Two dominant approaches to climate risk assessment and, in different ways on different aspects of the farm system.

Adger, 2006; Aydinalp and depend on factors such as scale, location and the vulnerability of people and activities concerned (Adger, 2006; Aydinalp and Cresser, 2008). There are many uncertainties around the degree to which global and regional climate could change, and many of the effects are unpredictable and depend on complex feedback cycles that are still poorly understood (Fowler et al., 2007; Parry et al., 2007; Solomon et al., 2007; Swart et al., 2009). Uncertainty is further increased by the complexity of pastoral agro-ecosystems (Bryant and Snow, 2008) as specific effects of climate change, such as rising atmospheric CO2 concentrations, may have an impact in different ways on different aspects of the farm system.

Traditionally, adaptation studies have focussed on the analysis of specific risks under climate change scenarios. There are two dominant approaches to climate risk assessment and adaptation studies: 'Top-down' approaches, which feed downscaled climate scenarios into impact models in order to calculate probable impacts and test potential adaptation measures; and 'bottom-up' approaches, which generally focus on ways to reduce the vulnerability of a community to climate events based on past experiences, often following an extreme event or disaster (Wilby and Dessai, 2010).

Integrated models, such as the DairyNZ Whole Farm Model (WFM) (Beukes et al., 2011) referred to in this review, provide a useful basis for assessment of climate change adaptation options, allowing the manipulation of management options under future climate scenarios and providing both biophysical and economic outputs. Although mostly characterised by a top-down methodology, such models provide an effective means to integrate key aspects of farm systems performance with estimates of climate variability.

Despite these advantages, the use of integrated models like the WFM in top-down studies has a number of limitations when applied to the analysis of adaptation. There are biophysical uncertainties, as currently no models are available that include a fully comprehensive range of biophysical processes important in the analysis of climate change adaptation options, such as pests and diseases, pasture species competition or soil carbon dynamics.

**Review**

An integrated biophysical and socio-economic framework for analysis of climate change adaptation strategies: The case of a New Zealand dairy farming system

Electra Kalaugher, Janet F. Bornman, Anthony Clark, Pierre Beukes

**Abstract**

The development of effective climate change adaptation strategies for complex, adaptive socio-ecological systems such as farming systems, requires an in-depth understanding of both the dynamic nature of the systems themselves and the changing environment in which they operate.

To date, adaptation studies in the New Zealand dairy sector have been either bottom-up, qualitative social research with farmers and communities, or top-down, quantitative biophysical modelling. Each of these approaches has clear benefits as well as significant limitations. This review considers concepts and approaches that support the potential for different disciplines to complement each other in developing a more in-depth understanding of farming systems and their adaptive potential. For this purpose, a Mixed Methods Framework is presented, using examples from a pilot study of a New Zealand dairy farm to illustrate the complementarities between the two current approaches.

By presenting this methodology in a specific context, the review provides the theoretical basis for a practical way to integrate quantitative and qualitative research for climate change adaptation research.

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**1. Introduction**

Analysing the future sustainability of a complex system such as a dairy farm in the context of climate change presents significant challenges. The impact of climate change on agriculture will depend on factors such as scale, location and the vulnerability of the people and activities concerned (Adger, 2006; Aydinalp and Cresser, 2008). There are many uncertainties around the degree to which global and regional climate could change, and many of the effects are unpredictable and depend on complex feedback cycles that are still poorly understood (Fowler et al., 2007; Parry et al., 2007; Solomon et al., 2007; Swart et al., 2009). Uncertainty is further increased by the complexity of pastoral agro-ecosystems (Bryant and Snow, 2008) as specific effects of climate change, such as rising atmospheric CO2 concentrations, may have an impact in different ways on different aspects of the farm system.

Traditionally, adaptation studies have focussed on the analysis of specific risks under climate change scenarios. There are two dominant approaches to climate risk assessment and adaptation studies: 'Top-down' approaches, which feed downscaled climate scenarios into impact models in order to calculate probable impacts and test potential adaptation measures; and 'bottom-up' approaches, which generally focus on ways to reduce the vulnerability of a community to climate events based on past experiences, often following an extreme event or disaster (Wilby and Dessai, 2010).

Integrated models, such as the DairyNZ Whole Farm Model (WFM) (Beukes et al., 2011) referred to in this review, provide a useful basis for assessment of climate change adaptation options, allowing the manipulation of management options under future climate scenarios and providing both biophysical and economic outputs. Although mostly characterised by a top-down methodology, such models provide an effective means to integrate key aspects of farm systems performance with estimates of climate variability.

Despite these advantages, the use of integrated models like the WFM in top-down studies has a number of limitations when applied to the analysis of adaptation. There are biophysical uncertainties, as currently no models are available that include a fully comprehensive range of biophysical processes important in the analysis of climate change adaptation options, such as pests and diseases, pasture species competition or soil carbon dynamics.
Models do not always include ‘softer’ elements in their system boundary, such as socio-economic factors, limiting their value for the practical evaluation of some climate change adaptation strategies (Dynes et al., 2010). In addition, such complex integrated models are not usually directly accessible to farmers, and in many cases these key farm decision-makers are excluded from the model development and application process. Thus implementing management decisions in practice necessitates collaboration between stakeholders and researchers. This aspect has also been emphasised by others, e.g., by Martin et al. (2011), whose scenario approach focused on encouraging participatory involvement of farmers in managing adaptation to climate variability, and which also connected the science with feasible farm applications.

A pivotal question is how to accommodate and synthesise different perceptions of the farming system and the ‘soft’ and ‘hard’ components of the system. Participatory bottom-up, qualitative research can provide a more direct reflection of the on-the-ground reality that farmers face in making management decisions. However, for any proposed adaptation measure, there are biophysical impacts that need to be evaluated, trade-offs to be made in present and future costs and benefits. Social research, by nature, is unable to adequately quantify these impacts and trade-offs.

This paper argues that in order to understand and address properly the available adaptation options and the context in which those options would be useful, an interlinked approach utilising both qualitative and quantitative research methods is necessary. This is neither ‘bottom-up’ nor ‘top-down’, but an interdisciplinary process that develops plural and conditional assessments of the trade-offs inherent in different management strategies. This paper presents a conceptual framework using a New Zealand dairy farm system as a working example, with concepts from resilience approaches and soft systems methodology as one way to facilitate the working together or synergy of two different methodologies for achieving a dynamic and inclusive analysis of complex farming systems.

