Appendix 1A CSIRO Summary Report on Southern Livestock Adaptation to Climate Change 2012

Abstract

This project was funded by MLA and the Australian Government to develop information about the likely extent of climate change – and options for adaptation to it – as it will affect livestock producers in southern Australia. Mathematical modelling is the only viable approach to this challenge. A set of modelling analyses were carried out using the GRAZPLAN simulation models of pasture and livestock production to explore the impacts of projected future climates and opportunities to adapt to them.

Our results indicate that there is a real prospect of 15-20% overall reductions in pasture growth across southern Australia by 2030 in the absence of adaptation; reductions in profitability will be larger again. Climate change impacts are likely to be most severe in the lower-rainfall parts of the cereal-livestock zone. No single alteration to management will be a “silver bullet” in response to climate change, but combinations of adaptations can probably be found to maintain the productivity of livestock production across southern Australia to 2030. By 2050 and 2070, on the other hand, it is likely that new technologies or systems will need to be found if livestock production at the dry edge of the farming zone is to remain viable.

Executive summary

Sheep and cattle producers who intend to remain in the industry over the next 20-40 years need to understand the extent of changes to productivity that may result from climate change, and the options available to adapt to changing climates. This project was part of *Southern Livestock Adaptation 2030*, a program of research, development and extension into adaptation options for southern Australian livestock producers that formed part of the Australian Government’s *Climate Change Research Program*. A key feature of *Southern Livestock Adaptation 2030* has been collaboration between research organizations (including CSIRO) and State government extension agencies from all 5 states in southern Australia.

In this project we used the GRAZPLAN simulation models of pasture and livestock production to explore a variety of issues relating to climate change. The centrepiece of our research was an analysis of livestock production systems for all combinations of 25 locations that are representative of southern Australia, 5 livestock enterprises, 3 future dates (2030, 2050 and 2070), 4 different projected global climates and 9 adaptive changes to management or genetics (singly and in combinations). No comparable study has been attempted worldwide for any agricultural industry.

Despite the enormous complexity of our research question, a set of key messages emerges from the mass of modelling results:

- In the absence of adaptation, the magnitude of climate change impacts will be large; the potential exists for a significant decrease in the total value of livestock production.
- Based on the available projections, there is a real prospect of 15-20% overall reductions in pasture growth by 2030 in the absence of adaptation.
- Declines in production and profitability can be expected to be significantly larger than declines in total pasture growth. This differential is caused by the need to leave herbage unconsumed to protect the soil resource, and is probably exacerbated by increased variability in future climates.

- Climate change impacts, and hence the need for adaptive responses, are greatest in the lower-rainfall parts of the cereal-livestock zone and tend to be less severe in the south-eastern parts of the high-rainfall zone.
- Taken across southern Australia, all broadacre livestock enterprises are likely to be strongly affected by projected future climates. It appears that impacts on beef breeding will be somewhat smaller in relative terms than the impacts on other enterprise types; these differences are unlikely to be large enough to make beef cattle more economically attractive than other enterprises, however.
- The uncertainty associated with these projected changes in livestock production is large – and is caused by uncertainty in rainfall projections – but the above trends are discernable nonetheless.
- A range of different adaptations, based on currently-available technologies, are potentially effective in ameliorating the impacts of projected climate changes. The most important of these are:
  - increasing soil fertility, so increasing the water use efficiency of pasture growth;
  - ongoing genetic improvement of livestock;
  - introduction or increased use of summer-active perennials (particularly lucerne);
  - in some locations, the use of confinement feeding to protect ground cover.
- No single adaptation will be completely effective adapting the broadacre livestock industries to climate change. In most situations, a combination of adaptive responses will be required.
- It is likely that in 2030, combinations of adaptations can be found to return most livestock production systems to profitability. By 2050 and 2070, on the other hand, our findings suggest that the lower-rainfall parts of the cereal-livestock zone will require either new technologies, a complete re-thinking of the feedbase or else sustained price increases in order for livestock production to remain viable.

