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Operationalising resilience in dairy agroecosystems

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Abstract

As demonstrated by the recent (2012/13) “once-in-a-lifetime” drought conditions that affected nearly the entire country, New Zealand’s diverse primary production sectors remain acutely vulnerable to climate extremes. Furthermore, the shift towards more intensive production and higher-input systems, have the potential to create new risks and increase uncertainty for producers.

Resilient systems have been characterised as those that have a higher capacity to absorb shocks and stresses; have the ability to self-organize into flexible and responsive networks for learning, distribution and change, and; have a high capacity for learning and adaptability through feedback mechanisms within the system. While these concepts have been well developed in the literature as theoretical and conceptual frameworks, there are few examples of operationalizing and empirically applying these concepts, particularly for agroecosystems which are among the most complex of social-ecological systems.

Using a ‘bottom-up’ and participatory-based approach, we reviewed and then empirically applied a set of behavioural indicators across three different types of dairy farm systems in eastern New Zealand: organic, low-input or grass-based, and high-input, intensive systems in which supplemental feed is the main input. The 19 characteristics of social, economic and ecological resilience the study developed were instrumental in evaluating the differences in the resilience of different farm types. The ‘lock in trap’ of highly intensive systems, while profitable in the near term, may be less resilient to climate shocks as these are likely to occur in conjunction with changing market and financial risks. Low-input systems are less dependent, in particular, on fossil fuels and were associated with higher levels of farmer satisfaction and well-being. The framework provides a useful template for cross-sector comparison, and demonstrates that in-depth, robust qualitative assessments of resilience can provide a complement to quantitative metrics. The characterisation of resilient farm-systems also has the potential to contribute to broader sustainability frameworks for agriculture.

Executive Summary

With annual exports in excess of $11 billion, the dairy sector is New Zealand's biggest export earner (DairyNZ 2010), and there is significant emphasis by central government to increase the dairy sector earnings as a component of overall GDP. The dairy sector is fundamental to New Zealand's economic growth, and therefore it is critical that the sector is able to anticipate and mitigate any emerging production and market-based risks. Climate change poses significant risks to and increased operating uncertainty for a sector dependent on consistent climatic conditions.

At the same time, dairying has undergone considerable change over the last decade with a significant shift in the percentage of farms operating with higher stocking rates and with a greater dependence on supplementary feed accessed from national and global markets. The rapid shift towards higher-input production systems could potentially create new risks and uncertainty for the dairy sector while it is attempting to mitigate existing risks and increase productivity.

This research aims to support the dairy sector in strategic risk identification and mitigation by:

- improving understanding of the vulnerabilities and resilience of Bay of Plenty dairy farms to the impacts of climate change and more specifically to persistent drought,
- evaluating the comparative resilience between organic, low-input and high-input, intensive dairy production systems, and
- in addition, contributing to international research exploring resilience as a conceptual and methodological framework.

To achieve these aims this study:

- identifies the key components of dairy farm systems that most influenced a farm's resilience to the impacts of climate change and more specifically to persistent drought
- uses these components as indicators to compare the resilience of different farm production systems to the region-specific stressors related to climate change
- develops, tests, and refines a conceptual model of farm level resilience that can be further tested on different pressure states (e.g. market, policy, or oil price shocks) and different agricultural farm types (e.g. sheep, beef).

Research method

The study undertook a literature review of agricultural and resilience research and key informant interviews to develop a model of a resilient dairy farm to climate change based on draft set of key indicators[1]. The indicators framework was operationalised for 15 dairy farms in the Bay of Plenty, using interviews, surveys, and farmer workshops. Potential impacts of climate change were explored using the 2012/13 drought as an analogue, together with national and regional climate data. Results show that in the short term, there is little difference in the resilience of different farm systems, though key vulnerabilities and opportunities were identified for each of the three systems examined. In the long term, higher input systems are potentially exposed to a larger range of market risks and price shocks, particularly energy. The indicators of resilient farming systems made the concept of resilience sufficiently operational for stakeholders to consider options.

Key findings and recommended next steps

1. A model of a climate-change resilient dairy farm was developed and refined through the course of the research (*Figure 1*). The model shows that the farm is only as resilient as the things and people on which it depends and therefore a number of critical factors that impact on farm-level resilience were identified 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.

   The framework provides a robust methodology to evaluate both specific and general resilience, to determine which farm system components influence resilience to a range of risks and which are only critical to specific risks. This assessment approach can help the dairy sector identify system vulnerabilities and develop and support specific adaptation strategies.

[1] The inherent challenge of 'measuring' resilience has led some to argue that developing context-dependent surrogates of resilience for each socio-ecological system, be measured in lieu of resilience itself (Bennett et al. 2005, Carpenter et al. 2006). Others have used quantified approaches such as applying mathematical models (Fletcher et al. 2006) or developing composite indices (Nelson et al. 2010a, 2010b) for resilience and vulnerability.

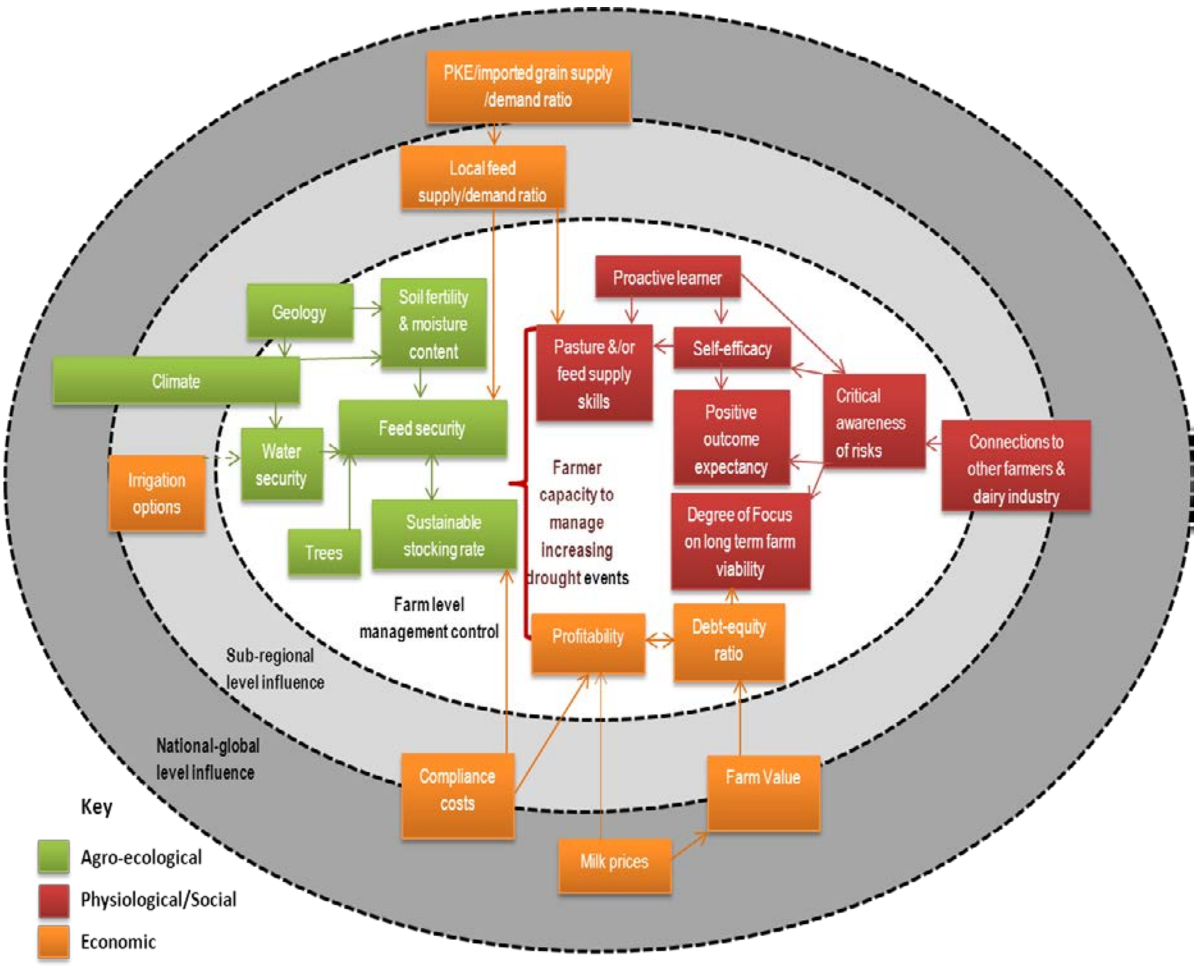

Figure 1: Model of a resilient dairy farm system in New Zealand

2. The psychological/social characteristics of the farmer play a pivotal role in creating dairy farm resilience. The research suggests the psychological/social characteristics of the farmer (or the group of people in the farm decision-making unit) play a greater role in variability in a dairy farm's resilience to drought than differences in production levels.

3. Important but subtle differences in the capacity of different farms systems to withstand and recover from shocks and stressors were identified. The impacts of climate change will not be felt uniformly, but rather will impact different types of farms in different ways.

   Changes in temperature and precipitation are likely to have a significant impact on production through changes in the range and distribution of subtropical C4 grasses. These will have a greater impact on low-input and organic producers, who are more dependent on pasture production and have fewer management options available in the short-term.

   Organic certification may constrain the ability of organic farmers to adapt effectively, and the higher costs associated with managing these grasses have the potential to influence the resilience of low-input farmers.

There is some evidence to suggest that organic and biological farming practices can enhance soil fertility and soil moisture capacity, which would help buffer those systems against future changes in climate.

4. In the short term, high-input farms were resilient to the recent drought. High-input farms, however, are exposed and sensitive to higher input costs. In addition the shift to high-input farm systems comes with high capital costs, and more detailed economic analysis may be required to determine the economic resilience of large-scale and relatively inflexible operations.

5. The study provides an initial model of farm-level resilience. The research can be further developed by:

   a) testing the model and the relative significance of the different indicators through a quantitative survey
   b) applying the model for other sectors including, for example, the wine sector and forestry,
   c) applying the model to explore variation in regional or catchment-scale resilience.

6. There is a need to adjust farm practices and sector decision-making frameworks to account for the uncertainties and the scale of future climate variability and change. Reducing riskiness in the face of uncertainty among agricultural producers will almost certainly require the identification and promotion of 'no-regret' strategies that yield benefits even in absence of climate change (Hallegatte 2009). This might be achieved through lower nitrogen-inputs, increased water monitoring, or changes in feed management systems. As one farmer noted in discussion, however, the identification of alternate strategies should come through education and participatory engagement and collaboration rather than from the 'top down'. This study has shown that through consultation with agricultural producers, a more comprehensive and complete assessment of resilience can be developed.

7. The study is based on a limited sample size (*n*=15) using in-depth, qualitative analysis, but should not be considered representative of the study area or systems.

1 Introduction

Dairying accounts for a significant portion of New Zealand's agricultural exports. With annual exports in excess of $11 billion and accounting for seven per cent of GDP, the dairy sector is New Zealand's biggest export earner, making up one-third of the international dairy trade (DairyNZ 2010). The country is also the world's largest exporter of dairy products (Gray & Le Heron 2010).

There are, however a growing number of social, economic and ecological pressures being brought to bear on the sector (Barnett & Pauling 2005; Clark *et al.* 2007). Local and regional councils are placing stronger controls on freshwater use and nutrient contamination, for example, and there are continued debates on the allocation of freshwater for irrigation, as well as the impact of dairying on water quality and local communities.

Furthermore, with expected changes in climate, many of these issues will become even more pronounced (Dynes *et al.* 2011). As the impacts of the recent 2012/13 drought demonstrated, primary producers are vulnerable to climate-related extremes. This vulnerability varies with scale: different regions of the country are affected differently because of variation in localised climates, and soil types; different farm types are affected according to the type of production and management systems; and individual farmers have different capacities to manage drought, based on for example learning from previous experience or their ability to access working capital.

This research used a qualitative approach to evaluate farm-level resilience to changes in the frequency, extent and severity of drought as a projected impact of climate change for the Bay of Plenty, New Zealand. The aim of the research was three-fold:

1. To operationalize resilience at a farm-scale through the development of indicators or surrogates[1] that can be used to help characterise the flexibility, adaptive capacity and degree of self-organization of dairy farms in the Bay of Plenty;
2. To use these indicators to compare the resilience of different farm production systems to region-specific stressors related to climate change to determine whether the level of intensification across organic, low-input and high-input farms, was positively or negatively correlated with resilience or whether other determinants were more critical, and
3. To contribute to international research exploring resilience as a conceptual and methodological framework.

Section 2 of this report outlines the research design of the study. Section 3 reviews literature to establish the conceptual and socio-ecological context of the empirical analysis. This includes: a conceptual understanding of resilience including key principles which inform this study, the economic and biophysical context within which Bay of Plenty dairy farms are currently operating, predicted climatic changes within the Bay of Plenty and possible impacts on dairy farming, and a draft model of a resilient dairy farm system to climate change comprised of 19 variables to be tested in the study.

Section 4 presents and discusses the main research findings and implications; Section 5 concludes the report with a series of recommendations.

2 Research design

2.1 Research methods

This study used a qualitative research approach using multiple methods, comprised of interviews with three key informants, 15 farmer interviews – all but one of whom completed a pre-survey interview – and two farmer workshops, attended by 16 people. Interviews and workshops were held between April and May 2013.

1. *Key informant interviews.* Three key informants from the dairy sector were interviewed to provide the broader national and regional context for dairying, and to solicit expert opinion on farmer responses to drought. Key differences between production systems were also discussed.

2. *Pre-interview survey.* A short survey was administered to 15 farmer participants before their interviews; 14 completed it. The survey was designed to gather contextual information about concerns related to climate change and the general characteristics of resilient systems (buffering, learning capacity and self-organization). Respondents were asked to self-evaluate, using a 5-point Likert scale to assess their opinions and attitudes. A copy of the survey and interview guide is available in the Appendices.

3. *Farmer interviews.* A total of 15 semi-structured interviews were held with farmers, representing different production systems, throughout the Bay of Plenty. All the interviews followed a similar format, and lasted from 1 to 2 hours. Questions were developed in advance based on a close reading of previous work on agricultural risks, vulnerability (Smit & Skinner 2002; Vásquez-León *et al.* 2003; Ziervogel *et al.* 2006) and resilience, and alignment with the proposed indicators framework. An advantage of the semi-structured format is that it provides the flexibility to develop questions, pursue comments, and develop ideas as the conversation progresses (Dunn 2005). Working with three different types of dairy farming systems, the generic nature of the interview format also allows the research to pursue lines of inquiry specific to particular farms, farmers, or management systems.

   The study sought to identify the presence of multiple climatic and climate-related risks to which producers are exposed/sensitive, as well as to establish the context within in which production occurs. Questions were designed to solicit input on a range of topics related to agricultural risk, and not climate alone. Interviewees were asked first about the general features of the farm (size, location, soil types, length of time in operation) and then responded to a series of questions on their experiences with the current drought, future prospects, and the farm management practices related to the characteristics of resilient systems we were investigating.

4. *Resilience Workshops.* Two farmer resilience workshops were held, at Awakeri and Te Puke. Both workshops were attended by eight people, including dairy farmers who had been interviewed as part of the study, other dairy farmers (often neighbours or acquaintances of those interviewed), and local government staff. The workshops were used to discuss the likely impacts of climate change on dairy farming in the Bay of Plenty, the characteristics of resilient production-systems, differences between production systems and what – if any – options might exist for supporting resilience to

climate change. Workshops were interactive and generated additional insight into resilience.

2.2 Recruitment of farmer participants

Participants were recruited through purposive and 'typical case' snowball sampling to obtain an illustrative sample of size and spatial distribution of farms (Bradshaw & Stratford 2005). Farmers were contacted by a member of the research team by telephone, and invited to take part in a structured interview and complete a survey in which they would be asked for empirical information to document the range of climate-related exposures-sensitivities and adaptive capacities. Farms were sampled over a wide geographic area, to ensure a diversity of farms with differing management system, soil type, climate, topographic and other bio-physical characteristics (*Table 1*).

Table 1 Distribution of farms (*n*=15) participating in study

Catchment	Low-input	High-input	Organic
Tauranga Harbour	**	*	*
Rotorua Lakes	**	*	
Te Puke	*	**	
Rangaitaki Plains	*	**	
Opotiki	*		*

2.3 Alignment of research design to the focus of the study

Resilience is based on understanding the dynamic interactions between climatic variability and change and the social, institutional, economic, and social structures in which it occurs (O'Brien *et al.* 2007). To examine resilience from this perspective, the emphasis is on empirically derived qualitative data. The use of qualitative data implies a greater emphasis on processes and meanings as opposed to the rigorous examination and measurement (if measured at all) of the usual metrics for documenting hazards: quantity, amount, frequency or magnitude (Tobin & Montz 1997; Hewitt 1997; Keller & DeVecchio 2011).

In such research, the focus is on insight, discovery, and interpretation rather than hypothesis testing (Merriam 1988). The emphasis was not on generating a quantitative measure or numerical ranking of indicators associated with resilience, though such studies have been done elsewhere (Schimmelpfennig & Yohe 1999; Alwang *et al.* 2001; Wilhelmi & Wilhite 2010; Yohe & Tol 2002; Hahn *et al.* 2009). Nelson and colleagues (2010a; 2010b), for example, have developed and applied a quantitative approach to assessing vulnerability based on statistical indices from national agricultural census data. This research is concerned instead with understanding the nature of farm-level resilience and its relationship to factors of production and management practices based on dairy farmers' experience.

The choice of methods was based on a close reading of the literature and a review of methods used elsewhere (Sutherland *et al.* 2005; Westerhoff & Smit 2008; Keskitalo & Kulyasova 2009a; Few & Tran 2010). It is broadly consistent with other analytical and methodological frameworks of resilience (Kasperson & Kasperson 1996; Turner *et al.* 2003; Ford & Smit 2004; Keskitalo 2004; Füssel 2007), and its documentation in other places (Adger 1999; Pearce *et al.* 2010; Faraco *et al.* 2010; Fekete 2009). The methodology also satisfies the criteria proposed by Schröter *et al.* (2005), who suggests impacts and assessments related to climate change should (1) be derived on the basis of stakeholder participation, (2) be place-specific, (3) consider multiple interacting stresses, (4) take into account differential adaptive capacity, and (5) be prospective as well as historical.

Important criteria for determining the rigour of qualitative research based on interviewing is triangulation (Baxter & Eyles 1997). Based on convergence, triangulation suggests that when multiple sources provide similar findings their credibility is considerably strengthened (Knafl & Breitmeyer 1989; Krefting 1990). In order to triangulate our initial indicators framework, the complete set of indicators was externally peer-reviewed by Prof. Douglas Paton, University of Tasmania, and Chris Perley, a New Zealand-based natural resources consultant. Additional discussion was held with Dr Nadine Marshall, CSIRO. The indicators were empirically applied through the farmer interviews; and the framework evaluated at the farmer workshops as well.

3 Framing Resilience

3.1 Defining resilience for the context of the study

The concept of resilience has been explored and developed within different fields of research including physics, phychology, natural hazards and ecology (Walker & Salt 2010; Young 2012). There is no universally agreed definition of resilience (Simmie & Martin 2009; Jones & Preston 2011), 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 system under examination (e.g. the human impact on a fisheries stock versus the impact of an earthquake on an urban settlement). In the literature, resilience is used to describe variously a biophysical attribute, a social attribute, characteristics of a social-ecological system (SES), and an attribute of specific areas (Engle 2011). In fact, until recently (see Paton 2006a) there does not appear to have been substantive theoretical integration across these different disciplinary areas of resilience research. 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). It is therefore important that we clearly identify how this research project defines resilience and related concepts and that we distinguish a set of resilience principles which guide the study.