2. Approaches to climate change adaptation assessments

Since the early 1990s, there has been a rapid expansion of research on adaptation to environmental change (Nelson et al., 2007). One of the earliest frameworks for the assessment of impacts and adaptation was provided by the Intergovernmental Panel on Climate Change (IPCC) (Dessai et al., 2005), which is also considered the standard approach (Burton et al., 2002). This approach defines seven steps: 1) Problem definition; 2) Selection of the method; 3) Testing of the method (e.g., sensitivity analysis); 4) Selection and application of climate change scenarios; 5) Assessment of biophysical and socio-economic impacts; 6) Assessment of autonomous adjustments; and 7) Evaluation of adaptation strategies. This framework provides for the systematic quantification of the severity of climate change impacts on a pre-defined biophysical or human system (Parry and Carter, 1998).

Many assessments still follow the broad IPCC framework. However, such assessments are heavily focussed on the development of climate change scenarios and the assessment of potential impacts from these scenarios (Dessai et al., 2005), rather than on current vulnerabilities or on adaptation options (Burton et al., 2002). Because of this, the results of such assessments can be highly sensitive to the uncertainties in the climate models (Dessai and Hulme, 2007), stimulating the development of increasingly sophisticated models for the purpose of adaptation assessments (Burton et al., 2002; Dessai et al., 2005).

More recently, risk management has become a central concept in many climate change assessments, particularly in light of the projected increases in extreme weather events. A core concept in risk assessment for climate change is the need to analyse not only average changes, but also the potential frequency of major losses (Yakushev, 2009). However, while there is broad agreement that the management of uncertainty and concepts of risk management are important, there are a wide range of approaches to risk assessment and each community of practitioners has adopted a different definition of the process (Dessai et al., 2005). The quantification of risks in the context of climate change adaptation research is particularly challenging due to the high level of uncertainty associated with climate change projections and difficulties in attaching probabilities to different development pathways, as well as the global nature of the problem (Dessai and Hulme, 2004). Stirling (2010) highlights the dangers of an overly narrow focus on specific, quantified risks, suggesting that it is an inadequate and oversimplified response to incomplete knowledge. He suggests that a more rigorous approach to incomplete knowledge is required, which takes into account less quantifiable aspects of uncertainty as well as “the deeper challenges of ambiguity and ignorance”.

A broad criticism levelled at adaptation studies to date is that they have a tendency to be rather prescriptive and normative about specific management practices. Particularly for top-down, scenario-based assessments of adaptation options, the options evaluated tend to focus on areas where immediate benefits can be gained. For this reason, there is often little progress in removing the more persistent and intractable vulnerabilities (Nelson et al., 2007).

In addition, because adaptation is considered in relation to specific risks, the assessments are often static in nature, i.e., measuring the levels of risk before and after adjustments have taken place (Nelson, 2011; Nelson et al., 2007). In the context of agricultural systems, prescriptive recommendations about management practices may have limited usefulness. Because systems are not static entities, but dynamic in space and time, there will be ongoing changes in the sensitivity and adaptive capacity of systems (FAO, 2008). Risk management perspectives continue to evolve to take into account the surprise, uncertainty and the long-term nature of climate change adaptation, as well as the multiple sources of stress and risk (Nelson, 2011).

A parallel conceptual development in adaptation research has been a focus on more systems-oriented ‘resilience’ approaches (Folke et al., 2010; Nelson et al., 2007). Farms are considered as ‘complex socio-ecological systems’. Such systems do not change in a linear fashion but rather incrementally as they reach particular thresholds (Briske et al., 2010), often to the (negative or positive) surprise of those trying to manage them (Nelson et al., 2007). This is closely aligned with the emerging ‘non-equilibrium’ perspective (Scoones, 2004), which embraces the complexity of systems and encourages more flexible and dynamic adaptive responses to climate change. In the case of New Zealand farming systems, it has been noted that “equilibrium is not an option and, if achieved, is short-lived” (Beijerman et al., 2009).

Given the uncertainties surrounding the assessment of adaptation measures, it has been suggested that it is now timely to allow the appraisal of adaptation options to take centre stage, rather than the climate change scenarios themselves (Wilby and Dessai, 2010). The safest approach to adaptation is to aim for flexible and diverse systems that are resilient to shocks (FAO, 2008). This approach focuses on ways to build a system’s ability to cope with adverse effects rather than on the effects themselves, which remain highly uncertain. By concentrating on the system, rather than on the problem, and assessing adaptation options in the context of their contribution to the overall resilience of the system, the outcomes may have a much stronger chance of being ‘no-regrets’ (Wilby and Dessai, 2010). However, the level of flexibility or diversity required for sustained adaptation so far has been difficult to ascertain.
Definitions of resilience vary and abound, particularly in the social literature (Windle, 2011), where the concept has long been applied to human response to adversity. In the context of adaptation to climate change, resilience has been defined as “the capacity of a system to absorb disturbance and reorganize while undergoing change so as to still retain essentially the same function, structure and feedbacks, and therefore identity, that is, the capacity to change in order to maintain the same identity” (Folke et al., 2010). Walker et al. (2002) adopted a broader definition, suggesting that resilience comprises either the ability of a system to maintain its function when perturbed, or the “elements needed to renew or reorganize if a large perturbation radically alters structure and function”.

While resilience is clearly important, achieving greater resilience may come at the cost of (short-term) productivity. The identification of the appropriate adaptation strategies requires consideration of the multiple management objectives facing farmers, and an understanding of the trade-offs among these objectives under different system arrangements (Nelson, 2011; Stoorvogel et al., 2004).

3. The need for an integrated approach

3.1. Current methodology

Much of the recent literature has focussed on the concept of complex, adaptive socio-ecological systems, and the failure of disciplinary approaches to address adequately the complexities of these systems. The consequences of this inadequacy have been described as a “profound failure of knowledge” (Cornell et al., 2010) and there is an urgent need for greater inter-disciplinarity and depth of perception in assessments of such systems.

There have been a number of pleas for a more integrated approach, highlighting the need for a ‘suite of tools’ together with field experimentation (Dynes et al., 2010) and integrated research methodologies (Mastrandrea et al., 2010; Norgaard and Baer, 2009; Patwardhan et al., 2009; Pearson et al., 2011) to effectively address the uncertainty and complexity of climate change processes. Mastrandrea and Schneider (2010) pointed to the need for a bottom-up/top-down vulnerability assessment and emphasised the necessity for direct partnerships between stakeholders and scientists – social scientists and climate scientists in this context.

