needed to assess resilience. Assessing resilience to support adaptation planning therefore should include a suite of different indicators and indicator types.
- A related consideration is that 'big picture' thinking and approaches are key to assessing resilience. Maladaptation and other unexpected findings often first manifest in more open-ended, qualitative data and/or measures of broader conditions. Qualitative analysis therefore is essential in capturing (local) knowledge regarding likely impacts of shocks and stresses. However, climatic variation is not the only long-term factor; social, economic, and environmental factors are also part of the wider enabling environment for pastoral farming and should be taken into account.
- *There is no single set of universal or standard resilience indicators.* One of the main conclusions of the study is that there is no single set of universal or standard resilience indicators. While climate change is a global phenomenon, resilience is fundamentally local, and it is best to select indicators that reflect the specific scale and context at hand. Given the local manifestations of climate change impacts, adaptation planning and resilience assessment lends itself well for local stakeholder consultation and other forms of participatory engagement. This engagement should include the processes of indicator development and selection, and data collection to capture both the local context and the wider enabling environment. The local climate system is dynamic, and there is uncertainty about how climate change will manifest itself at the local level.

Based on these findings, we recommend the following:

- *Incorporate resilience indicators in Land and Environmental Planning Toolkit or Farm Environment Plans.* Indicator-based monitoring and evaluation frameworks can support on-farm decision making. In particular, we recommend incorporating all the proposed resilience indicators into the Land and Environmental Planning Toolkit (Beef+Lamb) or Farm Environment Plans. Mainstreaming such monitoring and evaluation frameworks will help to build the capacity for foresight and strategic adaptation, help to 'normalise' adaptation planning within the primary sector, and help to increase adaptation planning efforts. The proposed indicators also provide an additional risk management tool to support farmers to better manage impacts related to other, non-climatic risks such as pest incursions, market shocks or personal loss or injury.
- *Further develop and refine the proposed resilience indicators.* While this study provides an initial set of indicators for assessing farm-level resilience specifically for the sheep and beef sector, it can be further advanced by:

a) undertaking farm systems modelling to determine the extent to which the proposed indicators accurately reflect local, regional and national-level farm conditions, as well as variations between different farm types (e.g., extensive vs. intensive) and landscapes (e.g., hill country vs. plains);

b) applying a similar process of characterising resilience and then identifying indicators for other sectors also likely to be affected by climate change, for example, the dairy or horticultural sectors;

c) further applying the stability landscape model at other scales to explore interactions and influences on resilience and its variability at regional or catchment scales;

d) developing a learning component for future resilience assessments. Climate change impacts and related adaptation interventions are complex, interconnected and characterised by inherent uncertainty. Any subsequent assessments therefore should contain a social learning component to inform interventions and to further mature the evidence base (Dunningham et al., 2015). This could include participatory workshops involving scenario develop with stakeholders to explore potential futures and possible responses. Learning plays a central role in resilience of social-ecological systems, in particular the recombination of experiences from different areas and diverse fields that may lead to new insights and pathways for development.

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Appendix 1 – Human ethics procedure

Research was conducted in an ethical manner, according to guidelines set out by Landcare Research. The research methods were peer reviewed prior to the first interviews/workshops. Appropriate permissions were be sought and respondents' rights and opinions respected. Before all interviews, participants were asked for permission to use a digital recorder. No names were used in the reporting of the findings and respondents were provided with a copy of their transcript. Subject to any conditions from MPI, we will provide participants with a copy of the final report. Current contact information for the researchers was provided prior to the interview/workshop.

The following conditions were adhered to, in keeping with current best practice and the terms of ethics approval:

- Respondents will be contacted by phone and invited to partake in the study.
- An information sheet, outlining the purpose and rationale of the project will be emailed or posted to the participant prior to the interview.
- The email will include contact details of the interviewer and the lead researcher, and confirmed time and date of the interview.
- Permission will be obtained to record the conversations.
- The results will be aggregated/no individual attributions made.
- A process for data storage and coding of the data to protect privacy in future years will be put in place.
- All interviewees will be provided with a copy of the transcript and allowed to comment, or redact any statements.

Appendix 2 - Indicator Tables, based on review of literature

Table 25: Economic and physical indicators

Source	Outcomes	Objectives	Indicator	Measure
DairyBase	C1 Financial well-being is maintained	C1.1 Managing investment wisely	Internal investment	Growth from Capital
Interview data	C1 Financial well-being is maintained	C1.1 Managing investment wisely	Internal investment	Internal rate of return
Interview data	C1 Financial well-being is maintained	C1.1 Managing investment wisely	Long range investment	Off farm investment
DairyBase	C1 Financial well-being is maintained	C1.3 Creating Wealth	Assets and asset turnover	Asset Turnover %
Meat & Wool (NZ)	C1 Financial well-being is maintained	C1.3 Creating Wealth	Assets and asset turnover	Capital value at open
Meat & Wool (NZ)	C1 Financial well-being is maintained	C1.3 Creating Wealth	Assets and asset turnover	Net worth at close
DairyBase	C1 Financial well-being is maintained	C1.3 Creating Wealth	Assets and asset turnover	Return on Assets
Meat & Wool (NZ)	C1 Financial well-being is maintained	C1.3 Creating Wealth	Assets and asset turnover	Total assets at close
Beef & Lamb, ARGOS, Dashboard	C1 Financial well-being is maintained	C1.3 Creating Wealth	Equity	Equity at close
DairyBase	C1 Financial well-being is maintained	C1.3 Creating Wealth	Equity	Growth in Equity %
DairyBase, BNZ sharemilker competition & Sustainable Business (NZ)	C1 Financial well-being is maintained	C1.3 Creating Wealth	Equity	Return on Equity
MPI, Beef + Lamb (NZ), Red Sky (Australian), ARGOS	C1 Financial well-being is maintained	C1.3 Creating Wealth	Physical	Effective area
MPI	C1 Financial well-being is maintained	C1.4 Performing efficiently	Efficiency	Interest+rent+lease/NCI
BNZ sharemilker competition	C1 Financial well-being is maintained	C1.4 Performing efficiently	Efficiency	Average cost of consumed feed ($/tDM)
MPI	C1 Financial well-being is maintained	C1.4 Performing efficiently	Efficiency	farm working expenses/Net cash income (NCI)
BNZ sharemilker competition	C1 Financial well-being is maintained	C1.4 Performing efficiently	Efficiency	Labour efficiency
BNZ sharemilker competition	C1 Financial well-being is maintained	C1.4 Performing efficiently	Efficiency	Labour efficiency
Beef + Lamb (NZ), DairyBase	C1 Financial well-being is maintained	C1.5 Enhancing profitability	Cost of production	Administration
Beef + Lamb (NZ), DairyBase	C1 Financial well-being is maintained	C1.5 Enhancing profitability	Cost of production	Animal health
Beef + Lamb (NZ),	C1 Financial well-being is	C1.5 Enhancing	Cost of	Cartage