In framing this study, we drew upon two fields of resilience science: socio-ecological resilience and disaster or hazards resilience. Socio-ecological resilience examines the interrelationships between human activity and resource use and the impact those activities and use has on ecological systems. These human-nature interrelationships are conceptualised as 'coupled social-ecological systems' (Berkes & Folke 2000; Berkes & Jolly 2002; Engle & Lemos 2010; Nelson 2011) and the literature describe the ways in which human activities and environmental processes as mutually dependent, co-evolving and linked through complex feedback relationships. Socio-ecological resilience is essentially about understanding the world as a complex adaptive system (Darnhofer *et al.* 2010b:187). It is predicated on the fact that change is constant, and that resource management must accommodate this (Walker & Salt 2006; Pomeroy 2011). Socio-ecological resilience provides the research project with an understanding of the dynamics between human management of land resources and ecosystem services in the rural sector.

In the field of disaster studies, resilience research explores the ways in which individuals and communities respond to risks (e.g., Bruneau et al. 2003; Coles & Buckle 2004; Paton 2006b) and identifies why some individuals, organisations and communities are better able to prepare, adapt to, and recover from hazards events. Disaster resilience has developed out of studies of human vulnerability to natural hazards and reflects a change in the problem-framing of hazards. Natural hazards have moved from being seen as 'Acts of God' visited on society, in the first half of the 20th century, to an increased understanding that problems of vulnerability can be found within social, political and economic realms (Hufschmidt 2008) and that many natural hazards are largely a consequence of the way humans interact with nature (Hufschmidt 2008; Smith *et al.* 2012). Humans therefore either increase or reduce their risk to hazards through their interactions with the environment.

In terms of understanding rural resilience, disaster resilience research can provide a rich understanding of how individuals, groups and organizations respond to risks, the dynamic processes of social resilience, and how social resilience might be assessed.

Our work also draws on conceptualisations of vulnerability (Turner *et al.* 2003). Vulnerability has been referred to as an antonym of resilience, and shares many of the same research foci. Like resilience, vulnerability still means different things to different people, in different fields (Chambers 1989; Dow 1992; Ribot 1995; O'Brien *et al.* 2004; Zhou *et al.* 2009; Hinkel 2011). Many of the discrepancies in the meanings of vulnerability also arise from different epistemological orientations and subsequent methodological practices. In the climate change literature, vulnerability is most often defined as a function of exposure-sensitivity of a system to stressors and its adaptive capacity (Smit & Pilifosova 2003). The IPCC (2007) defines it as "*the degree to which a system is susceptible to, and unable to cope with, adverse effects of climate change, including climate variability and extremes*".

Given the diversity of understandings within different fields, for the purposes of this study we define and distinguish the central concepts of the study as follows:

- ***A socio-ecological system*** is a 'multi-scale pattern of resource use around which humans have organized themselves in a particular social structure - i.e. the distribution of people, resource management, consumption patterns, and associated norms and rules. (Resilience Alliance www.resalliance.org/index.php/key_concepts).
- ***A dairy farm*** is a particular kind of social-ecological system, distinguished from the surrounding environment by the manipulation of biophysical or ecological, stocks, flows and stores (e.g. water, nutrients) for milk production. The system includes everything contained within 'the farm gate', as well as those components related to the functioning of the farm, including social, ecological and economic subsystems, and the interactions and inputs between those systems.
- ***A resilient socio-ecological system*** is one that has the capacity *to absorb disturbances and still retain the same structure and function, while maintaining options to develop* (Nelson 2011: 114, drawing on Carpenter *et al.* 2001 & Walker *et al.* 2002). Key system characteristics that build resilience are *buffering capacity*, *adaptive capacity*, and *self-organisation.*
- ***A resilient dairy farm system***. A proposed working definition of a resilient dairy farm is one that has the long-term ability to maintain an economically viable level of production in the face of localised climatic changes, while maintaining the land's ecological integrity.
- ***The adaptive capacity of a system*** can be conceptualised as the preconditions of a system that enables humans to moderate potential damage to that system, to take advantage of opportunities, or to cope with the consequences of disturbance (Tompkins & Adger 2004). Adaptive capacities are generic in that they can be utilised to respond to a variety of risks. Adaptive capacity usually resides in different types of capital (e.g. natural,

human or economic), and includes the ability to mobilise that capital in order to address risks and opportunities (Nelson 2011). These abilities are often found in the quality of relationships between different parts of the systems, e.g. social networks, trust between government agencies and constituents (Paton 2006b; Nelson 2011).

- ***Adaptation within a system*** is the process of utilising the adaptive capacity of a system to respond to a specific threat (e.g. using financial and human capital to build flood banks) therefore managing the resilience of that system. Adaptations tend to be focused at one scale while resilience assessments tend to examine the multiple scales and interrelationships between elements of a system (Nelson 2011). Not all adaptations are positive; some create or aggravate other risks, reducing the resilience of the overall system. Turner *et al.* (2010), for example, argue that current human adaptations to climate change are putting natural systems at more risk than the impacts of climate change itself (Nelson 2011)
- ***The vulnerability of a system*** reflects both the exposure and/or sensitivity of that system to hazardous conditions.

Further to these definitions, the review identified the following conceptual ideas and principles that inform the study:

1. *Resilience is increasingly understood as the ability to adapt as opposed to4.1 the ability to withstand change.* Resilience theory offers a vision of sustainability, not as stability, but as persistence born out of change – more specifically, out of adaptive renewal cycles (Gunderson & Holling 2002). Resilience is related to the magnitude of shock that a system can absorb and still remain within a given state, the self-organizing capacity of that system, its capacity for learning and experimentation. Managing for resilience implies maintaining options in a world of rapid change in which surprise is likely and the future unpredictable; hence resilience is forward looking.
2. *Resilience is dynamic*. Resilience and vulnerability are understood as dynamic processes within a system as opposed to being static states. The characteristics that shape vulnerability and resilience change over time, in response to changing biophysical and socio-economic conditions (Vogel & O'Brien 2004).
3. *Resilience is a systems property and best evaluated using systems thinking.* The resilience of a system depends as much on the nature of the relationships between the system components as on the individual components themselves. Therefore resilience thinking and assessment needs to take a systems perspective.
4. *Resilience in this study is interpreted as a normative concept.* Socio-ecological resilience is understood as a system property rather than a normative state. An ecological system, for example, may be a very resilient one but it may still be undesirable in terms of human goals (e.g. a eutrophic lake is resilient to changing into an alternative system). This non-normative framing can be problematic when resilience is commonly understood as a positive concept by other disciplinary fields including hazards research, and when socio-ecological resilience scholars are linking resilience to sustainability concepts. Socio-ecological resilience has more recently adopted the idea of 'transformations' (see Walker 2012) to describe the idea of a significant planned change to a socio-ecological system in order to address ecological challenges and meet ecological and social goals.

   This does, however, raise questions about who determines what a desirable dairy production system is, and, subsequently, which values or social groups win or lose from any adaptation strategies (for instance, the industrial norm of increasing production of a commodity versus the alternative of a socially, environmentally embedded farm maintaining market position of a product for profit and to maintain the functional integrity of a socio-ecological system). It is also likely that what is regarded as a desirable state will change over time as social and cultural preferences change. However, for the purpose and clarity of this research project, and in line with current understanding of resilience within the New Zealand policy and dairy industries, a resilient dairy production system is assumed to be normative and we attempt to describe a 'desirable state' in our definition of a resilient dairy farm system in the following section.

5. *There are limits to resilience*. There are limits to the degree to which a farm system can adapt in order to remain desirably resilient, especially over the long term. Severe climatic changes combined with the ecological degradation caused by current farming practices might demand what Walker (2012) defines as 'transformation' from one system configuration into a fundamentally new system. Under a transformation scenario, for example, one dairy farm might become forestry, another might transform into a wetland forming a natural protection to rising sea levels. Our study, however, limited itself to examining the relative resilience of three types of production systems to remain in the desired state, or maintain their identity: that of an economically viable dairy farm.

6. *Resilience is context-specific*. While there is some agreement to generic qualities of resilience such as diversity, adaptability, and flexibility, making use of those characteristics is context-dependent. To evaluate the resilience, we first have to ask the question posed by Cumming *et al.* (2005): the resilience of what, to what? This requires defining the scale and system of analysis, and the pressures that system faces. In this study the system is the dairy farm facing impacts of climate change using drought as the central impact under examination.

   While the external drivers of exposure and the determinants of adaptive capacity may be similar among farms in a region, the endogenous characteristics of farms may vary greatly (Smithers & Smit 1997). Among farms in any given area, differences in location, farm characteristics, and production characteristics can result in differential levels of resilience, and for this reason a qualitative approach comparing 15 case study farms was adopted.

7. *Resilience is dependent on key variables within the system generally across spatial scales.* Once the system and the pressure states are clearly defined, a resilience assessment needs to identify key variables in the system that influence its ability to be buffered, or adapt to the identified risk. Socio-ecological and hazards research have both identified that resilience is built or reduced by the interactions across spatial scales and therefore the resilience assessment of a dairy farm system will need to explore key variable at scales above the farm level as well as those within the farm gate.

3.2 Dairy Farming in the Bay of Plenty

Farmers (and the farming enterprise) operate within a broader socio-economic context in which systems of farm management, marketing and sales of agricultural products, and governance influence resilience. Some of these conditions are not unique to dairy farmers in the Bay of Plenty, but nonetheless influence resilience at the farm-level to varying degrees. The following sections situate dairy farming in the Bay of Plenty within the broader social and ecological setting, and within the scientific literature on resilience to provide a context for the subsequent empirical analysis.

3.2.1 Social-Ecological Context

The physical environment has been shaped by earthquakes, volcanic eruption and floods (Pullar 1985; Nairn & Beanland 1989) and extensively modified for human use (Gibbons 1990). It is tectonically active; the eruptions of Taupo (1850 BP), Kaharoa (600 BP) and Tarawera (1886 CE) left extensive tephra deposits which in turn altered river flow regimes, and contributed to soil formation (Lowe *et al.* 1998); seismic activity has resulted in continued downward faulting along much of the coast (Froggatt & Lowe 1990; McGlone & Jones 2004); a prograding shoreline has left remnant beaches and dune deposits inland, and frequent flood events have reworked and redistributed alluvium over vast areas, producing some of the most fertile agricultural land in the country (Pullar 1985).

Agricultural production takes place within the context of a dynamic physical environment shaped by volcanic eruption, earthquake and floods (Pullar 1985; Froggatt & Lowe 1990; Lowe *et al.* 1998; McGlone & Jones 2004). Major topographic features and related agricultural land-uses include the low-lying Rangitaiki Plains and flat coastal areas near Opotiki. Land use on the versatile soils includes dairying, dry stock and horticulture. Inland is terrace-like flattish country with thick layers of tephra. Soils are well drained, and used for dairying, dry stock and horticulture. The Galatea Basin consists chiefly of terrace-like surfaces covered by tephra, mostly pumice. It is drought prone and very well drained, and used for dairying and dry stock. Hill country forms much of the background of the above landforms, and tephra-covered steeplands (slopes >25 degrees) occur throughout the study area, on which dry stock and dairying are the main land uses. At a smaller scale are coastal and inland dunes used for kiwifruit orchards, and backswamp lowlands and peat swamps, as well as a natural levees system of rivers and streams and floodplains of largely mixed alluvium (Rijske & Guinto 2010).

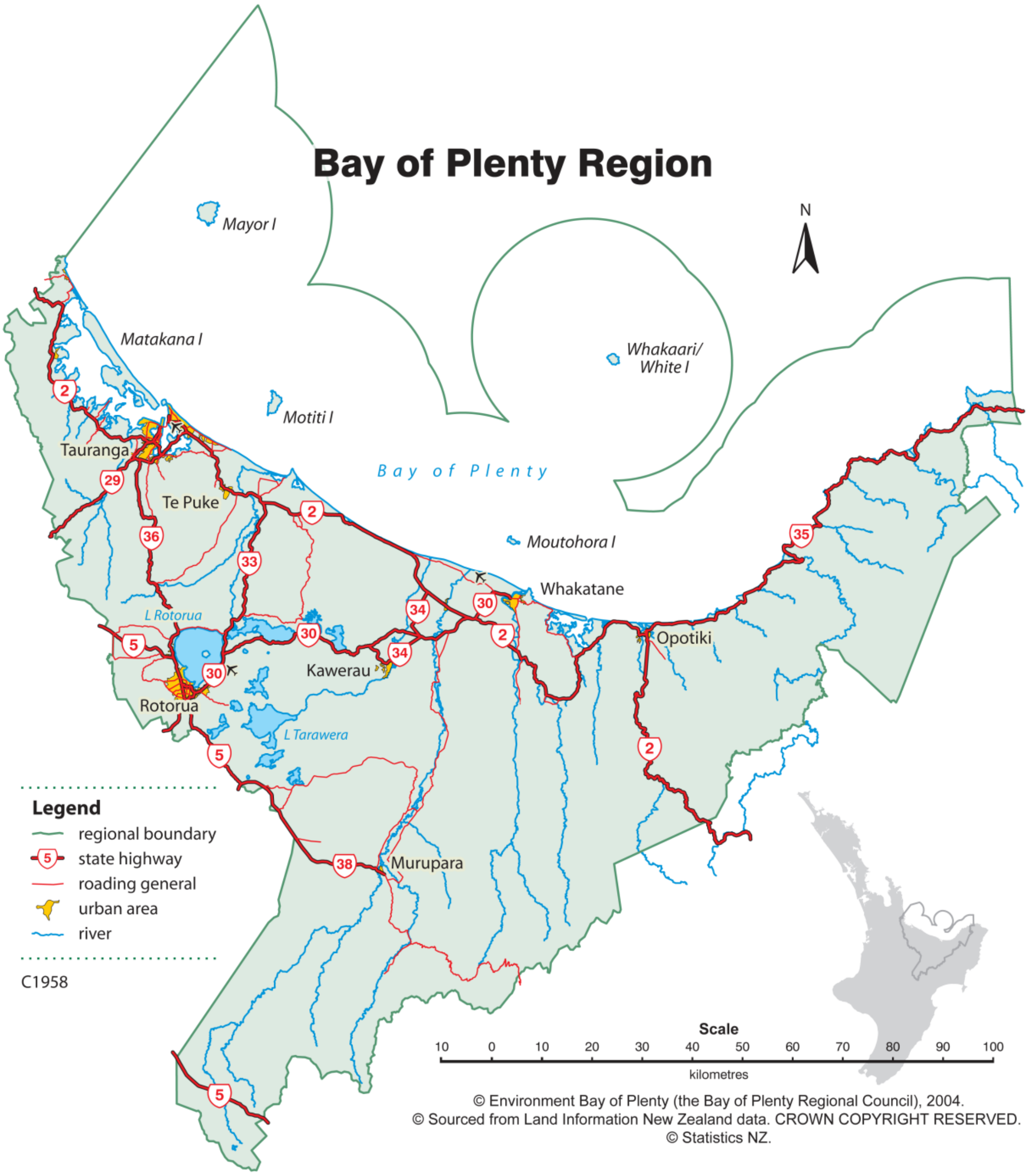

Figure 2: Bay of Plenty Region

Soil characteristics influence land use and were an important factor relating to farm resilience. Soils range from ash to peat, and vary with respect to slope, depth, texture, drainage, and other characteristics (e.g. depth of tephra layers). Most soils are loams derived from volcanic ash. They crumble easily and are free draining and drought prone, with limited moisture-holding capacity and low fertility, requiring large amounts of superphosphate fertiliser, to which they respond well (Leamy & Fieldes 1976). Well-drained coastal soils are formed from older ash (Leamy & Fieldes 1976; Pullar 1985); those derived from the more recent addition of the Kaharoa ash are friable and free draining. They have good moisture-holding capacity, and are productive soils, but require fertilising for sustained use (Rijske 1993). Most of the plains have layers of consolidated peat, which are deepest in the eastern areas, in low-lying areas between sand ridges, and along the Omeheu (Pullar & Patel 1972). Deep drains are required to lower the water table to develop pasture on these soils. As the peat decomposes and shrinks, the land sinks, especially near the drains, forming a domed landscape. Sinkage can be as much as 14–33 mm/yr, and can disrupt fences and buildings.

The rate of sinking can be reduced by damming the drains in spring to manage the level of the water table (Gibbons 1990).

Portions of the Bay area are interspersed with wind-blown sand ridges, lying generally parallel to the coast. The dunes formed over some 7000 years as the coast prograded approximately 10 km (Irwin 2004). These are covered or mixed with ash and tephra; near Kawerau, dunes reach to a height of about 30 m asl (Pullar & Selby 1971; Pullar & Patel 1972). The dunes are extremely susceptible to drought – grass burns off quickly – but the free-draining sandy soil is well suited for kiwifruit production.

There is a significant flood risk on a number of catchments in the study area. Flood risk is most pronounced on the lower reaches of the Whakatane-Tarawera and Rangitaiki catchments (EBoP 2008) where maximum recorded floods have only been two to three times normal flow (McKerchar & Henderson 2003). The Rangitaiki Plains is further drained by the 88 km of major canals, and 240 km of drains, comprising the Rangitaiki Drainage Scheme, which relies on gravity to divert excess water from the plains into the Tarawera, Rangitaiki and Whakatane Rivers.

Climate in the Bay of Plenty is currently well suited to agricultural production. Climate here refers not only to the long-term averages of weather elements, but also to the range of likely values and the occurrence of extremes (Griffiths et al. 2011). It is considered sub-tropical, with warm humid summers and mild winters; somewhat sheltered from the prevailing winds by the high country of the North Island. Consequently, the region has a sunny climate with dry spells, but may have prolonged periods of heavy rainfall as shown in *Table 2*.

Table 2 Bay of Plenty climate

Month	Rainfall (mm)			Growing degree days[1] (GDD)		
	2010/11	2011/12	Long Term Average	2010/11	2011/12	Long Term Average
June	283	234	143	31	48	29
July	68	93	164	17	30	20
August	413	79	158	49	24	25
September	225	36	126	79	36	61
October	36	256	143	103	130	104
November	61	37	110	169	176	146
December	189	413	129	272	221	214
January	425	119	106	290	255	257
February	87	116	110	299	237	246
March	173	182	132	236	200	219
April	273	63	142	146	171	139
May	283	225	138	132	64	77
Total	2 515	1 852	1 600	1 823	1 593	1 538

Note

1 GDD – growing degree days; a measure of heat accumulation, calculated by taking the average of the daily high and low temperatures each day compared with a baseline. (Source: NIWA, Te Puke)

Typical summer daytime maximum air temperatures range from 22°C to 26°C, but seldom exceed 30°C; winter daytime maximum air temperatures range from 9°C to 16°C. During the warmest months the temperature averages 23°C, while the region's reasonably warm winters average a 14.7°C daily high. Annual sunshine hours average 2000 in many areas, but the coastal region from Tauranga to Whakatane is much sunnier, with at least 2200 hours. SW winds prevail for much of the year. Sea breezes often occur on warm summer days.

Annual rainfall ranges from about 1200 mm at the coast to over 2000 mm inland at higher elevations. Precipitation is highly variable in the study area, temporally and spatially. Rainfall at Waihi varies from a record wet year in 1928 (3234 mm) to a record dry year in 1982 (1249 mm), a difference of nearly 2 metres (Griffiths *et al.* 2011); Whakatane receives an average of 1198 mm of rainfall. Precipitation decreases inland, and some inland basins – such as Galatea – are drought prone, though this is not only a function of low rainfall but of pumice soils, with low soil-moisture capacity (Rijske & Guinto 2010).