Calls for interdisciplinary methodologies to complex problems are not new – the potential power of combining different approaches to gain new insights has been recognised since at least the early 1940s (Miller et al., 2008). This also has been explored by numerous authors (Mansilla, 2010) in concepts such as ‘consilience’ and the ‘jumping together’ of ideas across scientific disciplines (Wilson, 1998) and theories of ‘conceptual blending’ (Fauconnier and Turner, 1998). Despite this recognition, in practice there are many challenges and barriers to the adoption of interdisciplinary methodologies and most studies still follow disciplinary lines (Nelson et al., 2007). Adaptation work in the New Zealand dairy sector provides an example of such dichotomy. Studies to date have been either bottom-up, qualitative social research with farmers, such as the work of Kenny (2010) and Burton and Peoples (2008), or top-down, quantitative biophysical modelling work such as that of Zhang et al. (2007) and Dynes et al. (2010). Modelling systems, such as SimCLIM and Climpacts (Warrick et al., 2001) and the Ecoclimate work (Wratt et al., 2008) reflect the science and availability of downscaled climate change projections in New Zealand, with several of the main drivers of variability in climate-pastoral systems being captured in the Ecoclimate model. However, these biophysical models do not integrate the inherent complexities of farming systems, such as pests, diseases, animal health effects, farmer coping ability or farm management (Newton et al., 2008). A recent study (Dynes et al., 2010) took one step further to compare a selection of adaptation management strategies under mid-range climate scenarios, in a case study setting. However, the study was still limited by the scope of the model and uncertainty in the climate change projections available.

Top-down, modelling based approaches generally reflect a mechanistic view of agricultural systems where the knowledge generated is objective and replicable, acquired via the scientific method; and seeks to demonstrate causality and allows for prediction. On the other hand, bottom-up, social science methodology provides an example of a ‘constructed’ view of nature where knowledge is viewed as a narrative – interpretive and critical. The knowledge obtained in this way is embedded in a particular context and recognises the values associated with such knowledge (Miller et al., 2008). For example, qualitative social studies that examined the resilience of dairy farmers to extreme events such as droughts (Burton and Peoples, 2008; Kenny, 2010; Payne and White, 2009), have shown the flow of ideas from farmers to researchers, highlighting the importance of context and engagement in understanding principles of resilience. This aspect is dealt with in more depth under Section 3.3.

3.2. Divergent perceptions

Researchers and farmers may have quite different perceptions of a farming system and different approaches to solving a particular problem. One issue is a difference in temporal perceptions and planning horizons between scientists and farmers. Strategic planning horizons for farmers rarely extend beyond 10 years (Gray, 2001). However, planning for adaptation to climate change is necessarily a long-term strategic process and climate change scenarios are usually analysed for a point in the future beyond the longest planning horizon of most farmers. Qualitative social studies, in contrast, tend to incorporate longer perspectives in the context of human involvement, resulting in a better match with the farmer’s planning horizons.

Scale is another factor that influences a difference in perception between farmers and researchers. Top-down research utilising models often operates from a global to farm level, usually following disciplinary boundaries. Again, social research tends to resemble more closely the scales on which farmers are operating for the simple reason that it involves engaging with farmers around their management systems and planning. The issue of bridging the scale gap represents a particular challenge to any research approach: it is difficult to gain an in-depth perspective of a system and apply the knowledge gained through research without understanding the linkages between different scales (Patwardhan et al., 2009).

3.3. Addressing resilience

The social research carried out to date (e.g. Kenny and Fisher, 2003; Burton and Peoples, 2008; Payne and White, 2009; Kenny, 2010) has resulted in significant insights into farmer decision-making and the resilience of New Zealand farming systems by asking about farmer experience of past climate events and their perceptions on climate change. Such social research can further provide a broad perspective that includes less tangible and quantifiable components of the system. However, it is often limited by reliance on subjective personal experience and a lack of hard quantitative data. There are also limitations in focussing on past and current events, as these are increasingly a limited guide to a future under climate change.

Models can have a more valuable role in improving the resilience of farming systems if development and use is embedded in the adaptation process itself through high levels of participation by
farmers (McCown and Parton, 2006; Voinov and Bousquet, 2010). If the farmers or managers of an agricultural system are viewed as ‘clients’ (Woodward et al., 2008), it is important that they are involved throughout the innovation process, from problem definition and model design and testing through to the policy planning and evaluation phases of any model-based research process. In the case of climate change adaptation in dairy systems, allowing for experimentation with adaptation options in a virtual, modelling world reduces the substantial risk involved in premature physical implementation and trials. It also allows adaptation options to be explored within the bounds created by climate change projections. Participatory modelling, which incorporates both technical and social elements, is now recognised as a powerful tool that can contribute to collaborative learning and quantification of the impact of proposed solutions to a given problem (Cabrera et al., 2008; Voinov and Bousquet, 2010; Woodward et al., 2008; Martin et al., 2011). By jointly defining the ‘virtual world’ to be modelled, this virtual world is likely to more accurately resemble the real world. Comparing the jointly defined virtual world to the real world creates learning opportunities. Such a participatory modelling approach requires the establishment of a common epistemology or way of understanding the knowledge generated. However, the establishment of a joint epistemology often ends with one epistemology winning over the other (Miller et al., 2008).

Another limitation to participatory modelling is presented by the technical challenges of the models themselves. For example, the scope of the study may be limited by the capacity of the model; and the more integrated and complex the model, the less accessible it is likely to be to end-users such as farmers, unless the process of modelling development expands the system boundary and viability of the model for specific uses. The boundary extensions of the model may include socio-economic factors in their structure for the practical evaluation of some climate change adaptation strategies (Dynes et al., 2010). However, softer elements of the system, such as the personal resilience and adaptive capacity of a particular farmer, can have a significant influence on the response to the severity of climate impacts (Darnhofer et al., 2010a) but may prove extremely difficult to model. While there is significant value in the inclusion of farmer perspectives in the overall analysis, the issues raised are still reduced to descriptive ‘factors’ in an otherwise objective and context-free research method, thereby losing part of the value that might be gained by a more balanced combination of epistemologies.

4. Methodological approaches to facilitate integration: towards a mixed models framework

4.1. Systems approaches

Systems approaches have been particularly designed to support studies that integrate different disciplines (Kropp et al., 2001). They have been applied to farm management since at least the 1970’s. The integrated nature of these approaches contrasts strongly with the highly reductionist approach taken by early agricultural scientists (see Beijerman et al., 2009). Early systems work took the form of ‘hard’ systems analyses that integrated physical aspects of the system (see Beijerman et al., 2009). As systems concepts continued to develop, the need to incorporate ‘soft’ systems components (such as social practices, economics, politics and culture) became apparent.