Source	Outcomes	Objectives	Indicator	Measure
DairyBase	maintained	profitability	production	
Beef + Lamb (NZ), DairyBase	C1 Financial well-being is maintained	C1.5 Enhancing profitability	Cost of production	Cash crop
BNZ sharemilker competition	C1 Financial well-being is maintained	C1.5 Enhancing profitability	Cost of production	Core Costs
BNZ sharemilker competition	C1 Financial well-being is maintained	C1.5 Enhancing profitability	Cost of production	Core Costs
Beef + Lamb (NZ), DairyBase	C1 Financial well-being is maintained	C1.5 Enhancing profitability	Cost of production	Cultivation/sowing
Meat & Wool (NZ)	C1 Financial well-being is maintained	C1.5 Enhancing profitability	Cost of production	Depreciation
Beef + Lamb (NZ), DairyBase	C1 Financial well-being is maintained	C1.5 Enhancing profitability	Cost of production	Electricity
Beef + Lamb (NZ), DairyBase	C1 Financial well-being is maintained	C1.5 Enhancing profitability	Cost of production	Feed and grazing
Beef + Lamb (NZ), DairyBase	C1 Financial well-being is maintained	C1.5 Enhancing profitability	Cost of production	Fertiliser
Beef + Lamb (NZ), DairyBase	C1 Financial well-being is maintained	C1.5 Enhancing profitability	Cost of production	Insurance & ACC
Beef + Lamb (NZ), DairyBase	C1 Financial well-being is maintained	C1.5 Enhancing profitability	Cost of production	Interest
Beef + Lamb (NZ), DairyBase	C1 Financial well-being is maintained	C1.5 Enhancing profitability	Cost of production	Lime
Beef + Lamb (NZ), DairyBase	C1 Financial well-being is maintained	C1.5 Enhancing profitability	Cost of production	Rates
Beef + Lamb (NZ), DairyBase	C1 Financial well-being is maintained	C1.5 Enhancing profitability	Cost of production	Rent
Beef + Lamb (NZ), DairyBase	C1 Financial well-being is maintained	C1.5 Enhancing profitability	Cost of production	Repairs and Maintenance (R&M)
Beef + Lamb (NZ), DairyBase	C1 Financial well-being is maintained	C1.5 Enhancing profitability	Cost of production	Seeds
Beef + Lamb (NZ), DairyBase	C1 Financial well-being is maintained	C1.5 Enhancing profitability	Cost of production	Shearing
Beef + Lamb (NZ)	C1 Financial well-being is maintained	C1.5 Enhancing profitability	Cost of production	Total expenditure
Meat & Wool (NZ)	C1 Financial well-being is maintained	C1.5 Enhancing profitability	Cost of production	Total expenditure % of GFR
Beef + Lamb (NZ), DairyBase	C1 Financial well-being is maintained	C1.5 Enhancing profitability	Cost of production	Vehicles and fuel
Beef + Lamb (NZ), DairyBase	C1 Financial well-being is maintained	C1.5 Enhancing profitability	Cost of production	Wages
Beef + Lamb (NZ), DairyBase	C1 Financial well-being is maintained	C1.5 Enhancing profitability	Cost of production	Weed and Pest
Beef + Lamb (NZ), DairyBase	C1 Financial well-being is maintained	C1.5 Enhancing profitability	Profit	EBITR
Beef + Lamb (NZ), DairyBase, MPI, ARGOS	C1 Financial well-being is maintained	C1.5 Enhancing profitability	Profit	Economic Farm Surplus (EFS)
MPI	C1 Financial well-being is maintained	C1.5 Enhancing profitability	Profit	EFS less interest and lease/equity EFS/NCI
Beef + Lamb (NZ), DairyBase	C1 Financial well-being is maintained	C1.5 Enhancing profitability	Profit	Farm Profit Before Tax

Source	Outcomes	Objectives	Indicator	Measure
ARGOS, MPI	C1 Financial well-being is maintained	C1.5 Enhancing profitability	Profit	FWE/GFR
DairyBase	C1 Financial well-being is maintained	C1.5 Enhancing profitability	Profit	Growth from Profit
ARGOS	C1 Financial well-being is maintained	C1.5 Enhancing profitability	Profit	NFPBT/farm ($)
DairyBase	C1 Financial well-being is maintained	C1.5 Enhancing profitability	Profit	Operating profit /ha
DairyBase	C1 Financial well-being is maintained	C1.5 Enhancing profitability	Profit	Operating profit margin%
MPI	C1 Financial well-being is maintained	C1.5 Enhancing profitability	Profit	Wages of management
Beef + Lamb (NZ)	C1 Financial well-being is maintained	C1.5 Enhancing profitability	Revenue	Cattle gross margin
Beef + Lamb (NZ)	C1 Financial well-being is maintained	C1.5 Enhancing profitability	Revenue	Cattle revenue
Beef + Lamb (NZ)	C1 Financial well-being is maintained	C1.5 Enhancing profitability	Revenue	Dairy grazing revenue
Beef + Lamb (NZ)	C1 Financial well-being is maintained	C1.5 Enhancing profitability	Revenue	Deer gross margin
Beef + Lamb (NZ)	C1 Financial well-being is maintained	C1.5 Enhancing profitability	Revenue	Deer+velvet revenue
Beef + Lamb (NZ), DairyBase	C1 Financial well-being is maintained	C1.5 Enhancing profitability	Revenue	Gross Farm Revenue (GFR)
Beef + Lamb (NZ)	C1 Financial well-being is maintained	C1.5 Enhancing profitability	Revenue	Sheep gross margin
Beef + Lamb (NZ)	C1 Financial well-being is maintained	C1.5 Enhancing profitability	Revenue	Sheep revenue
Beef + Lamb (NZ)	C1 Financial well-being is maintained	C1.5 Enhancing profitability	Revenue	Sheep+Wool revenue
Beef + Lamb (NZ)	C1 Financial well-being is maintained	C1.5 Enhancing profitability	Revenue	Wool revenue
Meat & Wool (NZ)	C1 Financial well-being is maintained	C1.6 Balancing liabilities and assets	Liabilities	Current liabilities at close
Meat & Wool (NZ)	C1 Financial well-being is maintained	C1.6 Balancing liabilities and assets	Liabilities	Term liabilities at close
DairyBase	C5 Production is efficient	C5.1 Enhancing production	Production	Replacement calves reared Non-replacement calves reared
MPI, Beef + Lamb, Red Sky (Australian)	C5 Production is efficient	C5.1 Enhancing production	Production	Stocking rate-
	C5 Production is efficient	C5.1 Enhancing production	Production	Total Liveweight of Beef Sold
Beef + Lamb (NZ)	C5 Production is efficient	C5.1 Enhancing production	Production	Wool net before freight
Beef + Lamb (NZ)	C5 Production is efficient	C5.1 Enhancing production	Production	Wool production (calculated)
Beef + Lamb (NZ)	C5 Production is efficient	C5.1 Enhancing production	Production	Wool shorn
Beef + Lamb (NZ)	C5 Production is efficient	C5.1 Enhancing	Production	Wool sold