Precipitation is markedly seasonal, with over 45% of the annual rainfall between May to August (Griffiths *et al.* 2011). Extremes of precipitation are not uncommon during this time, creating significant problems for pastoral farmers as these are critical months of the production season, with pugging (waterlogged pastures) and increased flood risk (McKerchar & Henderson 2003). The driest period is from November to February (Griffiths *et al.* 2011). Long-term data demonstrate the pronounced inter-annual variability, related to short- to medium-term (inter-decadal) climatic influences, as well as the varying influences of topography.

Although the Bay of Plenty is traditionally regarded as 'summer-safe', milk production during the summer/autumn of 2009 was down approximately 15% on average, even on land that traditionally holds up well in drier years (MAF 2010). While figures have not yet been released it is likely that for the summer/autumn of 2013, a similar if not larger drop in production will be noted. The 2012/13 drought was the most severe since the 1945/46 season (Porteous and Mullan 2013). The cause of the drought was the dominance of a high-pressure blocking system in the Tasman, which effectively shunted aside moisture-bearing systems (Porteous and Mullan 2013). These conditions were consistent with recent modelling results that show a historical trend towards increasing pressures over New Zealand during the summer months (MfE 2008; Clark et al. 2011). While total rainfall has decreased since the 1960s, there is no evidence for long-term changes in the frequency or intensity of rainfall extremes (Griffiths *et al*. 2011).

The climatic conditions described above are inherently variable. In individual years, annual temperatures nation-wide can deviate from the long-term average by up to ±1°C. Annual rainfall also deviates from its long-term average, by ±20 percent (Mullan 1998). Some of the shortest term temperature fluctuations arise due to natural variability in the weather and its random fluctuations or 'chaos', however other changes are associated with large-scale climate patterns over the Southern Hemisphere or the Pacific Ocean, the El Niño-Southern Oscillation (ENSO) and the Interdecadal Pacific Oscillation (IPO) (Griffiths *et al.* 2011).

3.2.2 Bay of Plenty dairy farms

Dairy farming takes place throughout the Bay of Plenty, but is concentrated on the fertile soils of the Rangitaiki Plains, coastal lowlands, river valleys, and uplifted terraces. Milk production varies between farms and areas due to differences in moisture availability, soil type, and management system. New Zealand's seasonal milk production system has traditionally relied on highly productive, rotationally grazed pasture (Verkerk 2003), though there has been a shift in recent years towards more intensive production systems that rely more heavily on imported feeds (*Table 2*).

The efficiency of the grass-based system has enabled farmers to produce milk substantially below average world costs (Basset-Mens *et al*. 2009; Gray & Le Heron 2010), giving New Zealand dairy farmers a competitive advantage that may be eroded with higher inputs (Mulet-Marquis & Fairweather 2008). Producers utilising a grass-based system are more exposed-sensitive to climatic variability and extremes than those on feed-based systems. Reliance on pasture production can be mitigated in some ways through the use of supplemental feeds and a shift to higher inputs; however, this may increase exposure-sensitivity and system-dependency elsewhere in the system.

Table 3: DairyNZ classification of farm systems (DairyNZ 2010)

System	Definition	Description
1	All grass, self-contained, all stock on the dairy platform	No feed is imported. No supplement fed to the herd except supplement harvested off the effective milking area and dry cows are not grazed off the effective milking area.
2	Feed imported, either supplement or grazing-off, for dry cows	Approx. 4–14% of total feed is imported. Large variation in % as in high rainfall areas and cold climates such as Southland, most of the cows are wintered off.
3	Feed imported to extend lactation (typically autumn feed) and for dry cows	Approx. 10–20% of total feed is imported. Feed to extend lactation may be imported in spring rather than autumn.
4	Feed imported and used at both ends of lactation and for dry cows	Approx. 20–30% of total feed is imported onto the farm.
5	Imported feed used all year, throughout lactation and for dry cows	Approx. 25–40% (but can be up to 55%) of total feed is imported.

In response to economic pressures, changing market conditions, and government deregulation, there has been an increasing drive towards intensification (Jay & Munir Morad 2006; Basset Mens *et al*. 2009). At the farm level, farmers have sought to create economies of scale by increasing total farm milk production though adopting more intensive grazing and feeding regimes (Parker & Holmes 1997), increasing production per hectare or increasing the number of hectares in dairy use, or both. At the milk-processing level, the sector has sought both to process all the milk it receives (since the milk suppliers are the owners of the facilities), and to increase the value of the processed products through more sophisticated processing technologies, packaging and marketing (Morad & Jay 1999; Gray & Le Heron 2010).

Table 4: Summary of NZ herd statistics since 1974/75 (LIC 2010)

Area	Year	Herd (n)	Total cows	Av. Herd size	Kg/Milkfat/cow	Av. Effective ha.	Av. Cows/ha
New Zealand	1974	16907	2,039,902	121	142	<60	<2.0
	1993	14597	2,603,049	180	160	74	2.4
	2009	11618	4,252,881	366	184	131	2.8
Whakatane	2009	316	96,579	306	180	110	2.91
Opoktiki	2009	80	24,723	309	178	113	2.73

As the data in *Table 4* shows, since 1975 the average size of farms has increased; the average size of herd has increased; average production per cow has increased (through selective breeding); and the number of cows per hectare has increased (through more intensive pasture production and pasture management). Many smaller dairy units have been bought out and amalgamated to make larger units (Morad & Jay 1999). These trends are apparent both nationally, and in the study area; farms in the study area, for which data are available, show a smaller than national average farm size, with slightly higher than average stocking rates. In the past 20 years, the number of dairy farms has fallen, but average farm and herd sizes have increased, while productivity, both per hectare and per cow, has improved (DairyNZ 2010).

3.3 Projected climate change impacts in the Bay of Plenty

Climate scenarios for the Bay of Plenty estimate changes in variables found in traditional climate studies, such as average temperature and precipitation, as well as changes in variability and extremes, including hot days, frost-free days, and severe winds. Key sources of projections under climate change are Griffiths *et al.* (2011), MfE (2008) and IPCC (2007). A climate scenario refers to "*a plausible and often simplified representation of the future climate, based on an internally consistent set of climatological relationships that has been constructed for explicit use in investigating the potential consequences of anthropogenic climate change, often serving as input to impact models*" (IPCC 2007, p.78). Climate scenarios have been used as the basis for comparison and analysis in other qualitative impacts assessment, often in conjunction with insights from stakeholders (Hadarits 2011; Garschagen *et al.* 2011; Sherval & Askew 2011). In these studies, researchers have drawn on national climate scenarios and empirically derived data drawn from a community or district to identify problematic, future climate-related conditions.

Table 5 (overleaf) summarizes projected changes in climate for a range of dates (Griffiths *et al.* 2011; MfE 2008; data from the IPCC 2007 are for the eastern North Island). Climate projections for the Bay of Plenty indicate warmer temperatures, consistent with those predicted for much of eastern New Zealand and hotter, drier conditions (MfE 2008). The Bay of Plenty warms by an average of approximately +0.80°C by the 2030s, and by about +1.80°C by the 2080s (Griffiths *et al.* 2011). There is widespread variation in the predicted temperatures. This is a limitation of current global and downscaled models of future climate (Jacques 2006; Moss *et al.* 2010). There are marked changes in rainfall predicted (Mullan *et al.* 2005). Precipitation in New Zealand is strongly influenced by ENSO/IPO (Salinger et al. 2001; Folland 2002) including variability and extremes (Ummenhofer & England 2007). Changes in precipitation will be superimposed on existing inter-annual and inter-decadal variability.

For the Bay of Plenty, changes in rainfall are likely. By the 2030s, annual precipitation may decrease by as much as 15%, varying seasonally from a slightly wetter winter to a much drier spring and summer, with implications for both pastoral farmers and kiwifruit growers. By the 2080s, the drying trend evident in the 2030s in summer and autumn has reversed. Summer rainfall for the Bay of Plenty is projected to return to near the current climatology, with increased flow in the westerly winds. Autumn is also wetter than currently by the 2080s, and winter also slightly wetter than the 2030s. Spring is expected to continue to get drier and by the 2080s spring rainfall is projected to be about 10% lower throughout the district (Griffiths *et al.* 2011).

In addition to changes in average temperature, a greater number of hot days above 25°C are anticipated (MfE 2008) as is an increase in drought frequency as a function of higher temperatures and decreased precipitation (Mullan *et al.* 2005). The drying of pastures in eastern New Zealand in spring is very likely to be advanced by 1 month, with an expansion of droughts into both spring and autumn (MAF 2011). Daily temperature extremes (overnight minimum and daily maximum) will also likely vary with regional warming (Griffiths *et al.* 2011).

Table 5: Projections of climate change for the Bay of Plenty

Climatic variable	Data source		
	Griffiths *et al.* (2011)	MfE (2008)	IPCC (2007)
Temperature (Δ in °C)	0.80 (2030), 1.80 (2080)	0.9 (2040), 2.1 (2090)	0.2 to 1.4 (2030s), 0.5 to 3.8 (2080s)
Summer	0.0–1.2, 0.3–3.8	1.0, 2.2	
Autumn	0.1–1.3, 0.4–3.9	1.0, 2.2	
Winter	0.4–1.6, 0.8–4.2	0.9, 2.0	
Spring	0.2–1.2, 0.4–3.6	0.8, 1.8	
Precipitation (Δ%,Tauranga)	(9)–2, (15)–2	(1), (2)	(19) to +7 (2030s), (32) to +2 (2080s)
Summer	(10)–4, (7)–19	2, 2	
Autumn	(16)–4, (18)–15	3, 2	
Winter	(5)–7, (2)–9	(4), (3)	
Spring	(20)–8, (41)–(3)	(5), (9)	
Hot days >25° C		Likely increase in number of hot days	
Frost-free days	Increase in number of frost-free days		
Extreme rainfall			
Wind events	Increase in severe wind risk	Up to a 10% increase in strong winds (> 10m/s)	
Ex-tropical cyclones and mid-latitude storms	More intense mid-latitude storms		

The mean westerly wind component across New Zealand is expected to increase by approximately 10% of its current value in the next 50 years (Mullan *et al.* 2001) and wind changes may further contribute to a drying trend in the eastern Bay of Plenty (MfE 2008). On a daily basis, severe wind risk is likely to increase as it is strongly correlated with intense convection and low-pressure systems, which will be more common with a warmer climate (Griffiths *et al.* 2011). This may also exacerbate the risk of fire, related to dry conditions. By the 2080s, 10–50% more days with very high and extreme fire danger may be likely in eastern areas of New Zealand, including the Bay of Plenty (Pearce *et al*. 2005).

Other changes in climatic conditions include a likely increase in peak wind intensities and rainfall associated with tropical cyclones (Hennessy *et al.* 2007). Given that a warmer atmosphere is able to hold more moisture – approximately 8% more moisture per 1°C increase in temperature (Griffiths *et al.* 2011) – an increase in global flood risk related to extreme rainfall events is anticipated (Lenderink & van Meijgaard 2008; O’Gorman & Schneider 2009) While floods are complex hydrometeorological events, the Bay of Plenty may become more prone to such heavy rainfall (Griffiths *et al.* 2011). This is likely to exacerbate the existing flood-risk in the study area.

3.4 Developing a draft model of a Resilient Dairy Farm System

This section introduces a draft model of a resilient dairy farm system which will be tested and refined through the farmer interviews and workshops. The model is drawn from a review of the literature and previous research by one of the researchers (Miller *et al.* 2006; Cradock-Henry 2008, 2012). The model shows generic components of a typical dairy farm system in the Bay of Plenty, as part of a nested socio-ecological system. It reviews resilience and farm-systems literature to highlight those components likely to have the greatest influence on the farm's resilience to climate change impacts.

3.4.1 The components of a generic dairy farm system

Table 6 identifies common components of a typical dairy farm in the Bay of Plenty. These include favourable climatic conditions, diverse soil types (ranging from fertile peat soils through lowland areas, to some well-drained pumice soils in upland valleys), and water resources including the availability of groundwater for irrigation. Alongside this natural or biophysical capital are extensive social and economic networks and actors, including the farmers themselves, who make direct use of those resources. At higher scales, the system also includes the regional support and extension providers such as farm consultants, rural banking, and Fonterra indirectly supported by dairying in the Bay of Plenty.

These components can be grouped into three interrelated categories: social, economic, and agroecological. The agroecological and social components provide the basis for, and influence and are in turn influenced by, the economic activities on and outside the farm.

Table 6: Components of a typical dairy farm system in the BoP (adapted after Miller *et al*. 2006)

Agroecological components	Economic components	Social components
Feed supply Pasture composition Supplementary feed	Milk price	Labour
Pasture composition	Logistics	Education
Supplementary feed	Credit	Access to information
Cows	Land values	Lifestyle
Genetics	Markets	Technology
Reproduction	Sector structure	Management strategy
Fertiliser	Enterprise diversity	Community perception
Irrigation	Energy	Communities (viability)
Off-site impacts Run off Feed/fodder	Policy structure	Human diversity
	Human behaviour	Place attachment
Soil resource Water resources Spatial configuration of native vegetation Species diversity Climate		Identity

3.4.2 Identification of key components influencing resilience

Assessing these typical dairy farm components against the resilience and agricultural literature and key informant interviews, a draft set of system influential components were identified. These were those characteristics and features of individual farms, we proposed were most likely to most influence a farm's resilience to climate change and, in particular, to persistent drought. Following peer review, these characteristic features were empirically applied. The rationale supporting the selection of characteristics is described as below.

Several assumptions underpin the selection of resilience indicators:

- Resilience assessment begins by defining the resilience of what, to what? The focus of this study is on the capacity for individual dairy farms to persist or continue (to maintain their identity) at approximately the same level of profitability within a certain set of biophysical parameters. The study does not measure or characterise the capacity for transformation (e.g., a farm converting from dairy to drystock). It is the resilience of the dairy farm type we are examining.
- The resilience of the dairy farm is an emergent property of the interaction between interdependent socio-economic and ecological attributes, per *Figure 3*.
- Assessment is focused at the farm scale but resilience is shaped by attributes at multiple spatial levels: i.e. the individual, the value chain, community, broader social and institutional frameworks.
- Generic attributes of resilience – referred to here as adaptive capacities – provide the preconditions for a farm to adapt to a range of disturbances. There are also specific resilience attributes that enable a farm system to adapt to a specific threat.

Table 7: Draft indicators for farm-level resilience

Indicators	Description
Social	
Critical awareness of potential risks	The ability to accurately identify the risks of climate change and its implications for the business (CCCR 2000; Marshall *et al.* 2007; Norris *et al.* 2008; Paton 2006b; Wilhite 2002). Farmers who are aware of the potential impacts of climate change, and the implications those impacts might have for their business, may be more likely to take action to reduce risks.
Positive outcome expectancy	Individuals who are more likely to take action to reduce risk of climate change if they believe that solutions will work (Marshall *et al.* 2007; Paton 2006b). Paton (2006b) found that having a critical awareness of a risk can result in people deciding not to take action, if they believe the risk too severe for their actions to make a difference (Paton JPRP:29). Therefore a person's positive outcome expectancy also needs to be assessed.
Self-efficacy	Individuals who are more likely to take action to reduce risk of climate change if they as individuals believe they can implement risk-reduction solutions. Self-efficacy is often developed through previous experiences of dealing with challenging situations at an individual level (Bandura 1977, 1982) or community level (Kelly 2000; Montada & Kals 2000) or through examples of others modelling a specific adaptation/behaviour (Bandura 1977, 1982).
The ability to plan, learn, and reorganize	Contributing factor to a positive outcome expectancy (Marshall *et al.* 2007).
Attachment to place	Research has identified that having an *attachment to place* and to the people living in that place can increase a person's 'emotional investment in their community' (Paton 2006a) making them more likely to adopt adaptation measures and more likely to work collaboratively to do so (Paton *et al.* 2008).
Environmental values	Individuals who organise environmental values high in their hierarchy may be more likely to adopt production practices which maintain ecological integrity. Managing dairy production while maintaining ecological integrity requires balancing economic and ecological outcomes. Even when people value the local environment , they also hold other values which relate to all different aspects of their lives (e.g. the value of having secure income, etc.) and people generally organise their values hierarchically (Paton 2006a). Assessing a farmer's hierarchy of values could provide insights on the degree that they will adopt practices which improve

	ecological resilience.
Social capital	Social capital describes the informal social networks and collective life of a community. Individuals tend to make sense of and explore ways to address risks in ways relevant to their specific context, through discussion with other people who share common values and circumstances with them (Hardin & Higgins 1996; Lion *et al.* 2002; Paton et al. 2008). Having strong social networks facilitates these discussions. Social capital also provides social support in times of crisis (CCCR 2000; Norris *et al.* 2008; Smith *et al.* 2011).
Trust in and participation with government and sector bodies	A subset of social capital (vertical social capital). If individuals trust and participate in government and sector networks they are often more likely to accept information on climate change risks. This is especially important when they are being asked to take action to adapt in an environment of high uncertainty (Earle & Cvetkovich 1995; Siegrist & Cvetkovich 2000). Vertical social capital includes the degree and quality of participatory decision-making between farmers, communities and public and sector bodies (Paton 2006b) which can increase the ability for collective agreement and action on climate adaptation.
Management structure & culture	The degree to which the (often complex) decision-making unit of the farm enables innovation, adaptive capacity, learning, long term thinking and rapid response (Chris Perley, *personal communication*).
Economic	
Financial resources	The availability of financial resources to buffer shocks and to facilitate drought adaptation measures. Quality of relationship with bank manager (links to social capital).
Profitability	The margin on production per kilogram of milk solids. Farmers with a higher margin are more resilient to any increased costs arising from drought or adaption investment (dependent on their debt loading).
Pluriactivity	The household is involved in other income-earning activities, off-farm (MacKinnon 1991; Darnhoefer 2010).
Feed security	This encompasses pasture composition and management as well as the use of supplementary feed (on-farm and imported). Different management decisions and biological processes influence feed security. Changing pasture composition (e.g. an increase in sub-tropical grasses such as paspalum and kikuyu) could lead to lower feed quality. On the other hand it could contribute to greater drought resilience. Pasture management practices such as longer covers can, along with appropriate soil management, lead to deeper rooting plants. Different species are more drought tolerant. On-farm and off-farm sources of supplementary feed relate to the degree of self-organisation.
Management practices which reduce impacts of drought	Some farm management practices may be adopted specifically for drought while others may be adopted for other or multiple benefits. It will be important to determine if some production systems find it easier to adopt drought measures than others.
Diverse local economy	Many farm households rely on off-farm income and rural communities are more resilient to economic shocks if there is diversity of local employment.
Agroecological	
Water security and effluent management	Farms may secure their water supply in a number of ways and may have different levels of use for that water supply. The principal uses will be for stock water and to ensure adequate soil moisture for pasture growth. The latter may be achieved through irrigation or through farm system management. Farms with secure and affordable water supply will be more resilient in times of drought. At the macro scale however over-dependency on drawing water from rivers may reduce catchment level resilience. Farmers around lakes and harbours, and with water ways through their farm, are being increasingly sensitised to runoff, sedimentation and water quality issues. In the BoP this is particularly true around Tauranga Harbour and the Rotorua Lakes. The capacity of the lakes to cope with nutrient loading will be diminished with increased lake temperatures.
Soil properties and management	Soil type will determine the underlying conditions that the farmer has to manage. There are a number of soil properties that can be used to indicate the relative resilience of a particular soil type. These are documented in detail in Shepherd's (2009) Visual Soil Assessment.
Stocking policies	The stocking rate in relation to the carrying capacity of the farm, including in time of drought.
Trees	The pattern of woodlands, wetland, and individual or groves of trees within a farm system

	can provide free ecological services (e.g. shelter, shade, microclimate, soil conservation, water infiltration, landscape water retention & flood mitigation, nutrient cycling from soil depths, sediment retention, reduction in run-off of natural capital, deep-rooting drought-resistant browse, stock health and quality stock water). In most farm situations, the siting of such elements is entirely compatible with location within lower production and higher risk areas under pasture, where the correlated costs are high (including directed 'overhead' costs – such as stock losses or weed control) and the net margins return from such areas when in pasture are actually negative.
Micro climate	Some farms might be more vulnerable to drought than others due to micro climatic conditions which will work in combination with soil type and other agroecological factors. Drought will impact the BoP at the meso-scale; at the micro level, farms may be impacted differently by, for example, late frosts, prevalent winds, etc., which might intensify or reduce macro-level climate change impacts. Potential exposure to the effects of rising sea-levels could be included here. Impacts could include salt water intrusion and risk of flooding and inundation.