Increasingly, businesses such as farms are viewed as complex, self-adapting systems capable of learning, synergy, and innovation (Beijerman et al., 2009). Systems approaches have a number of common elements: First, they work to avoid the traps of reductionist, linear thinking by focussing on the interconnectedness of variables in the system. They also work to incorporate multiple perspectives into the analysis in order to understand the dynamics of the system and the processes through which beneficial change can occur (Beijerman and Holwell, 2010).

The term ‘transdisciplinary’ has evolved to describe approaches that effectively transcend the boundaries between different scientific disciplines and non-scientific sources of knowledge, and a number of frameworks have been developed to enable integration of different kinds of knowledge (Pereira and Funtowicz, 2006). However, such frameworks are usually focussed at the regional level. Analysis of management strategies at farm level offers greater potential for the effective integration of stakeholder (i.e., in this context, farmer) perspectives.

4.2. Communicating and harnessing knowledge

The challenge of adapting to climate change is fraught with uncertainties. In order to address such a challenge effectively, strategies should be based not only on the explicit knowledge of researchers but also on the tacit, contextual knowledge that farmers have gained from experience. The knowledge developed by farmers is often different in nature to that developed by formal researchers. It is embedded in the context of their farming system, and based on the day-to-day experience that contributes to a tacit understanding of the system, without necessarily understanding the underlying mechanisms (Hoffmann et al., 2007). Hoffmann et al. highlight the importance of externalising the tacit knowledge of expert farmers so that it can be integrated into the research process. This can be facilitated by the creation of conceptual models, which externalise or make explicit a particular view of a system. Tacit knowledge may be used to address less quantifiable aspects of a system through the intuitive understanding that is based on seeing similarities with previous experiences (Hoffmann et al., 2007). For this reason, the harnessing of such knowledge is a valuable asset in the development of climate change adaptation strategies and in other areas of research where there is a high level of uncertainty.

The question of how to harness the different knowledge and experience of researchers and farmers for the generation of new knowledge has been the subject of much debate (Hoffmann et al., 2007). A wide range of participatory methodologies has been developed to facilitate communication, and yet arguably the most important element in the effectiveness of participatory research is the attitude of the system in it (Barreteau et al., 2010). This can be improved by the adaptation of the systems approach to the onion and the processes through which beneficial change can occur (Beijerman and Holwell, 2010).

4.3. Soft systems methodology

The technique of conceptual modelling for externalising a particular view of a system has been utilised in the Soft Systems Methodology (SSM) developed by Peter Checkland in the 1980s for the analysis of “problematical, messy situations” in an organised way. This approach has facilitated the development of the framework presented in this paper, because it is a well-established and broadly applicable methodology (Checkland and Poulter, 2010) for analysing complex situations such as those occurring in the adaptation of dairy systems to climate change. SSM is based on two key ideas: The concept of “learning your way through” problematical situations; and the organisation of this learning through using conceptual systems models of purposeful activity as a source of questions to ask in real situations (Checkland and Poulter, 2010).

A key strength of SSM is that it explicitly identifies the viewpoints of key actors in a system (Checkland and Poulter, 2010). In doing so, it has real potential to cross-reference different ways of perceiving knowledge. This addresses one of the main weaknesses of much interdisciplinary research (Miller et al., 2008). The SSM approach was developed in the context of business management; however, variations of the methodology have been used in the life sciences context as well. For example, Wilson and Balser (2009) applied a version of SSM to the analysis of soil respiration responses to global climate change. The framework presented in Section 5 includes components from both the Wilson and Balser version and the original SSM as described in Checkland and Poulter (2010). In particular, the SSM framework that explicitly describes the components of a soft system (see Section 5.2) is useful in this context. This methodology does not represent hard categories, but rather a flexible tool for describing a system, as a starting point for discussion and analysis (Checkland and Poulter, 2010).

4.4. Conceptual and quantitative models

Resilience thinking and techniques, using e.g., SSM, draw on conceptual models as tools for learning about systems. In this context a ‘model’ can be defined as “any representation of a system that is stable enough to serve as the basis for discussion about the system it represents” (Barreteau et al., 2010). When employing such methods together with quantitative computer models, such as the Whole Farm Model, it is therefore important to consider how they fit together conceptually. Fig. 1 provides a representation of the place of the Whole Farm Model, which serves to quantify and test specific quantifiable aspects of the system, in a conceptual model that includes some of the broader social and biophysical components of a dairy farming system. Fig. 1 aims to highlight the progression between ‘softer’ and ‘harder’ system elements. Less tangible, softer elements of the system are represented on the left hand side, progressing to more readily quantifiable (but often very complex) system elements on the right. Many of these elements may also potentially be incorporated into quantitative models.
5. A framework for analysing adaptation strategies for a New Zealand dairy system

This section presents a framework for the integrated analysis of adaptation strategies for a dairy system. By presenting this methodology in a specific context, the aim is to contribute to the development of practical ways to integrate quantitative and qualitative research.

5.1. Methodology

The framework has been developed against the background of relevant literature on climate change and risk management frameworks, as well as systems and resilience thinking. It also draws on a pilot case study carried out on a New Zealand dairy farm in the Waikato region, North Island.

The pilot study farm is pasture-based with ca 160 ha and around 500 cows. The owner/operator of the pilot study farm provided management and production information from his farm for input and validation in the Whole Farm Model, a semi-structured interview and further communications. While the pilot study did not test the complete framework, it provided initial insights into the processes, which were valuable in the development of the approach.

5.2. A Mixed Methods Framework

This framework is focused at farm level and is suitable for implementation in a case study or series of case studies of actual working farms. The focus of the framework is on ways to combine quantitative and qualitative inputs and actively promote the cross-fertilisation potential of such integration.

The analysis starts with two scoping exercises: one by the researcher; followed by a researcher-facilitated scoping exercise with the farmers (see Fig. 2). This is carried out in order to allow for the independent definition of researcher and farmer perspectives on the system, effectively creating two conceptual models of the farming system for analysis and integration. Through this process, researchers gain an understanding of their own and the farmers’ perspective, the differences between them and why these differences exist.

The development of future scenarios and modelling of their impact on the farm system using current management practices (step 3), provides a quantitative input into the assessment of risks and adaptation options. Together with the historical context and systems perspectives provided in the scoping exercises this information forms the basis for a joint assessment (step 4) of the current adaptive capacity of the farming system; risks to the system under future scenarios; types of uncertainty inherent in the analysis; and proposed adaptation options. Relevant quantifiable adaptation options are analysed by the researcher in step 5. The results of these analyses are then validated with the farmer (step 6). If necessary, the process can be repeated until both researcher and farmer are satisfied that the outputs of this quantitative analysis give an accurate enough reflection of the trade-offs inherent in different strategies to provide a useful basis for the next step.