Source	Outcomes	Objectives	Indicator	Measure
		production		
Red Sky	C5 Production is efficient	C5.2 Enhancing productivity	Labour productivity	Full time paid labour equivalents Full time unpaid labour equivalents FTE unpaid management
Red Sky	C5 Production is efficient	C5.2 Enhancing productivity	Labour productivity	Stock per FTE
Beef + Lamb (NZ)	C2 Vulnerability is minimised	C2.1 Ensuring stability of production	Intensity/intensification	Crop fertiliser
Beef + Lamb (NZ)	C2 Vulnerability is minimised	C2.1 Ensuring stability of production	Intensity/intensification	Other fertiliser
Beef + Lamb (NZ)	C2 Vulnerability is minimised	C2.1 Ensuring stability of production	Intensity/intensification	Pasture fertiliser
Beef + Lamb (NZ)	C2 Vulnerability is minimised	C2.1 Ensuring stability of production	Intensity/intensification	Pasture K
Beef + Lamb (NZ)	C2 Vulnerability is minimised	C2.1 Ensuring stability of production	Intensity/intensification	Pasture N
Beef + Lamb (NZ)	C2 Vulnerability is minimised	C2.1 Ensuring stability of production	Intensity/intensification	Pasture P
Beef + Lamb (NZ)	C2 Vulnerability is minimised	C2.1 Ensuring stability of production	Intensity/intensification	Pasture S
Beef + Lamb (NZ)	C2 Vulnerability is minimised	C2.1 Ensuring stability of production	Intensity/intensification	Sheep: Cattle SU ratio
Beef + Lamb (NZ)	C2 Vulnerability is minimised	C2.1 Ensuring stability of production	Intensity/intensification	Stocking rate
Beef + Lamb (NZ)	C2 Vulnerability is minimised	C2.1 Ensuring stability of production	Intensity/intensification	Total fertiliser
Beef + Lamb (NZ)	C2 Vulnerability is minimised	C2.1 Ensuring stability of production	Intensity/intensification	Total fertiliser
Beef + Lamb (NZ)	C2 Vulnerability is minimised	C2.1 Ensuring stability of production	Product diversification	Cash crop area
Beef + Lamb (NZ)	C2 Vulnerability is minimised	C2.1 Ensuring stability of production	Product diversification	Cattle:sheep: deer ratio
Interview data	C2 Vulnerability is minimised	C2.1 Ensuring stability of production	Product diversification	Off farm income
Beef + Lamb (NZ)	C2 Vulnerability is minimised	C2.1 Ensuring stability of production	Production levels	All lambs tailed
Red Sky	C2 Vulnerability is minimised	C2.1 Ensuring stability of production	Production levels	Average Carcass Weight of Lamb Sold
Red Sky	C2 Vulnerability is minimised	C2.1 Ensuring stability of production	Production levels	Average Value of Lamb Sold per Unit of Stock
Beef + Lamb (NZ)	C2 Vulnerability is minimised	C2.1 Ensuring stability of production	Production levels	Beef production
Beef + Lamb (NZ)	C2 Vulnerability is minimised	C2.1 Ensuring stability of production	Production levels	Calf loss
Beef + Lamb (NZ)	C2 Vulnerability is minimised	C2.1 Ensuring stability of production	Production levels	Calves marked
Beef + Lamb (NZ)	C2 Vulnerability is minimised	C2.1 Ensuring stability of production	Production levels	Calving
ARGOS	C2 Vulnerability is	C2.1 Ensuring stability	Production	Carcass weight/ha