An important conclusion is that there are changes to management – in particular management for increased soil fertility and the adoption of systematic genetic improvement of flocks and herds – that are (i) likely to be sound adaptations to changing climates, (ii) need to be carried out over the long term and (iii) are likely to be sound investments in the present-day climate. The case for these adaptations should therefore be made by industry bodies with renewed force.

This project played a vital "back-office" role in ensuring that the *Southern Livestock Adaptation 2030* met its overall target communication target of 10,000 producers aware of findings relating to local climate change impacts and adaptation options. Within our project, our primary objective was to develop credible and consistent information about climate change impacts: this information is of particular relevance to industry bodies and policymakers. It has been disseminated through a workshop with industry stakeholders and through scientific publications, and will be made available to the public via a program website.

An intended side-effect of this project was to increase the capacity of the livestock industries to make use of modelling to address a range of issues into the future. We did this by extending the GRAZPLAN models to apply to C_4 native perennial grasslands, developing a set of representative grazing systems models that can be re-used to analyse a wide range of different R&D questions, and by training and building the confidence of a network of staff (across multiple organizations and states) who can apply models to RD&E activities. Finding – and funding – opportunities to allow this network to of people to put their skills to good use is an important next step arising from *Southern Livestock Adaptation 2030*.

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Background

Sheep and cattle producers who intend to remain in the industry over the next 20-40 years need to understand the extent of changes to productivity that may result from climate change. Uncertainty about these changes limits the ability of producers – and other stakeholders in the industry – to plan for the long term. The main kinds of adaptation that livestock producers can make to new circumstances are to alter the proportional mix of livestock enterprises; change the management within each enterprise (key "profit drivers" here include stocking rate, mating date, timing of livestock sales and supplementary feeding policy); better match the genotype of their sheep and cattle to the new situation; or alter the pasture base, by sowing different pasture species or altering fertilizer regimes.

The Australian Government's *Climate Change Research Program* (CCRP) was instituted in 2009 to help prepare Australia's primary industries for climate change and build the resilience of the Australian agricultural sector into the future. One element of CCRP has research into options for producers to adapt to unavoidable climate change. The project described in this report is CSIRO's contribution to *Southern Livestock Adaptation 2030*, a program of research, development and extension into adaptation options for livestock producers that has been funded by the CCRP and by industry (Meat and Livestock Australia, Dairy Australia and Australian Wool Innovation). A key feature of *Southern Livestock Adaptation 2030* has been collaboration between CSIRO, the University of Melbourne, the Tasmanian Institute of Agriculture and Government agencies from all 5 states in southern Australia.

Project Objectives

In conjunction with other projects in the *Southern Livestock Adaptation 2030* program:

1. By 2011, a knowledge base will be established to underpin ongoing engagement with broadacre livestock producers, and to facilitate further research, development and extension in climate change adaptation.
2. By 2011, 10,000 livestock producers across southern Australia will be aware of the key research outcomes of the program through a combination of field days, workshops and written material.
3. By 2011, a program of on-farm trialling of key recommendations within each of the agro-climatic regions of southern Australia will be defined, for implementation during the period 2012-2015 via the MLA Producer Demonstration Sites (PDS) program and similar programs supported by other RDE providers.
4. An improved modelling capacity will be established across a range of industry RD&E providers that will assist industry in evaluating adaptation options in more detail across a range of agro-climatic regions.

Methodology

<u>Simulation of grazing systems – the GRAZPLAN models</u>

Experimental investigation of the likely effects of changing climates is extremely difficult and expensive, in particular because of the expense of enriching atmospheric carbon dioxide (CO_2) concentrations over large areas. When there is also a requirement to develop an understanding of climate change impacts across many regions and different production systems, mathematical modelling becomes the only viable approach to the research questions. The GRAZPLAN models (www.grazplan.csiro.au) have therefore been used extensively in this project. GRAZPLAN is a set of daily time-step simulation models of the dynamics of grazed temperate grasslands that is widely employed within Australia for purposes of research (e.g. Cayley et al. 1999; Clark et al. 2003; Mokany et al. 2010) and also in decision support for producers (Donnelly et al. 2002 and references therein; Moore 2005; Warn et al. 2006).