The final phase of the analysis consists of the evaluation of the adaptation options identified and the logical steps towards feasible implementation. In this process, the trade-offs identified in the modelling assessment are evaluated in the context of the ‘rich picture’ painted of the system through previous steps in the assessment.

5.2.1. Scope (researcher)

The first step in the scoping exercise is to consider the development of a system over time. A historical profile of influences and changes in the system (in this case, the New Zealand dairy industry), particularly how it has coped with past shocks, reveals much about its adaptive mechanisms (Walker et al., 2002).

As a technical term, the word ‘mess’ is used by soft systems researchers to express the complexity and diversity of perspectives present in a problem situation (Checkland and Poulter, 2010).
Recognition of a range of perspectives and potentially conflicting interests can facilitate a richer appreciation of the problem situation. In the case of adaptation needs for a New Zealand dairy farm, the point of view of the farmer may be quite different from that of the researcher, and industry representatives such as milk processors may have a different perspective again. These differences can be quite clearly expressed if they are solicited. For example, the New Zealand (Waikato) dairy farmer in the pilot study highlighted the emphasis of researchers on reducing stocking rates and improving per-cow productivity, particularly in the context of climate change mitigation. He considered the idea of focusing on higher per-cow production to be a “luxury” after three years of drought had left the family struggling financially.

Actively defining the farming system from the researcher perspective enables a direct comparison in the next step with the farmer perspective, as a basis for understanding the differences. For this purpose, this section draws on the SSM tool for generating ‘root definitions’ that identify core components of the system (Checkland and Poulter, 2010).

Two of the key root definitions expressed in SSM are the concepts of ‘worldview’ and the perception of the ‘transformation process’ occurring in the system that is being analysed. Researcher perceptions of the system are strongly influenced by their worldview including norms, values and approach to understanding knowledge. The transformation process occurring in the farming system can be represented in different ways: in its simplest form, a dairy farm is seen as a process of transforming grass into as much milk as possible, by keeping and milking cows. It might also be described as a process of transforming money into a lifestyle by running a complex farm. In essence, this is a process of clarifying the most important goals of the system and what contributes to their achievement.

In order to gain a comprehensive picture of the power dynamics at work in the system, the primary actors, with their particular roles, are then recognised. In identifying those directly affected by the functioning or non-functioning of the system (Checkland and Poulter (2010) refer to these as ‘customers’) and those with the power to stop or change the system (‘owners’), influences and consequences become clear. For example, in an owner-operated farm, the farmers are both the primary decision-makers and the most affected by the farm system processes. However, influential industry bodies such as farmer-owned cooperatives may also have
the power to define aspects of the system through their role in providing access to the market.

Finally, the environment in which the system operates needs to be defined. This involves recognition of the challenges and risks facing the system in question, and also the uncertainties inherent in the identification of such risks (Stirling, 2010). Many of these challenges have the potential to interact and compound potential risks and uncertainties. For example, in New Zealand, the dairy industry is a cornerstone of the economy, with an export value of NZD 11,323 million (Ministry of Agriculture and Forestry, 2009).

The competitive advantage of New Zealand’s dairy industry is based on the efficiency of its low cost, pasture-based systems compared with more intensive systems reliant on feeding concentrates, such as most European dairy systems (Basset-Mens et al., 2009; Gray, 2001). However, pasture-based systems are also more vulnerable to climate fluctuations. Climate change projections indicate that the climate change process will increase not only average temperatures but also climatic variability and the frequency of extreme weather events such as droughts and floods (Renwick et al., 2010). Demand for water resources is increasing as a result of agricultural intensification and environmental restrictions (KPMG, 2010) as well as population demand in peri-urban areas. Demand for other resources, such as pesticides and fertilizers, which are energy-intensive to produce, may also become limiting. In addition, pressure on farmers to reduce their environmental footprint is increasing (Beukes et al., 2010; Jay, 2007; MacLeod and Moller, 2006) as well as pressure to improve animal welfare practices. Global and regional markets will be affected both directly and indirectly by climate change, and dynamic market responses to global change are the subject of considerable uncertainty (Aber et al., 2000).

5.2.2. Scope (with farmer/manager)

The second step is to scope the study from the perspective of the (case study) farmer, facilitated but not influenced by the researcher. First, an historical perspective of the farm’s development is a key mechanism for gaining an understanding of the farming system. Past studies (Burton and Peoples, 2008; Kenny, 2010; Kenny and Fisher, 2003; Payne and White, 2009) have gained significant insights into farmer decision-making and the resilience of New Zealand farming systems by asking about farmer experience of past climate events and their perceptions of climate change.

There are a range of participatory methodologies that can be used to gain insights in this step and in further collaboration with farmers. Semi-structured interviews may be the most effective tool for the scoping exercise. However, as a research method these rely heavily on the skill of the researcher (Kvale and Brinkman, 2009). Formulation of the questions should elicit response about the way farmers view the key components and processes occurring in the farming system, to enable articulation of the ‘root definitions’ as outlined in step 1. This will then form the basis for creating a richer picture of the system from the farmer’s perspective.

A combination of methodologies may be appropriate, depending on the resources available for the study. For example, for the purpose of the scoping exercise, an informal farm walk may yield insights that do not arise in a more formal interview setting. Particularly for steps 4 and 7 (following), group activities, such as workshops, focus groups and group farm walks may be of considerable value in promoting the cross-fertilisation of ideas. In such settings it is also possible to incorporate the use of tools such as Venn diagrams (Lynam et al., 2007) or game scenarios (Martin et al., 2011) to gain an in-depth understanding of the relative influences of different actors and institutions. In practice, however, most studies are limited by resources. Whichever methodologies are selected, the focus of the research should be on understanding the farmer’s worldview and perspective of the system, as well as accessing some of the tacit knowledge built up through experience.

As part of the scoping exercise, basic farm management data needs to be collected for input into the model for the next step, the modelling of future scenarios.

5.2.3. Scenario generation (researcher)

The development of future climate scenarios is an important basis for assessing future risks that may threaten a farming system. Farmers’ learning is based primarily on past experience. However, in the case of issues such as climate change, the past may not provide a reliable basis for planning the future. The usefulness of modelling as a tool was recognised by the pilot study farmer: while noting the limitations of models in picking up the complexity of the farming system, he noted that they were useful in “narrowing down” and identifying key issues and important trade-offs.