Source	Outcomes	Objectives	Indicator	Measure
	minimised	of production	levels	
Beef + Lamb (NZ)	C2 Vulnerability is minimised	C2.1 Ensuring stability of production	Production levels	Cattle loss
Beef + Lamb (NZ)	C2 Vulnerability is minimised	C2.1 Ensuring stability of production	Production levels	Cows + heifers mated
ARGOS	C2 Vulnerability is minimised	C2.1 Ensuring stability of production	Production levels	Crop %
Beef + Lamb (NZ)	C2 Vulnerability is minimised	C2.1 Ensuring stability of production	Production levels	Deer loss
Beef + Lamb (NZ)	C2 Vulnerability is minimised	C2.1 Ensuring stability of production	Production levels	Deer production
Beef + Lamb (NZ)	C2 Vulnerability is minimised	C2.1 Ensuring stability of production	Production levels	Ewes mated
Beef + Lamb (NZ)	C2 Vulnerability is minimised	C2.1 Ensuring stability of production	Production levels	Fawn loss
Beef + Lamb (NZ)	C2 Vulnerability is minimised	C2.1 Ensuring stability of production	Production levels	Fawning
Beef + Lamb (NZ)	C2 Vulnerability is minimised	C2.1 Ensuring stability of production	Production levels	Fawns marked
Beef + Lamb (NZ)	C2 Vulnerability is minimised	C2.1 Ensuring stability of production	Production levels	Hinds mated
Beef + Lamb (NZ)	C2 Vulnerability is minimised	C2.1 Ensuring stability of production	Production levels	Hogget lambs as a % of all lambs
Beef + Lamb (NZ)	C2 Vulnerability is minimised	C2.1 Ensuring stability of production	Production levels	Lamb loss
Beef + Lamb (NZ)	C2 Vulnerability is minimised	C2.1 Ensuring stability of production	Production levels	Lamb production
Beef + Lamb (NZ)	C2 Vulnerability is minimised	C2.1 Ensuring stability of production	Production levels	Lambing
ARGOS	C2 Vulnerability is minimised	C2.1 Ensuring stability of production	Production levels	Lambing %
Beef + Lamb (NZ)	C2 Vulnerability is minimised	C2.1 Ensuring stability of production	Production levels	Lambs from ewes
Beef + Lamb (NZ)	C2 Vulnerability is minimised	C2.1 Ensuring stability of production	Production levels	Lambs from hoggets
Beef + Lamb (NZ)	C2 Vulnerability is minimised	C2.1 Ensuring stability of production	Production levels	Mutton production
BNZ sharemilker competition	C2 Vulnerability is minimised	C2.1 Ensuring stability of production	Production levels	Pasture DM harvested
	C2 Vulnerability is minimised	C2.1 Ensuring stability of production	Production levels	Predominant breeds
Beef + Lamb (NZ)	C2 Vulnerability is minimised	C2.1 Ensuring stability of production	Production levels	Sales all lambs
Beef + Lamb (NZ)	C2 Vulnerability is minimised	C2.1 Ensuring stability of production	Production levels	Sales prime lambs
Beef + Lamb (NZ)	C2 Vulnerability is minimised	C2.1 Ensuring stability of production	Production levels	Sales store lambs
Beef + Lamb (NZ)	C2 Vulnerability is minimised	C2.1 Ensuring stability of production	Production levels	Sheep loss
Red Sky	C2 Vulnerability is minimised	C2.1 Ensuring stability of production	Production levels	Total Value of Wool Sold per Hectare
Red Sky	C2 Vulnerability is	C2.1 Ensuring stability	Production	Total Weight of Lamb

Source	Outcomes	Objectives	Indicator	Measure
	minimised	of production	levels	Produced per Hectare
Red Sky	C2 Vulnerability is minimised	C2.1 Ensuring stability of production	Production levels	Weight of Wool Produced per Unit of Stock
	C2 Vulnerability is minimised	C2.1 Ensuring stability of production	Production levels	wool quality (break, colour)
Beef + Lamb (NZ)	C2 Vulnerability is minimised	C2.2 Ensuring stability of supply	Procurement channels	Meat Co, supplied
DairyBase	C2 Vulnerability is minimised	C2.4 Managing liquidity	Cash-flow	Cash Operating Surplus (COS)
DairyBase	C2 Vulnerability is minimised	C2.4 Managing liquidity	Cash-flow	Cash Surplus/Deficit
DairyBase	C2 Vulnerability is minimised	C2.4 Managing liquidity	Cash-flow	Farm Working Expenses (FEW)
DairyBase	C2 Vulnerability is minimised	C2.4 Managing liquidity	Cash-flow	Net Cash Income
DairyBase	C2 Vulnerability is minimised	C2.4 Managing liquidity	Safety net	Discretionary Cash
Meat & Wool (NZ)	C2 Vulnerability is minimised	C2.4 Managing liquidity	Safety net	Reserves at close
BNZ sharemilker competition	C2 Vulnerability is minimised	C2 Vulnerability is minimised	Risk Management	Cost of production per kg product
BNZ sharemilker competition	C2 Vulnerability is minimised	C2 Vulnerability is minimised	Risk Management	Operating profit margin
BNZ sharemilker competition	C2 Vulnerability is minimised	C2 Vulnerability is minimised	Risk Management	Pasture as % of feed consumed
Interview data	C2 Vulnerability is minimised	C2 Vulnerability is minimised	Risk Management	Stocking rate flexibility
Interview data	C2 Vulnerability is minimised	C2 Vulnerability is minimised	Risk Management	Stored feed on hand
	C2 Vulnerability is minimised	C2 Vulnerability is minimised	Water availability	% of farm area irrigated
DairyBase	C2 Vulnerability is minimised	C2 Vulnerability is minimised	Water availability	NIWA 10 year average rainfall Season's rainfall
	C2 Vulnerability is minimised	C2 Vulnerability is minimised	Water availability	Soil moisture
Beef + Lamb (NZ)	C2 Vulnerability is minimised		Physical	Land class/ steepness
Beef + Lamb (NZ)			Physical	Lime
DairyBase			Physical	Location
ARGOS			Physical	Olsen P
ARGOS			Physical	pH
DairyBase			Physical	Predominant Soil Type
DairyBase			Size of business	Business Type
Beef + Lamb (NZ)			Size of business	Effective area
Beef + Lamb (NZ)			Size of business	New grass area
Beef + Lamb (NZ)			Size of business	Opening cattle
Beef + Lamb (NZ)			Size of business	Opening deer

Source	Outcomes	Objectives	Indicator	Measure
Beef + Lamb (NZ)			Size of business	Opening sheep
Beef + Lamb (NZ)			Size of business	Opening total
DairyBase			Size of business	Organic
			Size of business	Start of lambing
Red Sky			Size of business	Total area
Beef + Lamb (NZ), Red Sky			Size of business	Total labour units
Beef + Lamb (NZ)			Size of business	Working Owners
Dashboard	C3 Product quality and information is enhanced	C3.1 Managing food safety	Hazardous pesticides	
Dashboard	C3 Product quality and information is enhanced	C3.1 Managing food safety	Food contamination	
Dashboard	C3 Product quality and information is enhanced	C3.2 Enhancing food quality		
Dashboard	C3 Product quality and information is enhanced	C3.3 Providing reliable product information		
Dashboard	C4 Contribute to creating value in local economy	C4.1 Enhancing local economy	Procurement practices	
Dashboard	C4 Contribute to creating value in local economy	C4.1 Enhancing local economy	Regional workforce	
Dashboard	C4 Contribute to creating value in local economy	C4.2 Investing in community		