3.4.3 Draft model of a resilient dairy farm system

On the basis of the draft indicators presented in *Table 7*, a conceptual model of a 'typical' dairy farm was developed (*Figure 3*). The model is used to illustrate the ways in which climate change will influence the functioning of the farm through its impacts on the social, economic and ecological components of the farm.

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 (Hedley *et al.* 2006; Miller *et al.* 2006). The framework instead aims to highlight those generic elements common to dairy farms at a local scale, reflective of the broader scale processes and relating to resilience, and which was used to guide the case studies in the Bay of Plenty.

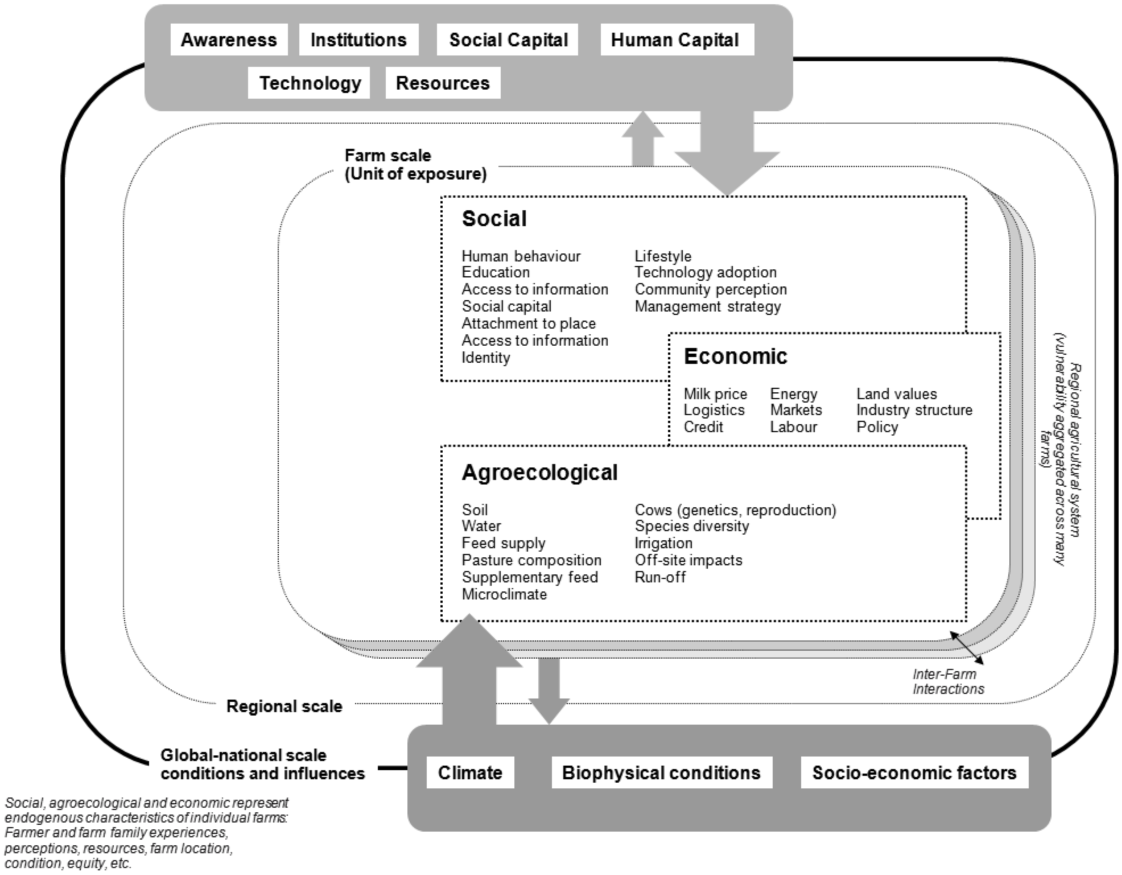

Figure 3: Draft Conceptual model of resilient dairy farm system.

A conceptual model of a resilient dairy agroecosystem in the Bay of Plenty is illustrated in *Figure 3*. The farm is conceptualized as the main exposure unit and unit of analysis. The model is a schematic representation of the components, relationships, factors, and conditions likely to influence resilience at the farm level. The farm's socio-ecological system is made up of the three interrelated groups of variables – agroecological, social, and economic – and the draft variables of resilience are listed within these three categories.

The farm system operates within and changes in response to, external, interconnected systems (Bryant & Johnston 1992; Giampietro 2004). The farm is nested within and teleconnected 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.

4 Results and discussion

4.1 Perceived impacts of climate change

Yes I'm concerned about climate change, because long-term it's disastrous... it's having an effect on a lot of things around the country and it's not a thing that's being measured. Might turn out to be climate change on inspection but instead people just say "Oh it's just a bad year". But it's not quite a bad year; it's an effect with some other causes. It's there and it's happening.

Used to be you had two bad years out of ten, now you're getting two good years out ten.

– Dairy farmer, Bay of Plenty

The indicators framework was operationalised for 15 dairy farms in the Bay of Plenty, using interviews, surveys, and farmer workshops. Potential impacts of climate change were explored using the 2012/13 drought as an analogue, together with national and regional climate data. Results show that in the short term, there is little difference in the resilience of different farm systems, though key vulnerabilities and opportunities were identified for each of the three systems examined. In the long term, higher input systems are potentially exposed to a larger range of market risks and price shocks, particularly energy. The indicators of resilient farming systems made the concept of resilience sufficiently operational for stakeholders to consider options. The section begins with a discussion of changes in climate variables for the region and potential impacts on dairy farming.

4.1.1 Farm-level impacts of climate change

The following analysis draws on insights from farmers and other key stakeholders, and the empirical application of the resilience indicators, together with impacts identified in the scientific literature. Studies identifying some of the impacts of climate change on dairy farming have already been completed (*Table 8*). However, while these are able to determine some of the potential impacts on distribution of pasture species or animal health, they neglect to capture the context or significance of often fine-grained, farm-level conditions.

While it is not possible to predict the future with certainty, important insights into the nature of impacts associated with climate change can be derived by documenting exposure to current risks as a starting point from which to consider the implications of projected changes in climate (Ford *et al.* 2010; Nicholas & Durham 2012). The results show that across all different types of dairy system, farmers are currently exposed-sensitive to a broad range of climatic conditions, including variability and extremes of temperature and precipitation. In the future, especially under climate change, several of the conditions to which Bay of Plenty dairy farmers are sensitive are likely to be exacerbated. The resilience of farmers, including their capacity to deal with these changing exposures relates to the opportunities and constraints of individual behaviour, management practices, and the biophysical characteristics of place (e.g. soil, microclimate).

Likely changes in precipitation and temperature, stakeholder perceptions and understandings provide a useful starting point from which to consider the implications of projected changes in climate and society (Næss *et al.* 2005; Ford *et al.* 2006; Pelling *et al.* 2008; Mustelin *et al.* 2010; Malone & Engle 2011). These 'analogues' can provide a deeper understanding of the influence of multiple interacting stressors, the significance of contextual conditions at the local-scale, and those barriers to behaviour change, such as the level of perceived risk, which is not effectively captured in exclusively model-based assessments.

Increased flood risk, drought, and greater climatic variability is expected for the region (Griffiths *et al.* 2011); however, future exposure to risk will also be a function of non-climatic factors, such as input costs and commodity prices. Resilience to climate change therefore is situated within the context of uncertainty and change within the linked social, ecological and economic domains of the farm. Climate change will not occur in isolation (Liechenko & O'Brien 2008).

Table 8: Table shows current climatic exposure-sensitivities identified by producers. Future impacts are drawn from climate change scenarios, impacts-based studies and insights from producers. N/A indicates there is no clear change, or insufficient data to not a change. (Drawn from: Research findings; White et al. 1997; McGlone 2001; Kenny et al. 2001; Griffiths et al. 2003; Green 2006; Kenny 2006; MfE 2008)

Climatic variable	Current related exposure[1]	Future related exposure and farm-level impacts[1,2]
Temperature	Warm weather, timely precipitation	Potential benefit, encouraging pasture growth if sufficient moisture available
	Warm winter temperatures	Slower grass growth in the spring
	High summer temperatures	Higher summer temperatures have negative effects on production and animal health, decline in yields
	Cold, wet spring	*N/A*
	Warmer average temperature/Invasive subtropical grasses	Likely increase in distribution of subtropical C4 grasses, resulting in lower milk production in grass-based systems; associated with high costs to control spread.
	Unseasonable frost	Warmer temperatures may also be opportunity to plant drought-tolerant grasses: lucerne, sorghum
Precipitation	Excessive precipitation	Increased problems due to pugging, associated with more severe rainfall events
		Increased in runoff and erosion on steeper hill country, may require change in stocking rates
	Reduced rainfall	Adverse effects on grass growth
	Wet autumn	*N/A*
	Cloudy weather	*N/A*
Climatic variability and extremes	Climatic variability (seasonal, inter-annual, inter-decadal)	Climate change likely to exacerbate existing variability and result in more frequent extremes
	Flood conditions	Severe rainfall events are more likely, increased flood risk for lowland farmers
		Frosts effective in "knocking back" unwanted grasses and other pests; fewer frosts may have adverse impact on pasture
	Strong winds	Potential for increased severity in Westerly flow; high winds effect soil moisture
	Ex-tropical storms	May increase in frequency/severity, increased likelihood of damage to shelter belts, infrastructure, disruption of production
Climate-related biotic and biophysical exposures	Livestock diseases	The incidence of facial eczema may increase with higher humidity due to warmer temperatures
	Pest infestation	Existing pests as well as new pests currently confined to Northland (clover root weevil, clover flea), may become more prevalent.
	Salt-water intrusion	Modest sea-level rise may affect low-lying areas and increase exposure to salt-water intrusion on plains, especially if irrigation demand increases pressure on existing supply

4.1.2 Changes in temperature

According to model scenarios, a trend towards hotter and generally drier conditions is expected for the Bay of Plenty (Griffiths *et al.* 2011). These climatic changes may increase certain exposure-sensitivities among dairy farmers. For dairy farmers, particularly those on organic and low-input, grass-based systems, one of the most significant temperature-related impacts will be the likely increase in the range and distribution of subtropical grasses.

New Zealand farming is based on a small number of pasture plant species and this number has reduced with intensification (Williams *et al.* 2007). Climate scenarios project an increased drought risk and drought severity for eastern regions, including the Bay of Plenty (Tait *et al.* 2008). Wedderburn *et al.* (2010) showed that under successive drought conditions, ryegrass root systems sustain significant damage. Future changes of climate and carbon dioxide concentrations may lead to changes in pasture composition and feed quality for animals (Newton *et al.* 2006).

There is evidence for southward movement of exotic *Paspalum* grasses during warm periods in the past (Field & Forde 1990) and they have become established in the Bay of Plenty where they are increasingly problematic. Dairy farmers have identified the presence of subtropical (C4) grasses – *Paspalum dilatatum* and kikuyu grass (*Pennisetum clandestinum*) in particular – as having a negative effect on production. These grasses have low nutritional values and can out-compete ryegrass in the pasture (Crush & Rowarth 2007). Analysis derived from model outputs and test plots show that with further increase in mean temperature, the range and distribution of C4 grasses will likely increase (Field & Forde 1990; Kenny 2006).

Farmers on low-input and organic systems described the problems associated with keeping these grasses under control. Most significantly, the costs associated with pasture management and production losses. Climate change and an increase in the distribution of C4 grasses then, is not simply a climate-related exposure but will be felt in conjunction with other, non-climatic pressures. One dairy farmer who described an increase in the distribution of kikuyu on their own farm and anticipated it being problematic in the future noted:

> *Do I see it as a risk? It could be a risk to New Zealand farming if it became sort of more widespread, I guess mentally I don't put it in the risk bracket so much as an expense. It is a risk because on a low payout you can't afford to do all the things we're doing to manage it, and it makes you not very competitive – you're getting the same price for your milk as everyone else but you're having to do all this tractor driving, mechanical control spraying, contractors to manage your pastures as opposed to just having the cows go into pastures, eat it, and have them turn it into milk.*

Keeping pastures free of these grasses requires input of labour, as well as time on the tractor. Other inputs include grass seed, fuel and fertilizer. If both fuel and fertilizer prices continue on an upward trajectory, as many analysts believe (Vaccari 2009; International Monetary Fund 2012), pastoral farmers trying to control their exposure to subtropical grasses will in a sense be 'double exposed' to both decreased production associated with these grasses as well as the higher input and management costs, reducing overall profitability. As one low-input farmer said:

> *The climate definitely has changed in the time that we've been here, which is going to become a bigger threat. The one for us is kikuyu grass which is, they call it a C4, warm climate grass. There was a little bit here when we came here, but the frosts in the winter*

> *–because the winter was more severe, really knocked it back – and so it didn't spread much, and it wasn't a specific pasture management issue, where it is now. In fact it's quite widespread on the farm. It doesn't grow in the winter, and it grows too fast in the summer and it's got low ME, we can't economically get rid of it.*

While there are alternatives to pasture, as this dairy farmer notes, it is a question of whether or not it is economically feasible to buy in supplementary feed. *"If the climate changes on you, it means that grass production is changing, that's the one that relies on the sun and the rain for free. You know you could buy in other stuff but then that's all just relative to milk price."* This demonstrates the need to consider the broader resilience implications when considering a specific climate impact as possible adaptation measures may create their own set of vulnerabilities.

In addition to the spread of subtropical grasses, warmer temperatures may also lead to new or more pest outbreaks. Producers noted that pests which were prevalent in other, warmer parts of the country were now becoming problematic in the eastern Bay of Plenty. *"Black beetle is another issue, and again, it's climatic. A lot of this stuff again, is all Northland, it's a Northland problem, and it's, I think, warmer winters and droughts and things, so we're getting it here,"* said one dairy farmer. Clover root weevil and clover flea might also become problematic with warmer temperatures. Producers may also be more vulnerable to pests, given the higher management costs and the lack of previous experience in dealing with them. Facial eczema, which is already prevalent in the Bay of Plenty, flourishes under warm, humid conditions (Smith & Towers 2002). This too may become more problematic for dairy farmers as temperature and humidity increase.

It is not only increased summer temperatures that will adversely impact dairy farmers, but changes in winter temperatures also. Climate scenarios indicate that the greatest warming will occur during the winter months and the number of frost-free days will increase (Griffiths *et al*. 2003). Cold winters were described as having several benefits: cold temperatures inhibit the spread of subtropical grasses and other pests, as well as providing a boost to grass growth in the spring. "*If you get a real cold hard winter, then when the grass grows it just blooms away,*" said one farmer. Warmer winter temperatures therefore are likely to be a negative climate-change-related impact. For low-input farmers, including organic, good spring pasture growth is essential (Verkerk 2003) and warmer winters may result in lower production, and overall returns. As this dairy farmer in Opotiki describes the future:

> *I think it's definitely got warmer, and I'm sure there's less frosts – which is probably a bit of a negative really… Why is that a negative? It seems to stimulate the growth patterns when spring actually comes, but when the winter's too warm it just doesn't really come… it's a bit more like Northland's climate and grass production in Northland's generally a lot lower than it is here. Rye grass is designed to grow in about eighteen degrees – too many years above that, and well… not really that good and we end up growing more of this gunky summer grass, and it's got low nutrient value. So we're creating a better environment for it. So that's a negative.*

High summer temperatures and the number of days with temperatures exceeding 25°C are also expected to increase (Griffiths *et al.* 2003). Inland areas, such as Kawerau, away from the moderating influence of the water, may experience greater temperature extremes in temperature. With respect to current exposure, one dairy farmer noted, "*The biggest thing for us is, in the summer, is the heat, because the cows lose their appetite and we get a real drop in production, when it gets hot.*" This has been supported by research overseas (Kadzere *et al.*

2002; West 2003) in which high temperatures were also shown to have adverse effects on animal health, including reduced feed consumption and declines in production, as well as reproduction (Pennington *et al.* 1985; Gwazdauskas *et al.* 1986) . As one farmer commented, rain also "*has an effect on your reproduction – if you have a lot of cloudy days in the spring, reproduction drops generally.*" Exposure-sensitivity can be reduced, and important adaptive strategies might include herd homes or additional on-farm shading. Tucker *et al.* (2007) have shown that shelter provides benefits for dairy cows in winter in the winter at least. Shelter is regarded by producers as an important adaptation, as this dairy farmer stated:

> *I think the other threat is that climate. It's getting hotter and cows don't like heat. I keep thinking am I going to have to shade top one-hundred and forty hectares so my cows can sort of stand off? I know a guy down our way has already put a shade over the yard.*

However, beyond a point decreased production can reduce farm profit, in turn limiting the capacity of farmers to invest in expensive technological adaptations.

Some studies have suggested that elevated CO_2 levels will in fact increase production of certain pasture species (MAF 2011). One farmer felt that warmer temperatures, while creating drier summers, could potentially enhance productivity in winter and spring.

4.1.3 Changes in precipitation

Estimated changes in precipitation also have negative implications for producers. Reduced rainfall will likely increase stress on pasture. Research by White and colleagues (1997) has shown that stressed pastures are in turn more susceptible to colonisation by invasive grasses. As described above, the increase in C4 grasses is likely pose a significant source of future exposure-sensitivity for dairy farmers and not only represents a climate related risk, but also affects farm income and is correlated with higher input costs and reduced production and income. Given that climate is predicted to be drier for the area, this will likely further increase the susceptibility of pasture to colonisation. Rainfall intensity may increase, though total precipitation declines. This may have important implications for groundwater recharge. Groundwater supplies globally are vulnerable to increased temperature and demand due to climate change (Döll 2009). Locally, it may place higher demands on irrigation, or on practices that increase the capacity for the landscape to infiltrate and hold water (whether in soils or on-farm water bodies).

> *If it got warmer and the water dried up that would mean big changes to farming. We take water for granted in New Zealand, and I think that's a big worry, that's the one thing – we wouldn't have been able to grow grass this summer without the underground water… I take it for granted – it's there.*

Groundwater resources in the study area not clearly understood (White 2005). Demand on groundwater supplies in New Zealand is increasing as dairy farms intensify production through higher stocking rates and irrigation (MacLeod & Moller 2006; Basset-Mens *et al.* 2009), trends also evident in the Bay of Plenty. Since irrigation is also used as frost protection by kiwifruit growers in the Bay of Plenty, any reduction in available groundwater supply would reduce those producers' capacity to adapt as irrigation is an adaptation to both dry conditions as well as frost risk.