The GRAZPLAN models are driven by daily weather data. Equations describing the key processes of pasture and ruminant growth are cast in physiological terms and are expressed in a generic fashion, so that the model can represent a wide variety of grassland plants and animal breeds. The pasture model responds to the main environmental conditions that are expected to alter under changing climates: rainfall amount and pattern, temperature and atmospheric CO_2 concentration. The ruminant model predicts production of meat, wool and milk. Equations describing livestock intake allow for selective grazing of forage, and also for substitution between forage and supplementary feeds. The fate of the metabolizable energy, rumen-degradable protein and rumen-undegradable protein in animals' intake is followed and their use for maintenance, pregnancy, lactation, wool growth and change in body weight computed using the equations of the Australian feeding standard (CSIRO 2007). The ruminant model predicts animals' responses to changes in climate (to temperature in particular). Methane emissions by livestock are predicted with a modified form of the equation of Blaxter & Clapperton (1965). In most – but not all – of the studies reported here, we used the GrassGro decision support tool (Moore et al. 1997). The GrassGro software adds a flexible scheme for the management of grazing systems and simple financial analyses to the GRAZPLAN models.

An earlier study (Alcock et al. 2010) identified increased climatic variability, leading to greater risk of low ground cover and so of soil erosion, as a key factor limiting livestock production under climates projected for 2030. Accordingly, in the work reported here the concept of an "optimal sustainable stocking rate" has been used: the stocking rate which maximises long-term average profit of a given grazing system, subject to a constraint that the frequency of low ground cover should remain below a threshold value.

Downscaling future climates into local weather

Predictions of future climate change resulting from emissions of greenhouse gases are derived using physical models of the atmosphere, known as global circulation models (GCMs). These models are designed to provide insight into the behaviour of the atmosphere at large spatial and temporal scales. Agricultural simulation models such as GRAZPLAN require daily sequences of weather data as inputs. To examine the impact of alterations in climate at different locations, it is necessary to convert the changes in climate into sequences of daily weather values that realistically capture the important changes in the climate at a particular place. This process is known as "downscaling".

In this project, daily weather data sequences for a range of projected climates and locations have been constructed using a downscaling technique adapted from that of Zhang (2007). In order to take account of the uncertainty in projected climates, climate predictions from four global circulation models (GCMs) have been downscaled and used in modelling analyses: UKMO-HadGEM1 (Johns *et al.* 2006), CCSM3 (Collins *et al.* 2006), ECHAM5/MPI-OM (Roeckner *et al.* 2003) and GFDL-CM2.1 (Delworth *et al.* 2006). ISAM reference time courses of atmospheric CO_2 concentrations (Houghton *et al.* 2001) have been used in conjunction with these downscaled weather data.

Climate change impacts – exploration of the issues

Literature reviews

A review of prior work relating to adaptation of southern Australian livestock production to climate change was carried out and circulated to CCASALI program participants (Appendix 1). The review covered previous overview articles published on the subject, experimental studies and 3 earlier modelling studies. A set of research questions was derived from this information and presented to the wider CCASALI program team. Feedback on the research questions from state-based project leaders, modelling research project members and the program steering committee was then used to develop the operational plan for the rest of the project.

A second literature review was completed during 2010 by Drs Bob Godfree & Richard Culvenor that examined the potential for species in southern Australian pastures to evolve in response to climate change (Appendix 2).