Table 26: Environmental Indicators

Source	Outcomes	Objectives	Indicator	Measure
Stats NZ	E1 Natural capital maintained	E1.1 Maintaining ecosystem processes	Land cover	Area of native land cover
September 2014, New Zealand Department of Conservation	E1 Natural capital maintained	E1.1 Maintaining ecosystem processes	Land cover	% of environmental unit under indigenous vegetation and protected.
ARGOS	E1 Natural capital maintained	E1.1 Maintaining ecosystem processes	Land cover	Bare ground
ARGOS	E1 Natural capital maintained	E1.1 Maintaining ecosystem processes	Pollination	
ARGOS	E1 Natural capital maintained	E1.1 Maintaining ecosystem processes	Soil Status	Soil status
Beef+Lamb-LEP	E1 Natural capital maintained	E1.1 Maintaining ecosystem processes	Soil Status	Soil health
September 2014, New Zealand Department of Conservation	E1 Natural capital maintained	E1.1 Maintaining ecosystem processes	Number, extent and control of fire.	
Stats NZ	E1 Natural capital maintained	E1.1 Maintaining ecosystem processes	Water quality & yield	Population with drinking water meeting standards
Stats NZ	E1 Natural capital maintained	E1.1 Maintaining ecosystem processes	Water quality & yield	Nitrogen in rivers and streams

Source	Outcomes	Objectives	Indicator	Measure
Stats NZ	E1 Natural capital maintained	E1.1 Maintaining ecosystem processes	Water quality & yield	Biological health of rivers and streams
Stats NZ and Waikato Regional Council	E1 Natural capital maintained	E1.1 Maintaining ecosystem processes	Water quality & yield	Lake water quality (water clarity (Secchi disc depth) .algal biomass level (as chlorophyll a) in the 0 - 10 m layer, total nitrogen level in the 0 - 10 m layer and volumetric hypolimnetic oxygen depletion rate (VHOD).
Stats NZ	E1 Natural capital maintained	E1.1 Maintaining ecosystem processes	Water quality & yield	Groundwater quality
Stats NZ	E1 Natural capital maintained	E1.1 Maintaining ecosystem processes	Water quality & yield	Bacterial pollution at coastal swimming spots, rivers and lakes
Rotorua Lakes/Headlands	E1 Natural capital maintained	E1.1 Maintaining ecosystem processes	Water quality & yield	Operating Profit/kgN leached/ha
Rotorua Lakes/Headlands	E1 Natural capital maintained	E1.1 Maintaining ecosystem processes	Water quality & yield	kg product/kg N leached/ha
Rotorua Lakes/Headlands	E1 Natural capital maintained	E1.1 Maintaining ecosystem processes	Water quality & yield	Nitrogen conversion efficiency %
Rotorua Lakes/Headlands	E1 Natural capital maintained	E1.1 Maintaining ecosystem processes	Water quality & yield	kg N leached/ha
Rotorua Lakes/Headlands	E1 Natural capital maintained	E1.1 Maintaining ecosystem processes	Water quality & yield	winter cropping % of farm
Rotorua Lakes/Headlands	E1 Natural capital maintained	E1.1 Maintaining ecosystem processes	Water quality & yield	kg P runoff/ha
Rotorua Lakes	E1 Natural capital maintained	E1.1 Maintaining ecosystem processes	Water quality & yield	riverflow
Rotorua Lakes	E1 Natural capital maintained	E1.1 Maintaining ecosystem processes	Water quality & yield	Use of the river (takes or discharges)
Rotorua Lakes	E1 Natural capital maintained	E1.1 Maintaining ecosystem processes	Water quality & yield	riverbed condition
Stats NZ	E1 Natural capital maintained	E1.1 Maintaining ecosystem processes	Water quality & yield	Water allocation compared to total water resource
Fonterra	E1 Natural capital maintained	E1.1 Maintaining ecosystem processes	Water quality & yield	water withdrawn per L of raw milk processed
Fonterra	E1 Natural capital maintained	E1.1 Maintaining ecosystem processes	Water quality & yield	% waste water treated
Fonterra	E1 Natural capital maintained	E1.1 Maintaining ecosystem processes	Water quality & yield	on-farm water footprint
Fonterra	E1 Natural capital maintained	E1.1 Maintaining ecosystem processes	Water quality & yield	waterways where all stock is excluded
Fonterra	E1 Natural capital maintained	E1.1 Maintaining ecosystem processes	Water quality & yield	crossing points have bridges or culverts
Fonterra	E1 Natural capital maintained	E1.1 Maintaining ecosystem processes	Water quality & yield	have nutrient budget
Fonterra	E1 Natural capital maintained	E1.1 Maintaining ecosystem processes	Water quality & yield	fully compliant effluent system

Source	Outcomes	Objectives	Indicator	Measure
Fonterra	E1 Natural capital maintained	E1.1 Maintaining ecosystem processes	Water quality & yield	efficient water use (minimal leakage from infrastructure)
Beef+Lamb-LEP	E1 Natural capital maintained	E1.1 Maintaining ecosystem processes	Water quality & yield	Water quality
DairyNZ-SMP	E1 Natural capital maintained	E1.1 Maintaining ecosystem processes	Water quality & yield	Farm Phosphorous loss
DairyNZ-SMP	E1 Natural capital maintained	E1.1 Maintaining ecosystem processes	Water quality & yield	Farm Nitrogen loss (leached)
DairyNZ-SMP	E1 Natural capital maintained	E1.1 Maintaining ecosystem processes	Water quality & yield	Effluent system
DairyNZ-SMP	E1 Natural capital maintained	E1.1 Maintaining ecosystem processes	Water quality & yield	Irrigation water use efficiency (%)
ARGOS, Dashboard	E1 Natural capital maintained	E1.2 Reducing agricultural pest threats	Agricultural disease, weed & pest dominance	
Stats NZ	E1 Natural capital maintained	E1.2 Reducing agricultural pest threats	Occupancy of environmental range	Distribution of selected pest animal and weed spp.
Fonterra	E1 Natural capital maintained	E1.3 Limiting environmental pollutants	Ecosystem levels of persistent toxins	Chemical use
ARGOS	E1 Natural capital maintained	E1.3 Limiting environmental pollutants	Environmental risk of toxins	Pesticide use
Sustainable Business NZ	E2 Resilience secured for future use	E2.1 Minimising material & energy subsidies	Energy	Energy consumption
Stats NZ	E2 Resilience secured for future use	E2.1 Minimising material & energy subsidies	Energy use	Total primary energy supply per person
Stats NZ	E2 Resilience secured for future use	E2.1 Minimising material & energy subsidies	Energy use	Energy intensity of the economy
Stats NZ	E2 Resilience secured for future use	E2.1 Minimising material & energy subsidies	Energy use	% of electricity generation from renewable resources
Stats NZ	E2 Resilience secured for future use	E2.1 Minimising material & energy subsidies	Energy use	Household energy used in the home, by income group
Stats NZ	E2 Resilience secured for future use	E2.1 Minimising material & energy subsidies	Energy use	Energy dependency
Stats NZ	E2 Resilience secured for future use	E2.1 Minimising material & energy subsidies	Energy use	Energy-related GHG emissions
Fonterra	E2 Resilience secured for future use	E2.1 Minimising material & energy subsidies	Energy use	electrical and thermal energy consumed per tonne product produced
Dashboard/SAFA/DairyNZ	E2 Resilience secured for future use	E2.1 Minimising material & energy subsidies	Energy use	Energy use