Severe rainfall events were also identified by producers as being problematic. When dairy cows are left standing in saturated fields, they can destroy pasture cover (Nie *et al.* 2001). If there have been significant changes in the composition of pasture, there may be increased soil compaction as animals graze for longer periods to eat sufficient grass, decreased interception and drainage, and therefore more frequent problems with pugging (Pande *et al.* 2000).

4.1.4 Changes in variability and extremes

Though difficult to predict using current climate models (Easterling *et al*. 2000; Tebaldi *et al.* 2006; Fischer & Schär 2008) a shift in the distribution and variability of climatic extremes is also likely to be problematic for farmers. Griffiths *et al.* (2011) suggest an increase in the severity of rainfall events. This would likely alter flood-risk for much of the Bay of Plenty. Pugging would be more problematic if rainfall is concentrated into shorter periods of time, overwhelming the soils' capacity for drainage.

Several farmers we spoke with described greater variability in precipitation, particularly over the last 10 years and a trend towards more subtropical conditions.

> *We seem to be in a different cycle… the rainfall events seem to be getting bigger, like stronger, bigger events – heavy, and the spread is getting not so good, like a lot of rain and then not much for six weeks and then another lot, and this year's only been nothing and then little bits.*

Increased drought frequency is very likely in eastern areas (Mullan *et al.* 2005), with potential losses in agricultural production, particularly for dairying. Estimates from MAF (2007) indicate a drop in export revenue from milk production to between 85 and 90% of the 1972–2002 average for the 2030s, and between 83 and 93% by the 2080s. The effects of changes in climate on flood and drought frequency will be further modulated by phases of the ENSO and IPO (McKerchar & Henderson 2003).

4.1.5 Summary

The use of climate projections captures many of the climatic conditions identified as significant by producers, particularly with respect to climatic variability and extremes, however certain vulnerabilities can be overlooked. For example, more variable weather could also imply that the likelihood of cold and wet periods or cloudy days will not necessarily be reduced with climate change (Griffiths *et al.* 2003). Cloudy, rainy days affect reproduction in dairy cows (Pennington *et al.* 1985; Gwazdauskas *et al*. 1986). If farmers had more 'empties' (cows that do not come into calf) this would result in decreased milk yield. The full extent of exposure-sensitivity to changes in climatic conditions then may be difficult to fully describe.

4.2 Assessment of the draft Resilient Dairy Farm System model

The draft factors which influence farm level resilience to drought (*Table 9, see also Table 7*) was tested against the findings of the farmer and key informant interviews, the farmer pre-surveys and farmer workshops. Additional detail on the framework, key references and detailed description of their relationships to resilience can be found in *Appendix 1*.

Table 9: Draft indicators for farm resilience

Social	Economic	Agroecological
Critical awareness of potential risks Positive outcome expectancy The ability to plan, learn, & reorganize Attachment to place Environmental values Social capital Trust in & participation with government & sector bodies Management structure & culture	Financial resources Profitability Pluriactivity Feed security Management practices which reduce impacts of drought Diverse local economy	Water security & effluent management Soil properties & management Stocking policies Trees Micro-climate

Our assessment considered:

- **Suitability.** Are the 19 characteristics of 'resilient dairy farms' sufficient to characterize resilience, with respect to the 2012/13 drought? And are these, in turn, robust enough to indicate future adaptability to climate change?
- **Self-contained.** Were there additional factors that needed to be accounted for, not present in the original framework? Are the indicators complete?
- **Scale.** Were conditions at farm level influenced by higher scales? And if so, how?
- **Synergy.** Are there interrelationships between factors that influence resilience

We then explored how those factors might be conceptualised as a farm-level model to illustrate key findings. The assessment begins with a discussion of the agroecological indicators.

4.2.1 Agroecological factors

The biophysical characteristics or attributes of any farm (e.g. micro-climate, soil and substrate, terrain and altitude) influence the farm's exposure to drought, its sensitivity, and its capacity to bounce back. These biophysical factors can be tempered or enhanced by different management practices utilised by farmers or land-managers. This combination of biophysical and management practices are defined in this report as agroecological factors. This includes the farm, distinguished from the surrounding environment by the manipulation of biophysical or ecological, stocks, flows and stores (e.g. water, nutrients) for milk production. It includes everything contained within 'the farm gate', as well as those components related to the interactions and inputs and management of those biophysical characteristics, such as soil and pasture management practices.

Table 10 shows the draft agroecological resilience factors and the revised version of the agroecological factors based on the findings of the study.

Table 10 Agroecological indicators

Draft Agroecological	Revised Agroecological
Water security & effluent management	Water security
Soil properties & management	Soil fertility and moisture content
	Feed security
Stocking policies	Sustainable stocking rate
Trees	Trees
Micro climate	Topography (Microclimate)
	Climate

The draft indicators were largely well-suited for the assessment of agroecological resilience. The most important, as identified across the three different dairying systems, was *water security*. Water security – which includes average rainfall especially over spring and summer, on-farm reticulation and irrigation – is critical.

Rainfall varied significantly between the farms surveyed, from 1200 to 2000 mm, within the same catchment. Those farms located in higher rainfall areas were able to withstand drought conditions much longer, than even neighbouring farms. *"We are just high enough, so that at night we would get a good dew, and that probably kept us going a lot longer than guys down the road, who are much lower down,"* reported one Rotorua Lakes farmer.

In addition to annual rainfall, irrigation was understood to be a critical indicator, particularly for future water security. Of the farms surveyed, only two were currently irrigated, though nearly all respondents indicated they would consider irrigation in the future if conditions became drier. One of the farms we surveyed had a consented river take, and another nearby property irrigated 50% of the farm, using a storage pond.

Irrigation can effectively reduce 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 adaptive capacity. Before installing irrigation, this farm near Kawerau, on a combination of sand and ash, struggled to produce sufficient quantities of grass. As the farmer noted:

> *The irrigation has given us the ability to grow – the ability to service whatever you want to borrow, and with irrigation we've had a much greater cash flow, going from a hundred odd cows to where we are now. We had irrigation, increased cash-flow and so could take on more debt. On an average year here without irrigation, you do seven-hundred kilos a hectare. And some years you might do five, and some years you might do nine, and now we sit at eleven-hundred, it was four-hundred over seven-hundred, so greater than fifty-percent. And it's had the effect of stabilising your income, and creating more income.*

There are limitations to irrigation as a response to climatic extremes, including capital costs, as well as questions surrounding long-term sustainability. "*Irrigation means a lot more work, an extra labour unit, housing, a new cow shed, heap more cows – it was a whole lot of capital costs beyond irrigation,"* said one farmer. In addition, irrigation comes with ongoing operating and maintenance costs, which can 'lock in' farmers to high-production systems, reducing the overall flexibility of the enterprise. Energy costs, which are likely to rise, are also much higher on irrigated farms, as one farmer put it:

> *Electricity, when we first put irrigation in five years ago, it was costing me around $1500 a month if we were running, last year on average I was paying between $2700 and $3200 a month to run that irrigation. It used to cost us about 6 cents a kilo, dry matter, to grow the grass out there on the back, on the sand hills, it's now gone up to between 11 and 14 cents a kilo of dry matter, or thereabouts. Not just the cost of electricity, but the cost of urea to try and encourage that grass growth too.*

Energy resources on a low-input farm have been shown to be half that of a nitrogen-fertilized system, and one-third those of a high input system (Monaghan et al. 2008; Basset-Mens et al. 2009). Water resources in the eastern Bay of Plenty are not well understood (White 2005) and it is unclear whether or not increasing demand for irrigation will be sustainable in the long term. In this way, irrigation may actually be considered a maladaptation (Barnett & O'Neill 2010; Holman & Trawick 2011). Long term, water security is also dependent on renewal of water consents. One farmer was in the process of renewing water consents and commented that the process had become more complex with more stakeholders to consult. Other farmers in the same catchment were interested in adopting irrigation but there was currently a lack of community-based irrigation schemes to access.

In addition to evaluating long-term security of supply, there are important short-term implications for water security, which is dependent on both technology and management. One farmer's irrigation system broke down for 2 weeks, nearly destroying the pasture, and another said that with irrigation, "*staff had to be on the ball, much more than before*". Irrigation on a farm multiplied the number of decisions that needed to be made, and finding staff able to manage that effectively was seen as a future 'social' risk.

The ability to adapt to changing climatic conditions – not only to reduce exposure to climatic variability and extremes but also to take advantage of opportunities associated with changed climatic conditions – will likely be influenced by technological innovations. Technologies including the development of genetically modified crops, drought- and pest-resistant cultivars, have been identified as being important adaptations to climate change elsewhere (Smithers & Blay-Palmer 2001; Lotze-Campen & Schellnhuber 2009; Metzlaff 2009). For New Zealand producers, modification of existing sprinkler systems for variable rate irrigation (Hedley et al. 2010a, 2010b) might be an opportunity to improve water use efficiency, and enhance resilience.

Warmer temperatures are likely to result in the spread of sub-tropical C4 grasses, shown to be a significant future exposure for pastoral farmers. However, as one farmer noted, it may also present an opportunity for a technological adaptation:

> *I think it [climate change] is an opportunity. I reckon the Bay of Plenty will get warmer and wetter; we're seeing an increase in what they call C4 species, which are temperate grasses the likes of kikuyu, which is seen as a weed but with technology and management these days, somehow we've got to learn to use that. It's going to happen, but we can learn to control that and utilize it – in good growing conditions it can outgrow anything…just got to learn to utilize it. It's another opportunity.*

Repeated drought years have been shown to damage ryegrass root systems, meaning that perennial ryegrass cultivars have to be replaced by other grasses (Wedderburn et al. 2010). There is however, a long lead time required for technological innovation (Smithers & Blay-Palmer 2001) and unless climate change is regarded as a viable concern, government, research institutions and other stakeholders are unlikely to invest. There are also social barriers to GMO adoption in New Zealand (Cronin 2008). Technology also often requires significant investment by the individual producer or grower, in terms of equipment, additional labour and replanting. It is possible that only the largest farmers therefore, will be able to take advantage of these opportunities.

This comment was echoed by a dairy farmer who noted that while shifting to a high-input dairy production system could be an adaptation to climate change due to lower yields and declining pasture quality that:

> *If you want to go into a more supplemented system, you've got to have the right scale because you might have to put some concrete down to feed, to put in some troughs. Economies of scale: you also need machinery to feed the stuff out. So for a little farm, that all grass is a nice, efficient, low-cost system. For a little guy to go to supplement - there's all those things to do with labour, machinery and all that.*

Two other indicators – *stocking policies* and *soil properties and management* – were refined, and are now *sustainable stocking rate* and *soil fertility & soil moisture capacity*. With respect to soils, there was considerable variation between the different farms, each with related management challenges. The majority of farmers described their soils as having 'low resilience' to summer dry. During the workshop with farmers at Awakeri, much of the discussion focused on farmer practices and experiences with trying to increase soil moisture capacity and fertility, often through biological means, to enhance the resilience of the pasture. Of the eight farmers at the workshop, half had recently (< 5 years) adopted biological farming practices in an effort to increase soil fertility, as well as to try to reduce costs. The farmers who had adopted biological farming were all systems 1 or 2. Three farmers described greater rooting depth of grass after 2 years of biological application and believed the biological soil management had helped their pasture hold on better over this year's drought. One of the commonly cited reasons for switching to biological soil management was that they had been applying increasing amounts of fertiliser without seeing gains in grass production while their soil was "turning to concrete."

In order to operationalise carrying capacity, as a function of a resilient system, we propose that a useful measure might be *sustainable stocking rate*. The sustainable stocking rate refers to a stocking level that maintains stock performance and but does not damage the pasture. In the Bay of Plenty, where soils are wet for much of the winter, and in places, poorly drained, higher stocking rates create significant pugging problems. The ability to stand stock off on a feed-pad or off the milking platform is an important characteristic of a more resilient farm.

Both the proposed agroecological and economic indicators are significantly influenced by spatial scales beyond the farm-level. Farm-level conditions, such as soil type, are an extension of larger, meso-scale processes. Drainage of swamplands, volcanic eruption and diversions have all contributed to the mosaic of very localised soil conditions in the Bay of Plenty. As one farmer put it, describing conditions on his own farm:

The Rangitaiki Plains is surrounded by hills, and that was part of the Bay of Plenty, and the Maoris lived around the edge – because this was all swamp. Originally it was a bigger Bay of Plenty, and as the water and the floods came and the earthquakes, all the mixture of soils ended up to form the Rangitaiki Plains. You get peat, rotten vegetation, pumice out of the Taupo eruption and ash – it's all in there.

Finally, it is important to note the influence of processes occurring at broader spatial scales (Adger *et al.* 2009; Eakin *et al.* 2009). Producers are exposed-sensitive at the farm-level in varying degrees. The capacity of individual farmers, their awareness, financial resources, and those characteristics of the farm or orchard, such as soil type and location, influence exposure-sensitivity at the farm level (Reid *et al.* 2007; Wall *et al.* 2007; Tarleton & Ramsay 2008) but often these are driven by processes and feedback mechanisms at higher scales (*Table 11*). This demonstrates the need to consider, not only the national or even regional context when evaluating resilience and adaptation options, but their influence at the farm-level.

Table 11: Significance of scale on agroecological and economic indicator

Macro-scale influence	Meso-scale conditions	Micro- (farm-level) stimuli
Climate (ENSO/IPO)	Elevation, aspect	Δ Precipitation, Δ Temperature, frost, wind
Biophysical conditions	Drainage and hydrology, regional soil types	Saltwater intrusion, disease, pests, invasive/subtropical grasses
Market and financial	Marketing networks, currency exchange rates, commodity prices, compliance costs	Δ Input costs, payout

4.2.2 Social factors

As per the conceptual framework, a second set of indicators was developed and assessed in order to characterise differences in the 'social resilience' of the different farms within the study. *Table 12* shows the draft social resilience factors and the revised version of the social factors based on the research findings. Where appropriate, the scale or 'level' at which the indicator is most often operationalized, is shown, whether: farm-level (FL), sub-regional or catchment (CL) or national-global scale interaction and influence (NGL).

Table 12 Indicators for social resilience

Draft Social Resilience Factors	Revised Social Resilience Factors
Critical awareness of potential risks	Critical awareness of potential risks (FL)
Positive outcome expectancy	Positive outcome expectancy (FL)
Self-efficacy (FL)	Self-efficacy (FL)
	Degree of focus on long term viability (FL)
The ability to plan, learn, & reorganize	Learning capability (FL)
	Pasture and /or feed supply skills (FL)
Attachment to place	
Environmental values	
Social capital	Connections to other farmers and dairy sector (CL/NGL)
Trust in & participation with government & sector bodies	
Management structure & culture	

The suitability of the social indicators for characterising resilience was also very high. The draft indicators were based on a review of the social impacts assessment, resilience and disaster- and risk-management literatures. Two of the indicators (*attachment to place, environmental values*) were tested, and found not to be an important factor. An additional indicator – *management structure and culture* – was recommended by one of the peer reviewers. This was tested for; however, it was only applicable for those farms in which there was a share-milker, manager or staff, and as only three of the fifteen farms met that criterion we have not included it in the final list.

Of the draft indicators, three social factors – *critical awareness of potential risks, positive outcome expectancy*, and *self-efficacy* – were found to be very useful determinants of the 15 farmers' proactive response to the drought. These three social factors also have important implications for resilience and responses to future climate change. Studies of disaster resilience have shown that these three factors – at the scale of the individual decision-maker, in our case, farmers – are interdependent. In order to respond effectively to a shock, to 'form the intention to take action' and thus be resilient, all three are required. These are discussed in turn.

Critical awareness of potential risks enables an individual be aware of a risk and assess the potential impacts exposure *to* that risk will have on their farm (Paton 2006b; Norris *et al*. 2008). *Positive outcome expectancy* is a measure of an individual's belief that there are solutions available that will be adequate to for the mitigation of that exposure (Paton 2006b; Marshall *et al.* 2007). Finally, *self-efficacy* is a measure of the individual's belief in their ability to carry out those solutions, to adapt (Bandura 1977, 1982). In this framing, there is a logical sequence that links the three factors:

> *Belief in the risk, belief in the solution to the risk, and belief in one's ability to implement that solution.*

Based on our interviews, the majority of farmers had taken early action in response to the recent drought conditions. This is characteristic of proactive and resilient farm decision-making. In the survey, critical awareness was tested for by asking farmers to respond to a series of questions related to their understanding or knowledge of climate change, and climate other climate-related risks. On a scale of 1–5 (very low to very high), the majority of farmers in our study ranked themselves as being medium to high. For example, several of the farmers mentioned that by early summer, despite enjoying an extremely good spring, they felt they might be in for a drought and therefore they had begun to prepare for one. One farmer, for example, observed that plants were flowering at different times which triggered concern that they were facing a drought year. Others recognised that the weather pattern was settling into a drought in January/February and started to buy in supplementary feed.

Most of the interviewees had a reasonably positive outcome expectancy that they would bounce back from the drought. This may have been helped by the fact that at the time of the first interviews (10 April) the Bay of Plenty had just received rain, though the quantity varied significantly between farms. For some the rain they had received had been enough to prepare them for winter pasture, while others still needed additional substantial rainfall. Interestingly, nearly every interviewee mentioned they felt that their farm had coped better than other farms in their area (including at times, farms belonging to other interviewees).

There was a marked contrast, however, between farmers' *critical awareness to drought* and *critical awareness of climate change*. The majority of farmers surveyed, when asked about their perceptions of the risk of climate change, either did not believe that climate change was occurring, or were neutral about whether it was occurring or not. These results are consistent with other studies showing low critical awareness of climate change risks, in other regions (Cradock-Henry 2008; Niles *et al.* 2013). Perhaps because of this lack of critical awareness, many of these same farmers felt climate change would not create additional challenges for dairy farming in the Bay of Plenty or risks for their farm and believed that their current solutions would be sufficient to deal with any future climate change (*positive outcome expectancy*). In addition, most of these farmers did not believe that more information on climate change was required to help farmers adapt. This suggests that a lack of critical awareness of climate change can lead to an overly positive outcome expectancy of the famer's current practice that is likely to constrain any adaptive responses to climate change. It also highlights Paton's (2006b) argument that these three factors (along with others) are interdependent – a person needs to possess a measure of all of them in order to proactively develop resilience to climate change.

In terms of *self-efficacy*, most of farmers surveyed scored themselves medium-high and the majority believed their responses to the drought were the right ones. Some farmers contrasted their personal ability to cope with the drought to the ability of their farm manager or share-milker, who were thought to have been too stressed. As one farmer said, if you couldn't cope with the challenges of the weather, you were in the wrong profession. For older and more experienced farm-owners, much of the learning to manage adverse conditions was based on previous experience. This suggests that farming requires considerable resilience at a psychological or emotional level, an ability to persevere in situations that cannot be accurately predicted or controlled, but only managed, such as drought. Previous experience with drought has aided farmers in predicting, responding effectively, and maintaining their belief that they would get through. This reflects Bandura's (1977, 1982) findings that self-efficacy is often developed through previous experiences of dealing with challenging situations.