The pilot study farmer considered climate change as an insidious process that would not have a significant impact in the time that he planned to be farming, and considered short-term climate variation to be more important. At the same time, he spoke at length about the difficulties of the past three drought years. Drawing the link between longer term climate change processes and likely increases in events such as droughts in the pilot study is likely to promote longer term strategic thinking and planning on the part of the farmer.

5.2.4. Pool ideas (with farmer/manager)

This step seeks to clarify the risks facing the farming system and its current capacity to cope with those risks, and to identify viable adaptation options. Based on the scenario modelled for the case study farm under analysis, a simple, context-specific risk management matrix for the region in which the farm is based will provide a basis for assessing the potential magnitude of risks to the system. Important parameters to identify in such a matrix include the key potential impacts, areas of greatest vulnerability, and priority areas of action (Cobon et al., 2009). Such an exercise should also consider the level of uncertainty associated with the risks identified and the reasons behind the uncertainty, in order to maintain a plural and conditional perspective on the quantified risks (Stirling, 2010).

The classical approach to climate change assessments considers as a baseline the ‘autonomous adjustments’ that may take place in response to climate change events without external intervention. However, because of the complex nature of a farming system and intensive, ongoing management, it is more useful here to analyse the basic state of the farming system using concepts of resilience and in the context of the adaptive cycle of the system.

In the pilot study, the farmer initially noted three main sources of risk to the farming system: the payout for milk solids, climate, and his personal resilience. He emphasised the importance of the human element in resilience, for example physical and mental health, and noted the role of past health issues in his goal to maintain a system that is less management intensive.

The farmer identified two main aspects of system resilience. First, he stated that the physical components of his farm were not resilient to weather extremes, particularly drought, but that they had tried to set the farm up to be resilient by having a moderate stocking rate, using mainly home conserved feed, and buying in small amounts of supplementary feed. The farmer considered flexibility in management to be a key source of resilience. For example, he had a very flexible drying off policy and had modified his stocking rate and bought in feed to manage the droughts over the past three years. After three difficult drought years in a row, the farmer expressed a cautious approach to innovation, noting that he would look carefully at strategies being modelled and
demonstrated by research before changing a practice. The impact of these three difficult years had clearly reduced the resources available to the farming system, and had a compounding effect: financial stress had increased the pressure to produce more milk. Combined with the drought, the pressure to produce had intensified both management requirements and stress on the biophysical resources of the system, including the need to re-grass approximately a quarter of the farm in the past year. This in turn increased pressure on the farmer and had a detrimental effect on his personal resilience and capacity to innovate.

Resilience in complex adaptive systems is by nature exceedingly difficult to measure, as the future of a complex adaptive system is considered unknowable (Darnhofer et al., 2010b). The ‘resilience thinking’ school of thought conceptualises the development of a complex adaptive system over time as moving through four successive phases of an ‘adaptive cycle’ (Allen and Holling, 2010; Darnhofer et al., 2010b). The first phase is exploitation, in which the young system capitalises on the resources available in a phase of rapid growth. This is followed by a stable conservation phase, in which the interconnectedness of the system increases and it specialises in order to capitalise efficiently on the resources available. The increasing specialisation and rigidity in this phase then leads to decreased resilience and a ‘release’ phase in which the system collapses due to stress. This is then followed by a phase of ‘reorganisation’, in which there is potential for the system to exit the current cycle and take on a new state (Allen and Holling, 2010; Darnhofer et al., 2010b).

Based on the farmer’s description of his system, the past three years had significantly reduced the resources available on farm, and the system had suffered from the external shock of three successive years of drought. This suggests that the farm is nearing a period of release after which reorganisation will be necessary. Questions which provide further insights in this context include:

- How interconnected, ‘closed’ or open is the system?
- How much buffering does the system have in terms of the resources available?
- How dependent is the system on external resources?
- At what stage in the adaptive cycle is the system currently?

As noted under step 2, there are different approaches to gain farmer input: Semi-structured interviews are one option, but group-based activities such as workshops of focus groups might allow for greater cross-fertilisation of ideas. It may be useful to compare adaptation options proposed by the farmer(s) with those drawn from the literature. Some farm level adaptation options identified in the literature include (based on Stokes and Howden, 2010; Kenny, 2010; Smit and Skinner, 2002; Guerringer et al., 2009; Reidsma and Ewert, 2008):

- Selection and management of pasture and animal species, diversification to increase resilience
- Infrastructure adjustments or tree planting to provide shade and shelter
- Spatial and temporal adjustment of management practices, for example, adjustments to the layout of the farm, changes to the timing of farm operations, fodder conservation and use strategies and a flexible stocking policy
- Reducing the intensity of production
- Measures to reduce soil moisture loss such as changes to the land topography, re-vegetation and soil organic carbon management, for example, through alternative fallow and tillage practices
- Measures to improve irrigation efficiency and store water more efficiently

The options then can be categorised and an initial assessment made on which of the options can be analysed using the model, and which will need to be considered separately. With regard to the options listed above, for example, it is possible to model most of the adjustments in management practices listed in the DairyNZ Whole Farm Model (WFM) (Beukes et al., 2005). However, it will not be possible to simulate options such as changes in land topography, infrastructure adjustments or tree planting.

In order to identify feasible adaptation options in the next step, it is necessary to agree on a joint set of indicators of success to refer to in the modelling analysis. These should be relevant to both the farmer and researcher and ideally include economic, social and biophysical indicators.

5.2.5. Analyse options (researcher)

Whole farm simulation models such as the WFM provide a complex ‘virtual world’ in which to model the effects of different management strategies on interactions between climate, management, and cow and pasture production in a farming system (Beukes et al., 2005; Bryant and Snow, 2008; Woodward et al., 2008). The WFM uses flexible decision rules and provides outputs for pasture growth and animal production on a daily time step, and economic results on an annual basis.

There are a number of approaches to integrating climate information into farmer-guided modelling experiments (Clark and Tait, 2008), ranging from: analogue studies where a period from the past is selected to represent change, thereby examining known natural climate variability; sensitivity studies where a range of possible climate changes are considered and the response of the system examined; and scenario studies where projections of future climate change from climate systems models are used, isolating the probabilities of change attributable to anthropogenic influences. Each of these methods has trade-offs between levels of certainty, and their ability to isolate the human influences on climate change. In the integrated framework, choice between these methods is guided by farmers concerning which climate stimuli should be the focus of adaptation. The case study presented here is an example of an analogue study, but high quality climate change projections suitable for farm systems analysis have been developed for New Zealand using the physical regional climate model PRECIS, and are available for future evaluations (http://www.metoffice.gov.uk/precis/).