Source	Outcomes	Objectives	Indicator	Measure
	E2 Resilience secured for future use	E2.1 Minimising material & energy subsidies	non-renewable materials	
Fonterra	E2 Resilience secured for future use	E2.1 Minimising material & energy subsidies	solid waste	recycle agrichemical containers &silage wrap
Fonterra	E2 Resilience secured for future use	E2.1 Minimising material & energy subsidies	solid waste	% solid waste either recycled or reused
Fonterra	E2 Resilience secured for future use	E2.1 Minimising material & energy subsidies	solid waste	Waste sent to landfill
Dashboard/SAFA/DairyNZ	E2 Resilience secured for future use	E2.2 Maintaining agro-biodiversity	Beneficial species	
Dashboard/SAFA/DairyNZ	E2 Resilience secured for future use	E2.2 Maintaining agro-biodiversity	Genetic stock	
Dashboard/SAFA/DairyNZ	E2 Resilience secured for future use	E2.2 Maintaining agro-biodiversity	Landscape functional Heterogeneity	
Beef + Lamb	E3 Contribute to national 'natural heritage ' goals	E3.1 Maintaining ecosystem representation & composition	Ecosystem composition	Biodiversity
New Zealand Department of Conservation	E3 Contribute to national 'natural heritage ' goals	E3.1 Maintaining ecosystem representation & composition	Occupancy of environmental range	Extent of potential range occupied by focal taxa.
Stats NZ	E3 Contribute to national 'natural heritage ' goals	E3.1 Maintaining ecosystem representation & composition	Occupancy of environmental range	Distribution of selected native spp.
Fonterra	E3 Contribute to national 'natural heritage ' goals	E3.1 Maintaining ecosystem representation & composition	Ecosystem representation & protection	protect wetlands
New Zealand Department of Conservation	E3 Contribute to national 'natural heritage ' goals	E3.1 Maintaining ecosystem representation & composition	Ecosystem representation & protection	% of environment in freshwater ecosystems and protected
ECan/SFF project (Guidelines for high country whole farm plans)	E3 Contribute to national 'natural heritage ' goals	E3.1 Maintaining ecosystem representation & composition	Ecosystem representation & protection	tussock density
September 2014, New Zealand Department of Conservation	E3 Contribute to national 'natural heritage ' goals	E3.1 Maintaining ecosystem representation & composition	Ecosystem representation & protection	Change in extent and integrity of nationally uncommon, significantly reduced habitats/ ecosystems that are protected
September 2014, New Zealand Department of Conservation	E3 Contribute to national 'natural heritage ' goals	E3.2 Preventing extinctions & declines	status of threatened species	Number of extinctions
September 2014, New Zealand	E3 Contribute to national 'natural heritage ' goals	E3.2 Preventing extinctions & declines	status of threatened	Demographic response to

Source	Outcomes	Objectives	Indicator	Measure
Department of Conservation			species	management at a population level for selected 'threatened' and 'at risk' taxa.
September 2014, New Zealand Department of Conservation, Stats NZ	E3 Contribute to national 'natural heritage ' goals	E3.2 Preventing extinctions & declines	status of threatened species	Number of 'threatened' and 'at risk' species.
New Zealand Department of Conservation	E3 Contribute to national 'natural heritage ' goals	E3.3 Reducing conservation pest threats	Conservation weed & pest dominance	Demography of widespread animal species.
New Zealand Department of Conservation , ARGOS	E3 Contribute to national 'natural heritage ' goals	E3.3 Reducing conservation pest threats	new conservation weed & pest species	Distribution and abundance of exotic weeds and animal pests considered a threat.
Stats NZ, sustainable Business NZ, ARGOS	E4 Global environmental change obligations met	E4.1 Reducing emissions	Reducing emissions	GHG emissions
Stats NZ	E4 Global environmental change obligations met	E4.1 Reducing emissions	Reducing emissions	GHG emissions by sector
Stats NZ	E4 Global environmental change obligations met	E4.1 Reducing emissions	Reducing emissions	Annual surface temperature
Stats NZ	E4 Global environmental change obligations met	E4.1 Reducing emissions	Reducing emissions	GHG intensity of the economy
Stats NZ	E4 Global environmental change obligations met	E4.1 Reducing emissions	Reducing emissions	Air pollution
ARGOS	E4 Global environmental change obligations met	E4.2 Increasing carbon sequestration	Carbon storage & fluxes	Carbon stored

Table 27: Social indicators

Source	Outcomes	Objectives	Indicator	Measure
Dashboard, SAFA	S1 Decent livelihoods are secured	S1.1 Improving livelihood assets	Livelihood Security	The ability to sell product and to gain employment is promoted within the value chain.
Dashboard, SAFA	S1 Decent livelihoods are secured	S1.1 Improving livelihood assets	Quality of life	All primary producers and employees enjoy a livelihood that supports culturally appropriate and adequate food and shelter and allows time for personal health and family, social and cultural responsibilities and activities.