Another important indication of farm-level resilience that was identified through our study was the *focus on long-term viability*. In other words, to what extent were producers willing to "take a hit", and dry off early. As one farmer said:

> *If it was just the Bay of Plenty, yeah, I probably would've milked, but it was all over New Zealand. Everyone was having the same problems, so it wasn't as if you could just truck them off somewhere, realistically, or buy in something. Like normally when we get dry here, we can still buy in feed from Gisborne, but because everyone's having the same problem, just pull the pin and figure it out next year.*

By not milking farmers are able to preserve cow health and condition, fertility and ultimately productivity, both of pasture and stock.

While nearly all the farmers in our study agreed that to be resilient one needed to be able to absorb the bad year, one farmer felt constrained by their high level of debt; they simply could not afford to stop milking.

This focus on long-term viability was also identified in an interview with a key sector informant. After holding a series of drought workshops throughout the North Island, this individual felt the farmers who were coping best with the drought were the experienced farmers, with excellent pasture management skills, who knew how and when to secure supplementary feed. Furthermore, farmers with repeated experience of droughts, or farmers in drought-prone areas, have learned to be proactive. Those farmers have "*20 or 30 years' experience reading, managing and successfully coping with drought. They know what's important.*" Experienced farmers understand and can identify the 'system critical thresholds' (Walker & Salt 2010); they know where to direct their attention, what to focus on, and have designed and refined their systems accordingly. The most successful, or resilient, farms have built in buffers to ensure long-term success.

Several other social indicators were also refined. The draft factor *ability to plan, learn and reorganise* was refined into two interdependent factors: *learning capacity* and *skills in pasture and feed supply management*. Eight farmers could be described as being 'highly proactive' in learning new skills to apply on farm, while another six were 'moderately proactive'. This above-average score in learning (as well as in coping with the drought) may be a reflection of a positive bias in interviewee selection. Farmers who were not overly stressed, who were well connected and plugged into farmer networks, and who were interested in discussion and research were more likely to participate in our study.

This ability to plan ahead is reflected in the use, for example, of forward contracts for feed. Forward contracts reduce the risk of purchasing inputs on the spot market, and can be considered a form of risk sharing (Wandel & Smit 2000). One dairy farmer described it in the following terms:

> *I think if you're forward thinking you can plan, and buy 12 months out. So we've actually purchased 20 ha 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.*"."

Another aspect of this is the ways in which farmers gather information and apply it to their farms. Some interviewees described a structured, almost scientific approach, of testing and refining hypotheses; seeking out the best studies and supporting evidence and widespread adoption of various technologies (e.g. using lasers to measure grass growth, monitoring of soil moisture using remotely sensed satellite imagery). Other participants described their proficiency and confidence in being able to 'read' animal condition, or the health of their pasture, simply by looking at it or walking the farm. Many farmers mentioned that they first trialled new pasture species or regimes at a small scale to test their viability before adopting at a larger scale, or looked to their neighbours. "*I'm not the first guy out of the gate,*" said one farmer, "*but I'm always looking over the fence to see what* [the neighbour] *is doing. I let him muck around first and then if it works, I'll get on board. I'm not the earliest adopter, but I'm happy to follow suit.*"

Finally, the original indicators of social capital and trust in and participation with government and sector bodies were narrowed in focus. These were replaced by a new indicator, connections to other farmers and dairy sector (CL/NGL). Connections to other farmers were consistently ranked by respondents as being more important than their connection to the community. Farmers also scored themselves as having stronger ties to other farmers, identifying themselves first and foremost as dairy farmers, than as members of a geographic community.

The interviewees' connections to other farmers and to the dairy sector ranged from having informal connections through to being part of farmer discussion groups, being involved in sector research programmes, and holding positions of their local sector groups. The majority appeared to be well connected to dairy sector information networks; however, most felt they had managed the drought largely through their own decision-making unit (those family members and workers actively involved on the farm). The information and social connections appeared to play a greater role in ongoing learning and information provision than in supporting farmers during the drought. At least one farmer was not involved in any discussion groups and saw no need to be.

In the original framework, it was proposed that *attachment to place* might have an influence on social resilience. This indicator had been identified in Marshall's (2012) work on fishers in Australia and also in studies of rangeland farmers (Marshall 2010). When dairy farmers were asked the extent to which they agreed with the statement, "I feel a strong sense of connection to the place I live and work," it was ranked extremely low. This low sense of connection to the places in which they live and work, is particularly interesting, given the fact that the majority of the farmers interviewed had been in the Bay of Plenty for 30+ years, and over half (*n*=9) had taken over the family farm, either through direct inheritance or through a purchasing agreement. This indicator was dropped from the final framework.

The significance of stakeholders' age, and its influence on different aspects of resilience was considered by the researchers during the course of the study, but was not tested for during the fieldwork or included in the framework. Social and human capital are important aspects of an agricultural community's capacity to deal with variable conditions (Wall & Marzall 2006). As one farmer put it: "*I think that urban one does worry me, we're getting fewer and fewer farmers*". There is a substantial amount of social learning, or learned adaptive capacity that exists in the farming community. Producers' strategic and anticipatory, tactical and reactive strategies for dealing with climatic and non-climatic risks have been acquired in part through prolonged exposure. For farmers to successfully react/adapt to change, relevant experiential information needs to be available, "practical wisdom" (Schwartz & Sharpe 2006), so that feasible options can be evaluated and their likely technological, social, economic or managerial impacts understood. "*In terms of risk management*", said one farmer, "*experience has a lot to do with it. No one can tell you what to do. Every location is different. And what someone does to do something, and looks different, might not necessarily work on your farm*". **A**s the farm work force ages and fewer young people enter farming there is a risk that much of this social and human capital will be lost, as the farmer quoted above notes, and as shown in empirical work in Australian agriculture (Doole et al. 2009).

Population trends for the Whakatane District and eastern Bay of Plenty (BERL 2010) point to an ageing population in coming decades and continued out migration. Rising house prices in response to an influx of retirees (Whakatane District 2009), may act as a further barrier to employment in agriculture. Other barriers to the flow of human and social capital include the high cost of farm ownership and a perception of long work hours for low-returns (Tipples et al. 2002; Clark et al. 2007; Wilson & Tipples 2008). The ageing farming workforce potentially represents a loss of the accumulated experience and wisdom (embodied in individuals and in the collective adaptive strategies employed in the area), that may hinder or slow future adaptive capacity. As one farmer said, "*There's nobody new going into the industry. They did a survey, the average age of a dairy farmer is fifty-eight or something. Like the sheep farmers in New Zealand, because the reward's not there. Young people would rather go to Australia*".

4.2.3 Economic Factors

A third set of indicators was developed to help characterise economic resilience at the farm level. Of the three indicator sets, these have been the most substantially revised, and reflect the incorporation of a larger systems perspective, into the analysis. *Table 13* shows the draft economic resilience factors and the revised version of the economic factors based on the findings of the study. There were a number of changes to the economic indicators based on the results of the empirical work. The revised indicators now reflect a systems perspective, and are better suited to exploring the interactions and differences between on-farm profitability and feed security.

Table 13: Indicators for economic resilience

Draft Economic	New economic
Financial resources	Debt-equity ratio (FL) Land value (CL/NGL)
Profitability	Profitability (FL) Milk prices (NGL) Gov/Sector compliance costs
Feed security	Local feed supply/demand ratio PKE/imported grain supply/demand ratio Irrigation options
Management practices that reduce impacts of drought Diverse local economy Pluriactivity	

The original indicator, *financial resources,* has been replaced by *debt-equity ratio*. New Zealand dairy farmers are very highly indebted, making them vulnerable to interest rate increases, a drop in land prices, and fluctuations in payout. Over the past 10 years, the debt carried by the average New Zealand dairy farm has increased four-fold (Fox 2011). The average production farmer now owes NZ$2.8 million, up from NZ$700,000 in 2000 (DairyNZ 2010). Payout has risen; however, farm working expenses have also increased through inflation and input costs (Rennie 2009; Rutherford 2011).

A number of farmers in the study described themselves as being "asset rich", but having poor cash flow. The rise in land-prices, and rapid expansion of the dairy sector have been largely funded by debt. Debt servicing can take up a large portion of farm-gate returns, limiting producers' ability to invest in on-farm improvements and lowering their overall resilience to any unexpected shocks or stresses. As this farmer notes:

> *Our costs are pretty fixed – most farms between $2.50 and $3.00 a kilo, which obviously in a $4.00 payout year, it's over 50%, and this year it's 30%, so everything's sweet, but if it drops back to $4.50 – which was the long-term average, the banks were all using $4.25 going out 5 years, Fonterra was saying get used to $4.00 and we were saying we can't live there. My debt servicing is $1.60, I've got $2.50 of farm working costs, so I was going backwards, and we were – we were producing a loss each year, and were just farming for capital gain; which we've been doing for years.*

Lower debt-equity ratios provide farmers with greater ability to borrow money in a bad year, to purchase additional feed, and "just get through" when productivity is reduced. Higher debt can reduce flexibility, and make it more difficult for farmers to invest in long-term, strategic adaptative responses.

Milk prices and *compliance costs* – both those of government as well as sector – were identified as influencing short-term *profitability* and longer-term *stocking rates*.

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 & Smit 1997)**.** The term "pluriactivity" is used by MacKinnon et al. (1991, p.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. As with many adaptations, diversification of household incomes is unlikely to be undertaken directly in response to climatic perturbations alone (Le Heron et al. 1994; Bradshaw et al. 1998).

Farm operators have become more "pluriactive". Off-farm employment was identified as an important adaptive strategy. 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. Another dairy farmer, when asked if he would have done anything differently in response to the various climatic risks that had affected production, replied:

> *I would have worked off the farm, because by working off the farm you can introduce capital that isn't a risk – see, cattle were a part of the farm, and that was capital that was at risk from a whole lot of factors. If you're working off the farm, your income is guaranteed, it's stable, it's not affected by weather, it's not affected by exchange rates, it's not affected by interest rates, you can pay that level regardless of everything else going up and down, and that's the difference as opposed to farming, your income is going up and down: it rains too much, it goes down; it rains not enough, it goes down. If you earn money off the farm it's a constant.*

Farmers have also used diversification of production as a strategy. For some, the motivation to diversify was strictly in response to market and financial pressures; while for others, a mix of climatic stimuli 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 low returns, 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;

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 in order to earn extra income from the property.

In general, however, while there are benefits to diversification of income streams for households, *pluriactivity* was not considered to be an important factor by the majority of farmers we interviewed. A number of interviewees as well as workshop participants did have off-farm investments, but these were not regarded as critical to their resilience to drought. Farmers we spoke to had deliberately diversified their household and family trust investments into other sectors (e.g. commercial property) to spread risk to moderate the impact of price shocks and climactic extremes. Other famers had chosen to diversify into other farming activities. Of the 15 farmers interviewed, nine had had no other income activities.

Several of the remaining original economic indicators were incorporated into other social and/or agroecological sets of characteristics. For example, *management practices which reduce impacts of drought*, was revised and is now considered more broadly under those factors that enabled a farmer to adopt those practices, such as levels of debt and critical awareness of risks.

Other indicators were removed. A *diverse local economy* was not regarded as important. Land-use diversification, what might be described as ‘functional catchment diversity’, did provide a sometimes critical feed supply during the drought. For example, the kiwifruit sector provided *supplementary feed supply* through reject fruit, for several farmers in the Te Puke and Tauranga Harbour catchments. Farmers noted that the diversity of land uses in these areas made it easier to find runoff blocks, because there was less competition, although it also pushed land prices up and constrained farmers’ ability to expand or consolidate.

Finally, the availability of *irrigation options* at the sub-regional level (e.g. community catchment schemes) was seen to be an important feature of resilient farming systems, particularly to reduce exposure to drought. The draft indicator *feed security* was refined to include security of supply and the cost of supplementary feed. As with several of the other economic indicators, security of feed supply is a function of local, national and international drivers and multiple interacting stressors. This will be discussed in the subsequent section.

4.2.4 Refinement of the model of a resilient dairy farm to Climate change

This subsection introduces a revised version of the model of a resilient dairy farm system to climate change, based upon the research findings.

The draft model (*Figure 3*), developed before the farmer interviews and workshops, is comprised of 19 farm components that were believed to have most influence on a dairy farm’s resilience to climate change. These were categorised as social, agroecological, and economic and these three categories were broadly linked to one another within the model to illustrate that they were interrelated. The draft model also reflects the importance of multiple scales in resilience assessment (Paton 2006; Resilience Alliance 2007). It illustrates that a farm is influenced by risks and dynamic conditions at the regional, global, and national scales and, to a lesser extent, the activities of a farm (and accumulated impacts of multiple farms) influence social, economic and ecological systems at regional/national scales.

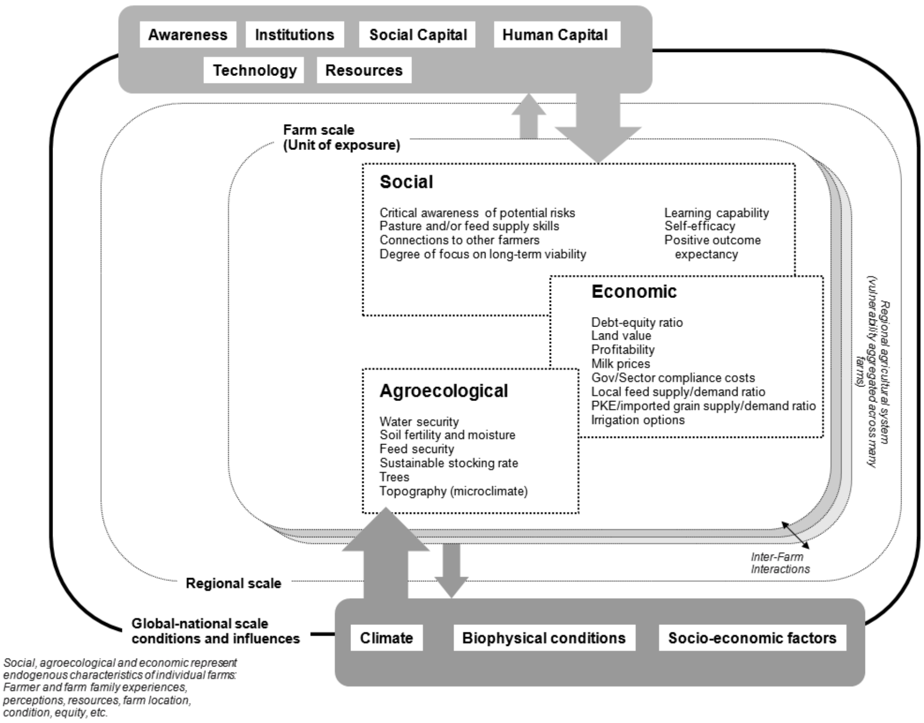

Figure 4: Revised model of farm-system and influence.

The revised model is introduced in *Figure 4*. A number of refinements have been made. The study has refined or changed a number of the original farm components critical to resilience. The qualitative nature of the research has also enabled us to identify the interrelationships between those refined components enabling the model to provide a multi-level systems perspective. The model now identifies 22 components of a farm system, situated at multiple levels, which influence a farm's resilience to climate change and more specifically drought. Some (e.g. 'farm value') are selected because they influence a critical farm-level component (debt-equity, which influences the availability of financial resources to undertake drought mitigation). The regional level has been refined to sub-regional to reflect the influence and sub-regional variety of local climatic and geological conditions.

We continued to find it useful to categorise the critical components influencing resilience within these three subsystems as it helps illustrate the distinct dynamics between the three. The psychological/social characteristics of the farmer were critical to whether they undertook management responses to minimise climatic risks (e.g. building soil fertility and moisture capacity, investing in irrigation, excellent pasture management), to whether they recognised the early signals of drought, and to whether they proactively undertook drought management responses (ensuring supplementary feed supplies and drying off early). The pivotal role the attributes and skills of the farmer (or group within the farm decision-making unit) play in creating dairy farm resilience is a key finding in the study.

However the farmer's ability to achieve drought resilient agroecological outcomes (*water security, fertile soil, feed security, sustainable stocking rate*) is still influenced and/or constrained by the biophysical characteristics of their farm (i.e. *geology, climate*) and the economic factors relating to their farm (*debt/equity ratio*) and to the sector (*milk prices* and *compliance costs*) and to feed supply chains (*availability of supplementary feed).*

Figure 5 (overleaf) shows our final model of a climate-change resilient farm-system.

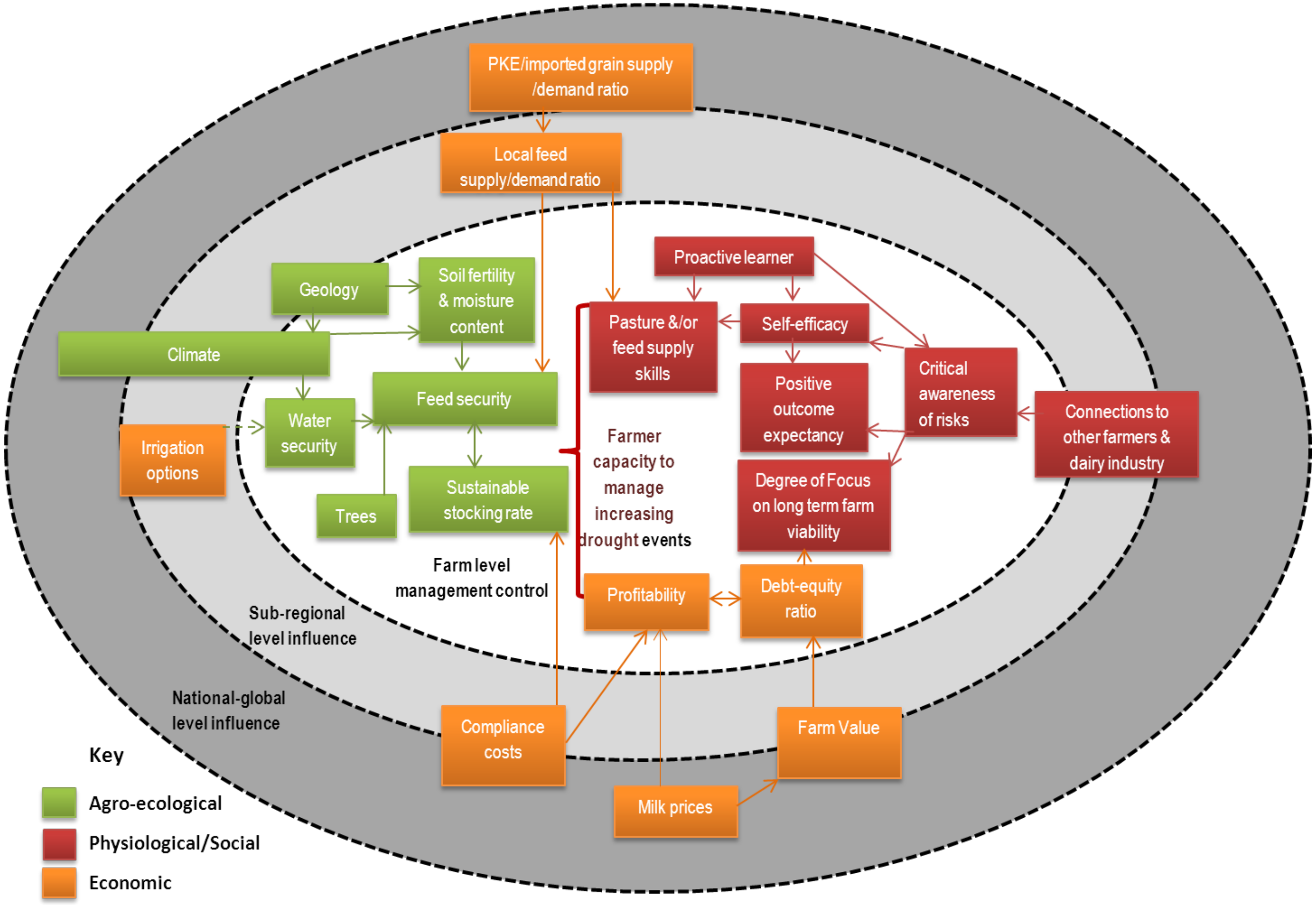

Figure 5: Climate-change resilient farm system

4.3 Comparative resilience of different dairy production systems

Using the qualitative case-study approach described earlier, how resilient are different farming production systems? Are there strengths and weaknesses, or features of different systems that can effectively support or act as a constraint on resilience? The following analysis and discussion are based on answering the questions, the resilience of what, to what? This information can be used to aid the sector in building resilience and reducing vulnerability to climate change risks.