Three different ‘weather years’ were modelled in our pilot study as a climate analogue: 2009–2010: the most recent year for which management data were available. Precipitation was below average at 1,068 mm; 2007–2008: a drought year, with 914 mm precipitation; and 1995–1996: considered a very favourable climate year with a total precipitation of 1508 mm (see Table 1). However, as they are based on past weather, analogue studies have the limitation that they are unable to account for projected increases in climatic variability. Where regionally downscaled climate projections are available, these may provide a more accurate picture of potential future variability.

For the pilot study farm, one adaptation strategy was analysed as an example, i.e. a reduction in stocking rate. For each of the model runs, economic parameters were kept the same to enable a simple comparison between the years. Economic data from the year 2008–2009 were used, as this was the most recent year for which it was available in the WFM.

The stocking rates modelled were based on the farmer’s comments on his management decisions. The farm in question had recently survived three difficult years, and the farmer had dropped his stocking rate from 3.7 cows/ha to 3.2 cows/ha. He noted that he was maintaining the system at this rate by buying in extra feed, in anticipation of a return to more normal weather conditions. For this
reason, an additional model run was carried out for the original stocking rate of 3.7 cows/ha for the high yield year (1995–96).

Table 1 shows that in the ‘virtual’, modelling world, a further reduction in stocking rate would be more profitable even in a high yield year.

<table>
<thead>
<tr>
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<tbody>
<tr>
<td>Stocking rate</td>
<td>3.7</td>
<td>3.2</td>
<td>2.7</td>
</tr>
<tr>
<td>Milksolids</td>
<td>266</td>
<td>287</td>
<td>313</td>
</tr>
<tr>
<td>Milksolids</td>
<td>983</td>
<td>933</td>
<td>861</td>
</tr>
<tr>
<td>Pasture production</td>
<td>12,345</td>
<td>12,245</td>
<td>11,946</td>
</tr>
<tr>
<td>Change in cow liveweight</td>
<td>–5</td>
<td>6</td>
<td>17</td>
</tr>
<tr>
<td>Dairy operating profit (NZ$/ha)</td>
<td>130</td>
<td>512</td>
<td>799</td>
</tr>
</tbody>
</table>

5.2.6. Validate results (with farmer/manager)

This step involves comparison of the modelling exercise with the insights provided by the social research. First, the results are considered against what is already known of the system, and key questions formulated. It is then useful to revisit the results of the exercise together with the farmer. Tools for this might include further interviews, a written survey or a discussion workshop.

In the case of the stocking rate question, there is a clear difference in perception between the top-down modelling exercise and the farmer who is in charge of managing this system. The farmer is unhappy with the current situation but feels the need to maintain a higher stocking rate and even underfeed his cows in order to pay the mortgage. However, the model suggests that even in a good year, he would be financially better off with a lower stocking rate.

The simple answer from a researcher perspective might be to suggest to the farmer that he would be better off dropping his stocking rate. However, exploring the reasons behind the difference in perception may provide more useful insights into solving the problem. In this case, the farmer noted that the results confirmed his own observations that he was overstocked. His solution was not to destock, but to buy in more feed for the next year.

From the farmer perspective, the complexity of the system means there are many issues that the model addresses in a simplified way, for example the quality of pasture and supplementary feed. The value of the farmer perspective is that it is embedded in the actual context in which the decision must be made. To gain a deeper understanding of the reasons behind the differences in perception, the following questions can be asked:

- How accurate is the modelling work from the standpoint of the farmer? Are there important gaps in the model’s representation of reality?
- What other factors influence the decision to maintain or reduce stocking rate? (for example, cashflow issues, adjustment costs, or even other less obvious disincentives such as the fact that culled stock would be sold at a lower rate than the average value shown in the farm accounts, giving the appearance of lost profit.)

The validation and modelling steps can be iterative until researcher and farmer are satisfied with the adaptation options identified. For example, it would be useful in this case to model the farm once more for the climate analogue years, with different levels of bought in feed.

5.2.7. Evaluate adaptation strategies (with farmer/manager)

In the final step, adaptation strategies are evaluated based on both the qualitative understanding gained of the system and its functioning, and the modelling analysis performed to quantify specific trade-offs. Quantification of specific biophysical and economic trade-offs in a model and then re-examination of these trade-offs in the context of the complex socio-economic system in which they take place will highlight the interactions between the biophysical, economic and social aspects of the system. For example, in the pilot study farm there was a clear synergy between the results of the modelling exercise and the needs of the farmer, who had drawn attention to the cost of knowing his cows were underfed to his own morale and personal resilience, as well as to the desire to reduce the management intensity of his farm. The validation of this limited modelling exercise has paved the way for an open dialogue on both the way in which the model operates and other interactions operating within the system, such as social and economic factors. In addition, it has opened a constructive debate on climate change from the perspective of adaptation. Like most Waikato farmers (Smith et al., 2008), the farmer in this pilot study was not convinced that climate change is responsible for increasing adverse weather events.

In order to identify ‘resilience pathways’, a starting point is to consider in reverse the types of adaptation that are undesirable. Barnett and O’Neill (2010) define five main kinds of ‘maladaptation’: actions that 1) increase emissions of greenhouse gases; 2) disproportionately burden the most vulnerable; 3) have high opportunity costs (high social, environmental, or environmental costs relative to their alternatives); 4) reduce the incentive to adapt (for example by encouraging unnecessary dependence on others, stimulating rent-seeking behaviour, or penalising early actors); and 5) create path dependency by investing in trajectories that are difficult to change in the future, reducing the flexibility and hence adaptive capacity of the system in question. To this can be added the maladaptation of increasing dependency on resources which may become scarcer in future, such as water or fossil fuels (Stokes and Howden, 2010). To reverse these maladaptive paths, assessment of adaptation options should need to be based on 1) synergies with mitigation; 2) equity; 3) low opportunity costs; 4) increasing the incentive to adapt; 5) flexibility, path independence and 6) reducing dependence on external resources. These goals need to be understood in terms of the management trade-offs underlying the activity. In particular, it may be useful to consider the trade-offs between production intensity, management intensity and diversification of the system at different levels.

The final product of higher level adaptation studies has been primarily either yes or no answers on whether the system has the potential to adapt successfully or not (Fitzgerald et al., 2009); or broad principles for supporting resilience and adaptive capacity and unquantified lists of adaptation options (Stokes and Howden, 2010; Kenny, 2010; Smit and Skinner, 2002; Reidsma and Ewert, 2008). Evaluation of these principles at farm level allows for the quantification of costs and benefits and makes it possible to answer key questions from a practical perspective, in particular:

- What are the interactions and interdependencies across the social, economic and biophysical dimensions of the system?
- Which adaptation strategies demonstrate synergies across the different dimensions?
- Which adaptation strategies contribute clearly to the resilience of the overall system in the face of perturbations?