Adaptations for shorter growing seasons

Our literature review made it clear that under the most likely scenarios, pasture growth in southern Australia will be characterised by shorter growing seasons with higher winter growth rates. We therefore carried out a preliminary simulation study with GrassGro that explored management options that might be adopted by managers of sheep enterprises in order to adapt to shorter, more intense growing seasons (Appendix 3). We constructed artificial weather records for 7 locations in which total annual rainfall and year-to-year variability of rainfall were the same but growing seasons were shorter. Average temperatures were increased by 2^{o}C and an atmospheric CO_2 concentration of 450 ppm was assumed, so increasing plant development, winter growth and evaporation rates. The long-term average profitability of a ewe enterprise producing first-cross lambs was then compared for each location under historical climate and shorter growing seasons, with and without (i) confinement feeding in summers with low ground cover; (ii) earlier and later age at first mating; (iii) earlier mating (November vs December); and (iv) addition of an early-flowering annual grass to the pasture; and (v) increased soil fertility.

Will managing for climate variability also manage for climate change?

In writing about policy options for climate change adaptation in agriculture, Pannell (2010) argued that farmers faced with a changing climate will successfully adapt their systems by means of successive small, short-term changes in management practice. His argument depends on two assumptions: first, that the feasible rate of on-farm practice change is greater than the rate at which changing climate will alter the production environment; and second, that farmers' perceptions of current conditions will be sufficiently accurate to allow them to adjust their management strategies.

To investigate these assumptions, a modelling study of adaptation policies under changing climates was carried out for a dual-purpose Merino ewe production system based on annual pastures at Lucindale, South Australia. The evolution of the model grazing system was simulated under changing climates from 2010 to 2099 that were projected by 2 GCMs for the SRES A1B emissions scenario, when each of four policies for progressively adapting stocking rate and joining date was followed:

- a "traditionalist" policy, i.e. maintain the optimal stocking rate and joining date from the 1970-2009 period.
- an "incremental" policy: make a small change in either stocking rate or joining date each year, based on relative profitability over the last 5 years.
- a "step-change" policy: every 15 years, choose the stocking rate & joining time that optimized net profit over the previous 15 years.

- a “forecast” policy: set stocking rate & joining time each year based on forecast long-term expected pasture production.

Novel features of this analysis included modelling grazing systems faced with changing climates (rather than multiple years of weather drawn from a single projected climate); analysis of small ensembles of realizations of the two GCM-projected climates; and the development of stochastic price sequences that allowed price as well as business risks to be taken into account.

Medium-term climatic variability and its effects on pasture and livestock production

At the commencement of this project in 2009, southern Australia had just emerged from the “Millennium Drought” – an extended period of dry conditions in Southern Australia. It was clear at the time that this drought had significantly affected the productivity and livelihoods of livestock producers. It was not clear, however, whether this long drought was a consequence of “normal” medium-term climatic variation or whether it was a unique event.

To explore this question, we used the GRAZPLAN grassland simulation models to simulate livestock production from representative grazing enterprises at 25 locations (see below) over seven 16-year periods starting with 1899-1914 and ending with 1995-2010 (Appendix 5). CO_2 concentrations of 350ppm were assumed. At each location, five grazing enterprises (self-replacing Merino ewes, crossbred ewes, self-replacing Angus beef cattle, Angus steers and Merino wethers) were modelled. Management policies (livestock replacement, the timing of the reproductive cycle, the sale of young stock and thresholds for supplementary feeding) were not changed between 1899 and 2010. For each set of 15 financial years, annual operating profits were calculated as the gross margin less overhead costs, an operator allowance and a further adjustment for the capital cost of the livestock required, and the optimal sustainable stocking rate was computed. The mean and distribution of pasture production and profit in each period were then compared.

<u>Impacts and adaptation across southern Australia in 2030, 2050 and 2070</u>

As its name suggests, much of the *Southern Livestock Adaptation 2030* program – especially the program of producer engagement – focussed on the relatively near term (i.e. climates projected for the year 2030). However the brief of the program included a requirement to consider climate changes out to the year 2070. The activities in this section were carried out to meet this requirement of the program.

Preliminary studies in New South Wales

The impact of projected climate changes at 2030, 2050 and 2070 on pasture production, sustainable stocking rates, deep drainage and livestock methane emissions was evaluated for representative grazing systems at eight locations across southern New South Wales that had been the subject of producer workshops in the partner project run by NSW Department of Primary Industries.