It should be noted that the empirical work draws on a limited sample of 15 interviews, and two workshops, with 16 participants. While such a small sample is not representative of the region, important observations and insights have been drawn elsewhere, from similar sized studies (Keskitalo et al. 2010; Nicholas and Durham 2012). The case-study approach was well-suited, as it allowed for intensive and detailed examination, within a real-world context. Case-studies have been used elsewhere for the generation and testing of hypotheses (Flyvbjerg 2006; Baxter and Jack 2008) and in this sense, narratives from the individual examples in our study provide a rich knowledge base from which to generate new ideas and hypotheses for quantitative testing.

Quantitative surveys using a larger sample size and other probabilistic types of assessment (such as regional climate modeling) can further supplement the work presented here, especially to characterise resilience over larger scales. While there are limitations to relying on climate projections for insight into future vulnerability, it is clear from the discussion above that a number of the conditions to which dairy farmers are currently exposed-sensitive will increase in severity and/or frequency. Changes in temperature, precipitation, drought, flood, and other climatic extremes will impact different farms to varying degrees, according to regional and local biophysical characteristics and those of the individual farm.

The application of the indicators was done through a combination of surveys, interviews and stakeholder workshops. Before the interview, farmers were asked to complete a questionnaire inviting them to rank themselves on a number of criteria related to our indicators (e.g., critical awareness, place attachment, etc.), which form the basis for the social characteristics in our framework. Interview questions solicited information about agroecological conditions, including the biophysical characteristics of the farm (e.g. soil type, water availability, micro-climatic conditions), and management practices (e.g. stocking rates). Economic data, such as the levels of debt a farm might be carrying, pluriactivity, and profitability, were also sought.

The results are shown in *Table 14*. Individual criteria were drawn from the results of the case-studies, surveys and individual farmer-interviews. Workshops were used to triangulate the indicators framework. The table shows individual criteria, comprising the social, economic and agroecological resilience of different farming systems. For each criterion, responses from stakeholders were transcribed, and coded according to the original framework. Researchers then assigned a ranking of high, medium or low for each statement. These were converted to a numeric value (3 – Significance is high, 2 – medium, 1 – low). For the purposes of visualisation and comparison, results in the table are shown as follows: *** is a strong indicator of resilience, ** a medium indicator of resilience, and * is low. Responses from the different farms were aggregated, and then a pairwise-comparison was made. The discussion which follows focuses on key climatic variables (changes in temperature, precipitation and extremes), as they relate to each of the different farm systems.

Table 14 Ranking of significance of criteria as indicators of resilience on each farm system. Criteria were identifed as HIGH (***), MEDIUM (**), LOW (*) within each domain and for each farm system. If blank then indicator is N/A. The findings indicate only small differences in resilience when considering the whole farm. Differences in strengths and weaknesses of different farms provide opportunities to enhance the resilience of the various systems

		Social						Agroecological							Economic					
Farm System	Critical awareness of risk	Positive outcome expectancy	Self-efficacy	Learning Capability	Connections	Pasture/feed management	Focus on long-term	Water security	Soil fertility and moisture content	Feed security	Sustainable stocking rate	Trees	Local Topography	Climate	Debt-equity ratio	Land-value	Profitability	Local feed supply/demand ratio	PKE/imported feed supply ratio	Irrigation feasibility
O	*	**	***	***	*	**	*	*	***	*	**	*	**	*	**	**	**	*		*
Lo	**	***	***	**	***	***	**	**	**	**	**	**	***	**	**	**	**	*	**	*
Hi	**	**	***	**	**	**	***	**	*	*	*	*	**	**	**	**	**	*	**	**

4.3.1 Organic

While only two organic dairy farmers in the Bay of Plenty participated in the study, some important observations were derived. The greatest impacts from climate change for organic farmers will be on pasture production, with additional impacts potentially associated with animal health. With respect to those characteristics of resilience this study sought to operationalise, the organic producers were less resilient to drought and climate change than were some of the other farming systems. The two organic producers in this study had both been impacted by the 2012/13 drought, losing production as a result of drying off early. Unlike other farming systems, organic producers are more constrained in their capacity to respond by the strict rules and conditions associated with certification.

> *We could get feed, but it was coming from the Hawke's Bay and it was low on the ground… there was a tanker of [certified organic] barley in port, in Tauranga, but they'd sold it all before the ship even docked. That [organic certification] makes it really hard for us to get feed quickly when we need it. There's only so much around.*

Organic producers did rate highly for agroecological characteristics, particularly for soil management. While there is considerable variation in Bay of Plenty soils at the regional and even farm scale, the two organic farmers were more familiar with their own soil types, were more inclined to "get a spade out" and inspect their soil regularly. One farmer noted that while the drought had had an impact on pasture growth, "*We were able to ride out the dry a* *lot longer than most, and I think that was because of our soil… we've worked hard to improve it.*"

Results from the social indicators section of the survey showed that organic farmers were less likely to consult with their peers about on-farm decisions, and had less developed social networks than their colleagues. Part of this may simply be due to the function of the small sample, it might reflect an individualistic nature of organic producers, or because there are fewer organic farmers they may have less options for peer consultation. Further research with a large sample would be needed to determine the reasons for their less developed social networks.

A significant positive factor for organic producers was the premium paid by Fonterra. Farmers on fully-converted properties earn a $1.05 premium on each kilogram of milk solids. This premium, which was recently reviewed, ensured that at least one of the farmers interviewed managed to stay afloat during the 2012/13 drought. As this farmer noted, "*without the premium we're getting [from Fonterra] it's not worth it. I'd go to a conventional farm – but on a biological system – if we didn't get that extra.*"

As discussed in the previous sections, with climate change, an increase in sub-tropical grasses is likely that will have an effect on productivity. Organic producers, furthermore, are constrained in their ability to respond by the guidelines for maintaining organic certification and by the length of time it takes to establish a certified organic system. Converting a farm to the required certified organic system and standards takes a minimum of 3 years, and profitability during that conversion is likely to be minimal. Managing invasive grass species using biological methods and ensuring the security of certified feed supply during drought are two of the biggest challenges to a more resilient organic dairy farm.

4.3.2 High-Input

As shown in *Table 15*, high-input, intensive farms (DairyNZ system 4 and 5) are also less resilient to the 2012/13 drought in key areas, and to potential climate change impacts compared with 'lower input' or predominantly grass-based systems. The key risks for intensive producers are their exposure to higher input costs and long-term security of feed supply.

Farm inputs can include labour, fertiliser, fuel, stock, seed, and materials. Additional inputs may also be related to the type of farm, the farm-management system, and the scale of the operation. There is tremendous variation as well in the scale of inputs between low- and high-input farms. The degree of resilience was correlated strongly with management (feeding) system. High-input systems, unsurprisingly, were most sensitive. Producers also described how input costs interacted dynamically with other market forces. All agricultural input costs increased, for example, as payout to dairy farmers increased.

Table 15 Differences in exposure-sensitivity to input costs (Source: Research findings)

Market exposure	Production system	Exposure	Conditions
Rising input costs	Dairy – High Input	High	Farmers reliant on supplemental feed or high inputs of fertilizer more exposed-sensitive to cost increases
	Dairy – Low input	Low	Low-input, all grass systems reliant on fewer inputs, but more sensitive to climatic conditions as they effect pasture production

Within the study, the biggest determinant of sensitivity to rising input costs was feed management system. The distinction is made here between between all-grass (pasture-based) or largely-grass based, low-input systems, and high-input systems, which by definition, source as much 55% of animal feed from outside the farm (Basset-Mens et al. 2009; DairyNZ 2010). Typical imported feeds include maize (Stockdale 1995) and increasingly common is palm kernel expeller (PKE), a by-product from the production of palm oil (Dias et al. 2008).

Dairy farmers are paid for milk solids (per kg). Research suggests that New Zealand is reaching the limit in terms of per cow production. The actual return to dairy farmers in inflation adjusted terms has remained relatively constant and so efficiencies have to be found in the system in order to improve profitability (Clark et al. 2001; Verkerk 2003). Increased protein intake, through supplementation is one way to boost production, and supplementation was also cited by a number of dairy farmers as a way to reduce their exposure to climatic variability and extremes by decreasing their reliance on pasture growth. Intensification (MacLeod & Moller 2006) and recurring droughts years have resulted in an increase in the amount of supplemental feed being used by New Zealand dairy farmers (MAF 2010). Between 2004 and 2008, imports of PKE rose from 42,700 tonnes to over 1,000,000 tonnes (MAF 2009). Palm kernel imports for 2012/13 are reported to be in excess of 1,500,000 tonnes.

With widespread droughts in recent years, prices have risen dramatically. Within a single season, a tonne of palm kernel landed on the farm, more than doubled in price (MAF 2010). Furthermore, these input costs are "sticky downwards"; rising quickly in response to external conditions such as a high-payout to dairy farmers, but falling slowly – if at all. *"Think about the long-term effects of this drought,"* said one farmer, *"right, grazing, for instance, is going to go up by at least fifty percent, and it's not going to go back to normal next year, is it? Palm kernel has gone from $230 to $450. You know, they give you a good payout, and everyone puts their costs up and then when the payout drops, those costs stay high and you're stuck with them. All that's happened is payout has gone up, but everything else has gone up too."*

Finally, high-input dairy producers found themselves exposed on the supply side. During the drought, not only did feed prices rise dramatically, but feed was difficult to come by. Some farmers reported paying $200 a bale (up from $60), for *"the dregs of the chest – if you can find it, because that constant supply has been a bit wayward this year."* Others described maize growers running out of silage: *"My neighbour, he's really upset. One of the major growers of maize around here ran out, just didn't get a good enough crop, so basically told him he couldn't have any. So that's his whole winter feed suddenly not arriving."*

By adopting a high-input system, farmers reduce their exposure-sensitivity to some climatic risks; however, they significantly increase their exposure to fluctuations in input costs, illustrating the dynamic nature of exposure-sensitivity, and ultimately the potentially lower resilience of certain farming systems. The risks of a high-input system relative to a low-input one, are not unknown to producers, who identified increased exposure to price increases, “sticky downward” prices and supply problems as concerns. As one dairy farmer commented: *“To me the risk factor behind brought-in feed is horrendous. Sure, weather is our biggest risk, but there’s nothing much we can do about that. But if you are high input you’re very exposed to what prices do, if you’re even able to get the feed in the first place.”*

While a shift from a low-input or all-grass system to a high-input system may enhance an individual dairy farmer’s total production (though there is research to suggest that the margins are lower than on all grass) and reduce exposure to climatic risks, it simultaneously increases exposure-sensitivity to rises in input costs. A shift in management system requires a feed-pad, a dedicated tractor, and often an additional labour unit as well as the ongoing cost of PKE or maize silage. This adaptation, changing from a low to high-input system, for example, changes the nature of the system to make it better adapted to the climatic conditions but potentially increases exposure to market stresses.

At the same time, intensification may increase market risk. Anecdotally, some dairy farmers stated that milk produced from cows that are fed a highly supplemented diet, may be of lower quality with higher cell counts and water content; and one study has concluded milk from cows fed a diet high in PKE contains elevated levels of harmful trans-fatty acids (Benatar et al. 2011). Another market-related risk that was identified by producers, and that would indicate lower relative resilience than lower input systems, is the perception of New Zealand dairy products in key overseas markets. *“We get a premium for our milk, and I’m not so sure that would last if everyone knew we were standing our cows on concrete and not out in the grass.”* Finally, a number of farmers commented on the potential biosecurity risks associated with PKE, particularly fears of foot and mouth, which would devastate the sector. Any event that curtailed the import of PKE from overseas would have the greatest impact on high-input systems. The degree to which farmers are dependent on imported feeds, with their long supply chains, is a potential vulnerability and those farms may be less resilient over the long term as a consequence.

The results of our analysis also demonstrated the resilience of low-input, grass-based systems. These types of farm (DairyNZ system 1 and 2) made up the majority of farmers interviewed. This is possibly due to the moderate climate of the Bay of Plenty region, and because intensification of dairying is not as pronounced as it is in the Waikato for example. Low-input farms were typically referred to by participants as “the way we’ve farmed this country for the last hundred years.” Using the indicators framework highlights both the merits and the exposures of these systems to climate change.

Low-input systems, reliant on grass growth, were most exposed to climatic conditions, shifting to a high-input system with supplemental feed, however, exposed producers to rises in input costs and changes in supply. A shift to high input also does not totally eliminate climatic risk as dairy cows cannot subsist on supplemental feed alone (Verkerk 2003). In this way, drought can also be experienced at the farm level as a financial or market-related risk.

Producers utilising a low-input or all-grass system are not totally sheltered from rising input costs. The dependence on grass growth requires the soils are ‘adequately resourced’ as some farmers put it, through the application of fertiliser, nutrients and moisture through irrigation, to maintain production. Farmers are also exposed to any increases in electricity costs. During drought, grass-based farmers are also more sensitive to the drier weather conditions and in many cases either dried off early (i.e. stopped milking), or purchased supplementary feed to see them through. If they purchased supplement, then they were just as exposed to the rise in feed costs as others. Some low-input farms are, in fact, more exposed. If supplementary feed is required, then they may not have access through social- and business networks from which to source the feed; without forward contracts, feed may be difficult to come by; and there is typically insufficient farm infrastructure (i.e. no feed pad), so wastage can be high.

For low-input producers, this problem is compounded by access. Most of the feed that was available to farmers in the last drought was absorbed by producers on high-input systems that already had forward contracts for feed purchase. As recent droughts have been more widespread, some farmers described problems with finding feed on short notice.

> *The problem we've had this year is that people like us, that didn't have things in place, if you like, didn't have their risk management for something like this, we couldn't source feed once it [the drought] came, because it was so widespread. The whole country was short of feed, and we just couldn't get it. Whereas some of the people that were on farms that dried every year, and had decided to manage it with feed pads, they got that feed organized before and it comes. They've been able to manage a lot better.*

Low-input farmers, in general, scored better on key agroecological indicators. Soil fertility, soil-moisture capacity, the 'engine room of the farm', was more closely monitored by farmers on grass-based systems, and was a key characteristic of resilience. Some producers took a long-term view, focusing on building the buffering capacity of their soils as a strategy to mitigate against future climate. As one dairy farmer stated:

> *What I'm doing is creating a soil that is a buffer; that is sequestering carbon, that is healthy, and passing that down the chain. And if the sun's up there for 24 hours a day, burning a bloody hole somewhere, it's having less effect inside my fences than anyone else's.*

Low-input farmers, in general, were also more likely to be forward thinking, in short, they had fewer safety nets, limited options – *"We can't just ring up and get feed"* – and so needed to have a longer term, strategic view. One dairy farmer ended up doing record production during the drought, an increase in yield that he attributed to closely watching all aspects of production. *"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."*

When pasture growth is limited, farmers on low-input or all-grass systems must bring in supplemental feed; while high-input farms will adjust the ratio of pasture to supplementary feed so that stock get a greater percentage of their diet from imported foodstuffs. This can be a short-term, tactical response, with farmers purchasing feed as needed; or as part of a longer-term strategy, involving forward contracts or changes in farm production practices. By installing a feed pad or meal feeder system, producers have more control over feed supply, reducing exposure-sensitivity to climatic variability and extremes as they pertain to grass growth. As this dairy farmer stated:

> *One of the reasons people went to feed pads was because they can control their feed through the year – used to be shitloads of grass in October, November, dry out in the summer, alright in the autumn, bugger all in the winter. So you get this up and down through the season, so alright, let's feed them all year and we can control the situation and growing grass becomes a secondary thing.*

There are limitations to this strategy, however. Buying supplementary feed is constrained both by farm income – only if the payout was good were producers able to make a margin – and the availability of feed. In 'normal' drought years, this response has been adequate. Recent droughts in 2008, 2009, 2010, and 2012/13 have been far more extensive, however, covering large portions of, if not the entire, North Island (MAF 2010), and rendering "normal" adaptive strategies insufficient.

5 Key findings and recommended next steps

This study operationalised resilience for dairy farms in the Bay of Plenty, by developing and then empirically applying 19 indicators for resilient systems. Through a participatory, qualitative approach, the research investigated the relationships between intensification of production, and the capacity of farmers and different types of farming system, to absorb, respond to, and maintain their identity when exposed to external shocks and stressors. The following section summarises key research findings and suggests future research directions and strategies for supporting and enhancing the resilience of New Zealand dairy farms.

5.1 Impacts of climate change vary with system-type

The review of climate change impacts for the Bay of Plenty combined with the results of the workshops and farmer interviews, revealed important differences in the exposure, sensitivity and resilience of different farming systems to climate-related extremes. The impacts of climate change will not be felt uniformly, but rather impact on different types of farm in different ways.

5.1.1 Key findings

1. For those producers on low-input and organic systems, changes in temperature and precipitation are likely to have a significant impact on production through changes in the range and distribution of subtropical C4 grasses. Conditions related to organic certification, may constrain the ability of organic farmers to adapt effectively, and the higher costs associated with managing these grasses have the potential to influence the resilience of low-input farmers. Higher temperatures will also have consequences for animal health. While there is evidence to suggest organic and biological farming practices can enhance soil fertility and soil moisture capacity, it is unclear whether such practices will be sufficient to buffer those systems against future changes in climate.
2. In the short term, the results show that high-input farms were resilient to the recent drought. As long as there was feed available and farmers were willing to pay for it, they were able to keep milking. It is unclear what the margins were on that production, but the high input farmers we spoke with were confident they had made the right decisions.
3. The qualitative approach we used to assess impacts also highlights the importance of considering conditions and context, at local, regional and farm scales. Climate change impacts assessments are most often conducted for large areas (nationally, globally); however, it is at the scale of districts, communities and households where the impacts of climate change will be most acutely felt (Brooks 2003; Næss *et al.* 2005; Adger 2006; Füssel & Klein 2006; Moser 2010). Robust, in-depth, qualitative studies can capture the complex influences on resilience, the interactions between climatic and non-climatic stimuli and conditions; systems and networks of production, market and economic conditions at regional, national, and international scales, as well as the scale of the individual unit of exposure – the farm itself. Furthermore, as this research has shown, the willingness and ability to adapt, to adopt more resilient practices, or to consciously shift a system's orientation towards greater resilience cannot be captured by models (Smit & Skinner 2002; Bradshaw 2007; Meinke *et al.* 2009). Individually and collectively responses within any system vary according to the social, cultural and economic characteristics of actors (Adger *et al.* 2007; Adger *et al.* 2012).
4. Local knowledge, observation, and experience can also be complementary to scientific modelling and support policy formation and development. Local knowledge can provide information about local conditions and redirect the foci of empirical investigations to

issues that have been overlooked by science alone (Kloprogge & Sluijs 2006). With respect to policy formation, local perception reflects local concerns (Danielsen *et al*. 2005) and helps focus on the actual impacts of climate change on people's lives (Laidler 2006) . These impacts are dependent on local factors and cannot be estimated through models (van Aalst *et al.* 2008). Local knowledge and perceptions influence people's decisions in deciding whether to act or not (Alessa *et al.* 2008) and what adaptive measures are taken over both short- and long-terms (Berkes & Jolly 2002; Brunner & Lynch 2010).