Source	Outcomes	Objectives	Indicator	Measure
Dashboard, SAFA	S1Decent livelihoods are secured	S1.2 Limiting livelihood constraints	Fair access to land and means of production	The access of primary producers to adequate fertile land and to the means of production is not unduly constrained by legal conditions, social structures or economic inequality.
Dashboard, SAFA	S1 Decent livelihoods are secured	S1.2 Limiting livelihood constraints	Livelihood aspirations	The opportunities to achieve livelihood aspirations and social mobility for all primary producers, small holders and employees (and their children) are not constrained due to their participation and role in the value chain.
Dashboard/SAFA /NZ labour regulations	S2 Working conditions are acceptable	S2.1 Maintaining fully compliant employment processes	Terms of employment	Operations **maintain legally-binding transparent contracts** with all employees that are **accessible** and cover the **terms of work**. Employment is **compliant with national laws** on labour and social security.
Dashboard/SAFA /NZ labour regulations	S2 Working conditions are acceptable	S2.1 Maintaining fully compliant employment processes	Forced labour	**No forced, bonded or involuntary labour,** neither in its **own operations nor those of business partners.**
Dashboard/SAFA /NZ labour regulations	S2 Working conditions are acceptable	S2.1 Maintaining fully compliant employment processes	Child labour	**No child labour** that has a potential to harm the physical or mental health, or hinder the education of minors, neither in its **own operations nor in those of business partners**.
Dashboard/SAFA	S2 Working conditions are acceptable	S2.2 Maintaining high quality working conditions	Wages and benefits	All **employees and self-employed earn** at least the **local living wage.** Includes salaries, income level and benefits
Dashboard/SAFA , Sustainable Business NZ			Staff retention	The level of staff retention indicates whether employees are satisfied with working conditions in an enterprise.
Sustainable Business NZ	S2 Working conditions are acceptable	S2.2 Maintaining high quality working conditions	Employee turnover	% of total no. of employees

Source	Outcomes	Objectives	Indicator	Measure
Stats NZ	S2 Working conditions are acceptable	S2.2 Maintaining high quality working conditions	Labour productivity	
Dashboard/SAFA	S2 Working conditions are acceptable	S2.2 Maintaining high quality working conditions	Freedom of association and bargaining	All persons in the enterprise can **freely** execute the rights to (i) **form** or **adhere** to an **association defending workers' rights**, (ii) **collectively bargain** and (iii) **participate in public political process**, without retribution.
Dashboard/SAFA	S2 Working conditions are acceptable	S2.2 Maintaining high quality working conditions	Working hours/work-life balance	
Dashboard/SAFA	S3 Equity is supported	S3.1 Maintaining equity processes	Non-discrimination	
Sustainable Business NZ	S3 Equity is supported	S3.1 Maintaining equity processes	Non-discrimination	Gender diversity
Sustainable Business NZ	S3 Equity is supported	S3.1 Maintaining equity processes	Non-discrimination	% women from total no. of employees and senior management
Stats NZ	S3 Equity is supported	S3.1 Maintaining equity processes	Non-discrimination	Pay equality by ethnicity
Dashboard/SAFA	S3 Equity is supported	S3.2 Improving support for vulnerable groups	Support to vulnerable people	
Sustainable Business NZ	S4 Human health and safety is prioritised	S4.1 Maintaining safe, hygienic & healthy environment	Lost time injury frequency	Rate of frequency per million hours worked
DairyNZ	S4 Human health and safety is prioritised	S4.1 Maintaining safe, hygienic & healthy environment	ACC claims	
DairyNZ	S4 Human health and safety is prioritised	S4.1 Maintaining safe, hygienic & healthy environment	Days sick	
Dashboard/SAFA	S4 Human health and safety is prioritised	S4.1 Maintaining safe, hygienic & healthy environment	Health and safety policy	
Dashboard/SAFA /Sustainable Business NZ	S4 Human health and safety is prioritised	S4.1 Maintaining safe, hygienic & healthy environment	Absenteeism	Rate of absence per annum
Dashboard/SAFA /Sustainable Business NZ	S4 Human health and safety is prioritised	S4.2 Improving facilities to meet basic human needs	Workplace safety and health provisions for employees and self-employed	Workplace safety management practices
Dashboard/SAFA	S4 Human health and safety is prioritised	S4.2 Improving facilities to meet basic human needs	Farm workers are well treated	
Dashboard/SAFA /Stats NZ	S4 Human health and safety is prioritised	S4.2 Improving facilities to meet basic human needs	Community health	Health expectancy at birth

Source	Outcomes	Objectives	Indicator	Measure
Stats NZ	S4 Human health and safety is prioritised	S4.2 Improving facilities to meet basic human needs	Community health	Prevalence of healthy lifestyles
Stats NZ	S4 Human health and safety is prioritised	S4.2 Improving facilities to meet basic human needs	Community health	Childhood immunisation coverage
Stats NZ	S4 Human health and safety is prioritised	S4.2 Improving facilities to meet basic human needs	Community health	Prevalence of psychological distress
Stats NZ	S4 Human health and safety is prioritised	S4.2 Improving facilities to meet basic human needs	Community health	Suicide rate
Stats NZ	S4 Human health and safety is prioritised	S4.2 Improving facilities to meet basic human needs	Community health	Avoidable hospital admissions
Stats NZ	S4 Human health and safety is prioritised	S4.2 Improving facilities to meet basic human needs	Community health	Cancer-survival probabilities
Stats NZ	S5 Community resilience is enhanced	S5.1 Respecting cultural worldviews and use rights	Commitment to bi-culturalism	Speakers of te reo Mäori
Stats NZ	S5 Community resilience is enhanced	S5.1 Respecting cultural worldviews and use rights	Commitment to bi-culturalism	Children attending Mäori language immersion schools
Rotorua Lakes	S5 Community resilience is enhanced	S5.1 Respecting cultural worldviews and use rights	Mahinga Kai	Safe tasting water?
Rotorua Lakes	S5 Community resilience is enhanced	S5.1 Respecting cultural worldviews and use rights	Mahinga Kai	Would you fish here?
Rotorua Lakes	S5 Community resilience is enhanced	S5.1 Respecting cultural worldviews and use rights	Mahinga Kai	Safe eating fish?
Rotorua Lakes	S5 Community resilience is enhanced	S5.1 Respecting cultural worldviews and use rights	Mahinga Kai	Safe to swim?
Rotorua Lakes	S5 Community resilience is enhanced	S5.1 Respecting cultural worldviews and use rights	Mahinga Kai	Food sources present?
Dashboard /SAFA	S5 Community resilience is enhanced	S5.1 Respecting cultural worldviews and use rights	Knowledges	
Dashboard/SAFA /Synlait	S5 Community resilience is enhanced	S5.2 Recognising stakeholder values & choices	Product quality	
Dashboard/SAFA	S5 Community resilience is enhanced	S5.2 Recognising stakeholder values & choices	Food sovereignty	
Dashboard/SAFA	S5 Community resilience is enhanced	S5.2 Recognising stakeholder values & choices	Contribution to local Community	
ARGOS	S5 Community resilience is enhanced	S5.2 Recognising stakeholder values & choices	Social connection and governance	Farming contributing to community
Dashboard/SAFA	S5 Community resilience is enhanced	S5.2 Recognising stakeholder values & choices	Social capital	