In order to evaluate the adaptation strategies in a way that will highlight the different trade-offs, one technique which may be useful is multi-criteria mapping, proposed by Stirling (2010) and others as a way of providing plural, conditional advice in the face of uncertainty. Criteria for such a mapping exercise should be defined, along with indicators of ‘success’, together with the farmer(s) whose farm is under analysis. Multi-criteria mapping would allow for matching the farmer’s goals with the economic, environmental and social capabilities of the farm, and help to identify priorities for implementation.

As noted above, adaptation of a farming system to climate change is a continuous and dynamic learning process. The evaluation step should be followed up with a mechanism for providing feedback to the researcher on the assessment process, as well as on the usefulness and implementation of the outcomes of the assessment.

6. Discussion and conclusions

This paper has briefly reviewed some of the key methodologies commonly used in assessment of adaptation to climate change to date, and their main advantages and disadvantages. The strongly disciplinary nature of current research into adaptation options for New Zealand dairy farms represents a constraint to understanding complex socio-ecological systems. The present dichotomy in research and discussions on the subject of whether top-down, quantitative or bottom-up, qualitative approaches are more useful should be replaced by the question: what can each approach contribute to understanding the farming system? This review has highlighted the need for an integrated methodological framework to capture a richer systems perspective by embracing both the qualitative, social science approaches and the quantitative, biophysical approaches to the analysis of adaptation strategies. Based on the gaps and needs identified, a Mixed Methods Framework has been proposed (Fig. 2), supported by information obtained from a pilot case study farm which allowed for concrete examples to be presented. This framework represents a starting point for the integration of the two dominant kinds of research currently being undertaken.

Adaptation of farming systems to climate change is a continuous, dynamic process, starting with present needs and the current operational environment. In order to ensure that the adaptation research carried out supports farmers and other stakeholders, and keeps policy development relevant, quantitative research such as biophysical and economic modelling needs to be embedded within the context of the realities facing decision-making. Successful adaptation of agriculture to climate change will depend ultimately on the actions of individual farmers (Stokes and Howden, 2010) and their flexibility in applying new management strategies. As an example, the VERDI simulation model by Ripoche et al. (2011), using a ‘mixed’ strategy approach to a vineyard study, showed that high flexibility offset potential effects of climate variability on vineyard performance. Farmer perspectives and perceptions, and the context in which adaptation decisions are made need to take a central role in adaptation studies.

Because of the inherent uncertainty in predicting the future of complex systems, the most important way that researchers can contribute to farmer adaptive capacity in the context of climate change is not by providing prescriptive answers or lists of options. Rather, a dialogue is required for both researchers and farmers to fully benefit from one another’s perspectives and knowledge, thereby gaining an in-depth understanding of the range of adaptation options, the barriers to implementing these options, and the specific trade-offs involved in different management choices.

The need to build the ‘adaptive capacity’ of system managers is now also reflected in a range of literature on adaptation to climate change (Dessai et al., 2005; Adger, 2006; Folke et al., 2010), as well as business management and farm management (Beijeman et al., 2009). Managers need to understand and articulate their own particular context (Allan and Stankey, 2009). Research aimed at understanding and challenging how farm managers perceive the farm system will afford insights into the way in which farmers establish strategies. Important in this context is taking into account farmers’ tacit knowledge, built up from current and past experience within the operational environment of the farm and the external factors that perturb the farm system.

Approaches to climate change adaptation, like many other complex issues, can be significantly enhanced if quantitative modelling is valued as a tool in the context of a broader assessment. For this purpose, it is important to clarify the role of integrated, quantitative models in the broader conceptual models utilised by farmers and researchers. Since the challenge of adapting to climate change is subject to a great deal of uncertainty, quantitative modelling is a key tool in the development of future scenarios and in the analysis of trade-offs between different adaptation strategies. Ongoing work is continuously expanding the horizons of quantitative computer modelling. However, in utilising such models, it is important to maintain a perspective on their relationship to the system that are not included in a quantitative model. Positioning the quantitative model in the context of a wider system that includes both soft and hard elements (Fig. 1) means that the quantifiable aspects of the system can be measured without losing sight of the softer aspects, which can then be analysed using social science research methodologies.

The integration of qualitative and quantitative research approaches can contribute to effectively analysing the most important interactions and feedbacks at work in agricultural systems at farm scale. While challenging in practice, efforts towards such integrated approaches will generate much more grounded and realistic information about potential adaptation responses and improve the flexibility in response to climate change variables and associated impacts of society.

By incorporating systems thinking concepts and multiple (interdisciplinary) methods, the proposed Mixed Methods Framework has the potential to provide a more integrated ‘rich’ picture of the farming system, obtained through a participatory approach. A key strength of this approach to interdisciplinary research is the process of actively defining the system independently from different perspectives, and then through a participatory exercise, bringing the two perspectives together. This has the effect of providing two windows through which to observe the system, facilitating a greater depth of perception. It is vital that the differences in perspective between farmers and researchers are communicated, recognised, respected, valued, and integrated for analysis and evaluation.

Finally, as with all interdisciplinary research, there are likely to be significant challenges in the actual implementation of such a mixed models framework, including the availability of expertise and resources. However, the potential benefits are significant. In particular, embedding the research in a joint learning and co-development process involving researchers and farmers, based on an open recognition of the validity of both perspectives, is likely to improve the credibility and legitimacy of the research in farmer perceptions. In doing so, it will facilitate a dialogue for increasing the understanding on climate change adaptation issues by both farmers and researchers and contribute to the implementation of...
adaptation practices based on accommodating the ‘soft’ and ‘hard’ methodological approaches. A successful outcome will be an increased overall resilience of the farming system both in the present and future.

The working example presented in this article is a single case study farm. However, the methodology could well be applied to a series of farms. Each additional example would add depth to the analysis as farms will differ considerably both in the environment in which they operate and in the preferences, goals and management practices of the farmers.

The analysis of multiple farms could be approached in two ways: either by analysing each farm separately and comparing the results at the end, or by creating opportunities for the cross-fertilisation of ideas during the analysis. Steps 4 and/or 7 of the MMF would lend themselves well to such cross-fertilisation, for example, in the form of workshops and participatory exercises with researchers and farmers. Such an approach would help to identify cross-cutting principles and areas of difference earlier in the analysis and potentially provide useful insights to a range of end-users, from farmers to policy makers.

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