5.1.2 Recommended next steps

1. New Zealand's agricultural economy is characterised by diversity and regionalisation (Patterson *et al.* 2006). While this study has identified and assessed characteristics of selected dairy farms in the Bay of Plenty, there are a number of other agricultural sectors and regions that have yet to be examined.

   New Zealand's wine sector, for example, contributes over NZ$1.5 billion to GDP and supports over 16,500 full time equivalent jobs. The sector generates over $3.5 billion of revenue through its own direct sales and the sales it induces from related sectors (NZIER 2009). Viticulture is dependent on climatic conditions for both grape quality and quantity (Beverland 1998; Jones & Davis 2000; Schamel & Anderson 2003). Climate change is likely to have significant impacts globally on wine returns (Tate 2001; Jones *et al.* 2004; Hadarits 2011) and has been identified as an emerging challenge (Jones 2007; Schultz & Stoll 2010; Diffenbaugh *et al.* 2011). However no assessment has yet been made of the sector's vulnerability in New Zealand. Forestry is another primary sector that has the potential to be affected by long-term changes in climatic conditions (Leathwick *et al.* 1996; Millar *et al.* 2007; Kirilenko & Sedjo 2007). As with agriculture, the impacts will not be limited to biophysical conditions, but will also have consequences for forestry-dependent communities and employment as shown in results from overseas research (Davidson *et al.* 2003; Kirilenko & Sedjo 2007; Burch 2010; Keskitalo 2010a; Brown *et al*. 2010; Williamson *et al.* 2010; Keskitalo et al. 2011).

2. Additional place-based case studies from elsewhere in New Zealand may also provide further insight into the particular challenges and impacts of climate change on rural production and the varied capacity for adaptation. A collection of resilience and impacts assessments may help provide both a more comprehensive or longitudinal understanding of the impacts of climate changes on the economy, and the basis for comparative analysis. Such studies might also serve as 'spatial analogues' (Glantz 1996; Tol *et al.* 1998; Ford *et al.* 2010) to examine more closely future exposure-sensitivity and adaptive capacity (McLeman & Hunter 2010). Spatial analogues have been used in other climate change research (Diamond 2006; McLeman 2009), to identify the potential impacts and adaptive strategies. Dairy farmers commented on the similarity between current climatic conditions in Northland and what might be expected in the Bay of Plenty with climate change. Problematic conditions including black beetle, clover weevil, poor pasture growth, an increase in C4 grasses, warmer winters, and lower production were identified. Some dairy farmers were already informally investigating farm management techniques from the region. Detailed analysis of producers' responses, feed management systems, and other adaptive strategies might provide valuable insights into potential future adaptations for the Bay of Plenty.

5.2 A model of a climate change resilient dairy farm

This study identified, tested, and refined a set of farm system components that had the greatest influence on the famers' resilience to climate change and more specifically to persistent and increasing drought. We developed, tested, and revised a model that illustrates a multi-level systems perspective of these influencing components (*Figure 4*).

5.2.1 Key findings

1. The central focus of study was on farm-level resilience versus, for example, regional economic resilience. As a consequence, most of the identified resilience components were identified within the farm level. However a dairy farm was found to be only as resilient as the things and people it depends on and therefore a number of critical factors that impact farm level resilience were identified at the sub-regional and national/global levels. This study therefore further validates the findings of socio-ecological residence studies that have found resilience dynamics need to be assessed across multiple spatial scales.
2. The psychological/social characteristics of the farmer play a pivotal role in creating dairy farm resilience. These characteristics were critical to whether the farmers undertook management responses to minimise climatic risks (e.g. building soil fertility and moisture capacity, investing in irrigation, excellent pasture management), to whether they recognised the early signals of drought, and to whether they proactively undertook drought management responses (ensuring supplementary feed supplies and drying off early). The research suggests that the psychological/social characteristics of the farmer (or the group of people in the farm decision-making unit) play a greater role in variability in a dairy farm's resilience to drought than differences in production levels.

5.2.2 Recommended next steps

The resilient farm model provides a more nuanced understanding of a system of influence on a farm's resilience. There are 22 identified farm components that directly or indirectly influence a farm's resilience to the drought impacts of climate change. This is, however, a very initial study and further research could enhance the model, its findings, and its relevance to sector and public policy;

1. The model could be tested against other impacts of climate change and for other sectors. The impact of drought for the drystock sector, for example, or water-security for horticulture. The framework provides a robust methodology to evaluate the both specific and general resilience; to determine which farm system components influence resilience to a range of risks and those which are specific to certain impacts. This type of assessment might help the sector build resilience as well as develop and support specific adaptation strategies to those risks that are most relevant.
2. The model can also be used in a similar fashion to explore variation in regional or catchment-scale resilience.
3. The model could be tested quantitatively through a survey to dairy farmers first to identify which farmers coped with and recovered from the 2013 drought and then to test the extent to which those identified farmers possessed the farm-level resilience characteristics. As well as testing the validity of each of the components, it might also indicate whether some are more critical than others. These findings would be useful for prioritising climate change response strategies.
4. A more detailed examination of household activity and farm characteristics might reveal the influence of other factors on resilience. Further refinement of the conceptual

framework and methodology, might include as part of the interview, a short form of farm census. Data on nutrient inputs, feed budgets, access to short-term operating capital, a breakdown of input costs and profit margins, for example, might provide additional insights into the relative resilience different systems and allow for more detailed comparison. Work by Nelson and colleagues (2010) in Australia, for example, has shown how metrics of vulnerability can complement and add value to the sort of empirical work represented by this study.

5.3 Comparative resilience of dairy farm production systems

By operationalizing resilience, important but subtle differences in the capacity of different farms systems to withstand and recover from shocks and stressors, were identified.

5.3.1 Key findings

1. An important factor in the resilience of organic producers was the $1.05 premium per kilogram of milk solids. Fonterra also recently renewed contracts with the majority of its organic suppliers, for a further two years, citing growing demand from China. There is also anecdotal evidence, and some scientific evidence to suggest that organic and biological farming practices can enhance soil fertility and soil moisture capacity (Reganold *et al.* 2001; Eltun *et al.* 2002; Bhardwaj *et al.* 2011). It is unclear whether that will be sufficient to buffer those systems against future changes in climate. The biggest challenges for organic producers will be the management of invasives and pests, and securing certified feeds in the event of climate-related extremes.
2. High-input producers are currently resilient to climate risks. However, high-input farms are exposed and sensitive – given the often small margins on increased production – to higher input costs. Energy and feed prices are both expected to continue to increase.
3. By adopting high-input systems, farmers reduce their exposure-sensitivity to some climate risks while potentially increasing their exposure in other ways, including input-dependency through the reduction in free ecological services associated with high-energy inputs. One dairy farmer noted that shifting to a high-input dairy production system could be an adaptation to climate change due to lower yields and declining pasture quality, but there was no such thing as being “half-pregnant”.

> *If you want to go into a more supplemented system, you’ve got to have the right scale because you might have to put some concrete down to feed, to put in some troughs. Economies of scale: you also need machinery to feed the stuff out. So for a little farm, that all grass is a nice, efficient, low-cost system. For a little guy to go to supplement there’s all those things to do with labour, machinery and all that.*

The increases in scale come with very high capital costs, and more detailed economic analysis may be required to determine the economic resilience of large-scale and relatively inflexible operations.

5.3.2 Recommended next steps

1. Developing more sustainable agricultural systems may provide one way to reduce not only emissions but also the vulnerability of agricultural production to climatic and non-stressors (Wall & Smit 2005; Kenny 2011). Reduced input costs may well be possible, as farmers and growers seek alternatives to fossil-fuel based inputs; higher returns in the marketplace for organic products may offset lower production or yield; and GHG emissions may be lower on organic farms and orchards as opposed to conventional ones.

> Under the rubric of sustainable agriculture farm production might achieve both ends: a long-term sustainable agricultural system that is more resilient and better able to cope with expected changes in climate.

5.4 Conclusion

There are several implications for this research with respect to policy and contributing to discussions on mainstreaming adaptation. The empirical work demonstrates the need to support further research on adaptation at a local and regional level. The research has also alluded to the need for a bottom-up approach with respect to policy development. Many of the agricultural producers who participated in this research identified as a source of future risk the apparent disconnection between policy formulation and implementation. While significant reductions in GHG emissions are likely to be required, what is also needed is policy to support agricultural decision making in the face of a changing and uncertain climate. Such policy should, ideally, be cognisant of local conditions and concerns. As one producer noted:

> *There's nothing more scary for a farmer than being told to do something. When you do it because you want to, or you've been educated to do something, it is a lot easier; a lot easier to use a carrot than a stick, and a lot of growers feel at the moment there's too much of the stick, and they're just losing control.*

With the responsibility for climate adaptation now resting with local government (Greenaway & Carswell 2009) there is a greater need for engagement with local stakeholders in vulnerable sectors. Agriculture in particular is uniquely sensitive to climate change. 'Bottom-up' approaches have been formalised through a step-wise assessment of climate change related risks in guidance material developed by the Ministry for the Environment (Mullan *et al.* 2004, 2008) though there are still significant barriers to overcome (Reisinger *et al.* 2011). Local consultation is also not without its problems (Hayward 2008), as multiple stakeholders may often have conflicting views on the best adaptive strategies or allocation of crucial resources. There has been important work already done by regional councils (MfE 2003; Kenny 2006; Carbon Partnership 2011) and this study might serve as a template for other such initiatives.

One of the other great challenges for policy and wider uptake regarding the science of climate change will be to develop an effective transdisciplinary 'knowledge system' premised on the truth that complex problems cannot be solved by narrow approaches, that knowledge is held throughout the system, and that effective engagement therefore leads to better policy decisions as well as a shared commitment to any implementation (Max-Neef 2005; Francis *et al.* 2013). Such knowledge systems overcome both possible misconceptions and misinformation among all parties (science, policy makers, farmers and growers), and the preconceptions of policy and science in attempting to produce universal approaches where place-based solutions are required. The hierarchical adversarial approach is probably most succinctly represented by disdain for the last Labour-led government's attempt to introduce a carbon tax, mislabelled the "fart tax" (Fickling 2003; Thorpe 2010).

In order to achieve this, enhanced collective participation among agricultural producers is likely required. This might involve the use of experienced facilitators rather than technical experts or scientists alone (Tompkins *et al.* 2008). The creation of forums, utilising existing social networks and venues for demonstration and information sharing such as field days, might allow for debate and discussion of broader problems and priorities and inclusion of neglected viewpoints and more sensitive attention to appropriate formats for ensuring the participation of different groups. Increased efforts at education regarding climate change and impacts in the region may also be important. In the UK, Tompkins and colleagues (2008) for example, have shown how public education and stakeholder participation and inclusion can increase willingness to participate in and contribute to adaptive responses in coastal areas.

Increased scientific knowledge of the biophysical implications of climate change is crucial if the aim is to improve the adaptive capacity of agricultural producers; however, the uncertainty of climate modelling must be acknowledged and greater emphasis placed on intensive site-specific research informed by local knowledge and practices. As Batterbury and colleagues (1997, p.129) note:

> *The challenge… is not just to construct a more informed and democratised explanation of externally real biophysical change; but also to ensure this knowledge is used to influence policy at various spatial scales to enable practical and equitable environmental management.*

Perhaps most importantly, operationalising resilience through engagement with stakeholders, adopting "view from the ground" (Kenny & Fisher 2003) might serve to help identify entry points for policy. Concerns about adaptation to climate change have been expressed by Adger and Barnett (2009) saying that:

> *the task is unexpectedly urgent and hard; adaptive capacity will not necessarily translate into action; there is widespread existing maladaptation; and the measurement of adaptation success is profoundly complex.*

Given the uncertainties surrounding the scale of future climate variability and change, there is a need to adjust practices and decision-making frameworks to account for these realities. Reducing riskiness in the face of uncertainty among agricultural producers will almost certainly require the identification and promotion of 'no-regret' strategies that yield benefits even in absence of climate change (Hallegatte 2009). This might be achieved through lower nitrogen-inputs, increased water monitoring, or changes in feed management systems. As one farmer quoted earlier notes, however, the identification of alternate strategies should come through education and participatory engagement and collaboration rather than from the 'top down'. As this study has shown, exposure to changing climatic conditions will not happen in isolation, and through consultation with agricultural producers, a more comprehensive and complete assessment of resilience can be developed.

Appendix 1 Research design and activities

Table 16: Outline of research strategy

Project stage	Time	Purpose and activities
Project planning	October 2012 – February 2013	Review of literature Develop indicators framework Peer review
Fieldwork preparation	March 2013	Recruitment and engagement with stakeholders Refine indicators Prepare interview and survey Interviews with key informants Present research framework at overseas conference on climate change adaptation
Fieldwork	April–May 2013	Network of interviewees developed through purposive snowball sampling Surveys and structured interviews conducted with dairy farmers in the Bay of Plenty (n=15) Two resilience workshops held with dairy farmers in the Bay of Plenty (n=16)
Analysis and reporting	June 2013	Comparative analysis of findings between farms Further refinement of indicator framework Conference presentation, NZCCC Findings communicated to stakeholders Final report prepared for MPI

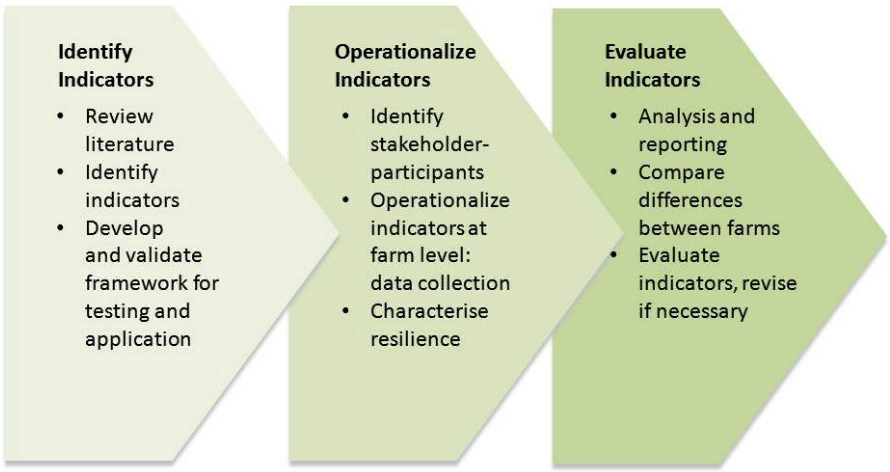

Figure 6: Research Design.

Pre-interview survey

The following is a brief set of questions designed to obtain some background information prior to the interview. The survey seeks information about individual characteristics related to resilience, and will assist the researchers in obtaining a deeper understanding of farming practices, conditions, risks and opportunities in the Bay of Plenty.

1. How would you describe the **past,** the ***current*** and the ***future*** general conditions for dairying on your farm, in terms of the following 5-point scale (please circle one for each):

   1 = very difficult; 2 = difficult; 3 = reasonable; 4 = good; 5 = very good

	Past	Current	Future
a. Water supply (rain & irrig.)	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5
b. Temperature	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5
c. Soil conditions	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5
d. Access to labour	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5
e. Profitability	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5
f. Access to feed	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5
g. *Other factors (list below)*	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5

For the remaining questions, please indicate to what extent you agree or disagree with the following statements *(1 = strongly agree; 2 = agree; 3 = neither agree nor disagree; 4 = disagree; 5 = strongly disagree):*

2.	I am confident in my ability to manage changes in the dairy industry.	1	2	3	4	5
3.	I am proactive in learning new skills I can apply on my farm.	1	2	3	4	5
4.	I am well-connected to other farmers.	1	2	3	4	5
5.	Being a dairy farmer is a lifestyle choice, it is not just my job	1	2	3	4	5
6.	If needed, I am prepared to completely change the way I manage my property in order to survive as a dairy farmer	1	2	3	4	5
7.	I feel a strong sense of connection to the place I live and	1	2	3	4	5

work

8.	I have strong connections with people in my community.	1	2	3	4	5
9.	Ensuring the environmental integrity of my farm is fundamental to its economic profitability.	1	2	3	4	5
10.	I believe that climate change is happening.	1	2	3	4	5
11.	Climate change will create additional challenges for dairying in the Bay of Plenty over the next 20 years.	1	2	3	4	5
12.	The current approaches I am taking for dealing with present climate challenges will be sufficient for dealing with future climate challenges	1	2	3	4	5
13.	If the climate changes, there are things I can do to respond to any negative impacts.	1	2	3	4	5
14.	I have the capacity to respond to climate change without leaving my farm.	1	2	3	4	5
15.	The risks to production on my farm will increase with climate change.	1	2	3	4	5
16.	More information about climate change impacts in the Bay of Plenty is needed to help farmers adapt.	1	2	3	4	5

Open ended Interview Questions

PART A. Your personal details

1. How long have you have been in dairy industry_______ *Years*

2. How long have you been in the BoP region ___________ *Years*

3. How long have you been on this farm __________ *Years*

4. What is the decision-making/farm ownership structure?

5. What is your herd size and size of farm?

6. What type of system do you run (DairyNZ 1-5)
   a. List key system characteristics related to feed supply in a 'normal' year
   b. Additional system characteristics

Part B. Key farm characteristics, drought and resilience

7. What is the predominant soil type on your farm and how is it managed: during 'normal' year? During a drought? How could moisture holding capacity be improved in the future?
   - *Make particular note of mentioned practices which improve capacity to hold moisture and assess if identified constraints are due to the farm production system*

8. What is your pasture management system? What changes (if any) might make your pasture more resilient to drought in the future?

   a. *Identify if the named species have held up well in drought*
   b. *Probe if they are constrained in changing the pasture management system*
   c. *Probe if any the identified reasons for not planting drought tolerant species are related to farm production system.*

9. What are your stocking practices: during a 'normal' year? During a drought? How flexible are these practices?
   a. *Probe if they are constrained in changing the stocking practices*
   b. *Probe if any the identified constraints are due to the farm production system.*

10. What has been the impact of the current drought on feed? How have you managed it?
    a. *Probe if they are constrained in managing any feed shortages*
    b. *Probe if any the identified challenges are due to the farm production system.*

11. Who or what has helped you respond to drought in the past/or currently?
    a. *Probe how important are external supports, and institutions for farmers*

12. What water quality challenges do you currently face and how are these managed? Are you constrained in any way in managing them? How would you cope with more frequent and extreme fluctuations between wet and dry conditions?
    a. *Probe if any the identified challenges and constraints are due to the farm production system.*

13. Have you maintained or deliberately afforested parts of the farm? Why/Why not?
    a. *Identify if farmers found afforested areas have increased farm's resilience to drought*
    b. *Assess if any the identified reasons for not planting drought tolerant species are due to the farm production system.*

14. Do you derive income from other sources? Why/Why not?

15. *(If not already covered)* Have you already changed your farming practices in recent years? If so, what have you changed and why? Have changes made it easier/more difficult to manage climate extremes?

Part C. Other risks

16. What is currently your biggest concern(s) for the future viability of your farm?

17. What are the biggest future threats to dairying?

18. What does success look like for you in terms of your farm and your life? If you ranked these are goals what would be your three most important goals?

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