Source	Outcomes	Objectives	Indicator	Measure
ARGOS	S5 Community resilience is enhanced	S5.2 Recognising stakeholder values & choices	Family	number of generations involved in business
ARGOS	S5 Community resilience is enhanced	S5.2 Recognising stakeholder values & choices	Family	number of children in household under 18yr.
ARGOS	S5 Community resilience is enhanced	S5.2 Recognising stakeholder values & choices	Family	scope for farm succession
ARGOS	S5 Community resilience is enhanced	S5.2 Recognising stakeholder values & choices	Family	Time for family
ARGOS	S5 Community resilience is enhanced	S5.2 Recognising stakeholder values & choices	Family	Time for community
ARGOS	S5 Community resilience is enhanced	S5.2 Recognising stakeholder values & choices	Family	Time for recreation
Dashboard/SAFA	S5 Community resilience is enhanced	S5.2 Recognising stakeholder values & choices	Human capital	
Sustainable Business NZ	S5 Community resilience is enhanced	S5.2 Recognising stakeholder values & choices	Human capital	Skills enhancement
Stats NZ	S5 Community resilience is enhanced	S5.2 Recognising stakeholder values & choices	Human capital	Educational attainment of the adult population
Stats NZ	S5 Community resilience is enhanced	S5.2 Recognising stakeholder values & choices	Human capital	Participation in tertiary education
Stats NZ	S5 Community resilience is enhanced	S5.2 Recognising stakeholder values & choices	Human capital	Literacy skills
Stats NZ	S5 Community resilience is enhanced	S5.2 Recognising stakeholder values & choices	Human capital	Access to early childhood education,
Dashboard/SAFA	S5 Community resilience is enhanced	S5.2 Recognising stakeholder values & choices	Identity/Sense of place	

Table 28: Governance indicators and measures

Source	Outcomes	Objectives	Indicator	Measure
DairyNZ	G1 Governance structure is effective	G1.1 Maintaining transparent decision making processes	Decision making and implementation processes	Leadership
DairyNZ	G1 Governance structure is effective	G1.1 Maintaining transparent decision making processes	Decision making and implementation processes	effective governance culture
DairyNZ	G1 Governance structure is effective	G1.1 Maintaining transparent decision making processes	Decision making and implementation processes	succession planning

Source	Outcomes	Objectives	Indicator	Measure
Dashboard/SAFA/DairyNZ	G1 Governance structure is effective	G1.1 Maintaining transparent decision making processes	Decision making and implementation processes	making right decisions
Dashboard/SAFA	G1 Governance structure is effective	G1.2 Enacting corporate ethics or mission statements	Mission driven	
DairyNZ	G1 Governance structure is effective	G1.2 Enacting corporate ethics or mission statements	Mission explicitness	determining purpose
Dashboard/SAFA/DairyNZ	G1 Governance structure is effective	G1.2 Enacting corporate ethics or mission statements	Mission explicitness	Business strategy
DairyNZ	G1 Governance structure is effective	G1.3 Practicing due diligence	Capability	a learning orientation
Dashboard/SAFA	G1 Governance structure is effective	G1.3 Practicing due diligence	Capability	Capability and resources to carry out sustainability reporting and to maintain record keeping and record storage.
Dashboard/SAFA	G1 Governance structure is effective	G1.3 Practicing due diligence	Due diligence	The enterprise is "pro-active in considering its external impacts before making decisions that have long term impacts - environmental, economic social or governance - of sustainability" (SAFA, 2013c: 14).
Dashboard/SAFA/DairyNZ	G1 Governance structure is effective	G1.3 Practicing due diligence	Methodology and tools to monitor and implement sustainability	benchmarking
Dashboard/SAFA	G2 Accountability is maintained	G2.1 Maintaining regular and transparent reporting	Holistic audits	
Dashboard/SAFA	G2 Accountability is maintained	G2.2 Management actions are responsible	Responsibility	
Dashboard/SAFA	G2 Accountability is maintained	G2.2 Management actions are responsible	Risk management	attitude to risk
Dashboard/SAFA/DairyNZ	G2 Accountability is maintained	G2.2 Management actions are responsible	Risk management	managing risks effectively
Dashboard/SAFA/DairyNZ	G2 Accountability is maintained	G2.3 Management actions are transparent	transparency	holding to account
Dashboard/SAFA	G3 Stakeholder participation is enhanced	G3.1 Maintaining effective stakeholder dialogue	effective stakeholder participation	
Dashboard/SAFA	G3 Stakeholder participation is enhanced	G3.1 Maintaining effective stakeholder dialogue	internal communication	
Dashboard/SAFA	G3 Stakeholder participation is enhanced	G3.2 Grievance procedures are in place	Grievance procedures, employees, contractors	

Source	Outcomes	Objectives	Indicator	Measure
Dashboard/SAFA	G3 Stakeholder participation is enhanced	G3.3 Conflict resolution procedures are in place	conflict resolution	
Dashboard/SAFA	G4 The rule of law is followed	G4.1 Maintaining commitment to fairness, legitimacy & transparency	Fairness	
Dashboard/SAFA	G4 The rule of law is followed	G4.1 Maintaining commitment to fairness, legitimacy & transparency	Legal compliance	
Dashboard /SAFA	G4 The rule of law is followed	G4.1 Maintaining commitment to fairness, legitimacy & transparency	Resource consent compliance	
Dashboard/SAFA	G4 The rule of law is followed	G4.2 Procedures for remedy, restoration & prevention are effective		
Dashboard/SAFA	G4 The rule of law is followed	G4.3 Meeting civic responsibilities		
Dashboard	G4 The rule of law is followed	G4.4 Resources are not misappropriated	Compliance with spirit of Treaty of Waitangi	
Dashboard	G4 The rule of law is followed	G4.5 Maintaining compliance with animal welfare legislation		
Dashboard/SAFA	G5 Management approach is Holistic	G5.1 Implementing a sustainability management plan	Implements a Land & Environment Plan/Farm Environment Plan	
	G5 Management approach is Holistic	G5.2 Practicing full-cost accounting		

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