Grazing systems were analysed using the GrassGro decision support tool. Climate projections at the eight locations from four GCMs under the SRES A2 emissions scenario were downscaled to daily weather sequences. GrassGro was used to carry out a simulation experiment with the following factors: location (8) x climate (historical + 4 GCMs x 3 future years) x stocking rate (11-16 levels depending on the location). For each simulation, physical and financial outputs (rainfall, temperature, pasture growth rates and composition, conception and weaning rates, wool and livestock sales and amounts of supplementary feeding, and the elements of a gross margin) were recorded, and the optimal sustainable stocking rate estimated given a requirement that ground cover (averaged over the farm) should be less than 0.70 on no more than 7% of days.

Representative grazing systems across southern Australia

The above preliminary study had a limited spatial extent, and only a single grazing enterprise was modelled at each of the eight locations. In order to extend it to a wider area of southern Australia, a representative set of grazing systems was systematically specified for 25 locations.

The set of locations was chosen by dividing the southern part of Australia into regions of approximately equal gross value of agricultural production. A single location was selected (from among those with measured weather data) to represent each region. For each location, a representative set of soils and pastures was then described using the attributes required by the GRAZPLAN simulation models. Wherever possible, the soil and pasture information was drawn from GrassGro "farm systems" developed by State agency officers as part of their modelling work in *Southern Livestock Adaptation 2030*. At locations in the cereal-livestock zone, consumption of stubbles was included in the grazing systems.

A set of 5 livestock enterprises was then modelled at each of the 25 locations:

- self-replacing Merino ewes;
- crossbred ewes purchased annually and producing prime lambs;
- self-replacing beef cows;
- wethers growing fine wool; and
- steer finishing.

Within each enterprise, the same livestock genotypes, prices for livestock and wool and variable costs of production were assumed across all locations in order to facilitate comparisons across sites. Management policies, on the other hand, were described separately for each of the 125 location x enterprise combinations. Management information was drawn from the GrassGro "farm systems" developed by State agency officers wherever possible; otherwise expert opinion, literature accounts and test simulations with GrassGro were used to derive sensible values.

The result of this process was a consistently-defined set of modelled grazing systems that is representative of present-day broadacre grazing systems across southern Australia It complements the wide range of locally-specific farm systems developed in State-based projects by providing a more even coverage of southern Australia and by using consistent animal genotypes and financial information.

Identification of adaptation options

Our literature review located a large list of possible changes to broadacre grazing systems that might be considered as adaptations to climate change, but little or no information that would allow us to identify adaptations that were likely to prove effective over large areas. We therefore prioritized the various possibilities from the results of our preliminary studies and by taking producers' views into account, drawing on the lists of potential adaptations elicited at producer workshops held by partner *Southern Livestock Adaptation 2030* projects.

The resulting set of candidate adaptations to climate change fell into three main classes: changes to the feedbase, changes to livestock genetics and changes to livestock management.

Table 1. Adaptation options that were modelled at 25 locations and for each of the 5 livestock enterprises for which they were meaningful

Feedbase adaptations	Genetic adaptations	Management adaptations
1. Higher soil fertility	4. Increased breed standard reference weight	8. Confinement feeding in summers with low pasture mass
2. Management to remove annual legumes, in order to slow the loss of ground cover	5. Increased wool production at constant standard reference weight	9. Altered stocking rate
3. Sowing a portion of land to lucerne pastures	6. Increased sire standard reference weight	
	7. Increased conception rate	

Some of the genetic adaptations were applicable to only some of the enterprise types. Based on the available literature, linear increases 0.5%/year were assumed to be achievable for standard reference weights and the ratio (potential fleece weight:standard reference weight), so that genetic gain was taken to result in different animal genotypes at each future date. Achievable increases in conception rate were assumed to be between 0.5 and 0.75%/year depending on the enterprise. Altered stocking rate was a special case, as it was always considered in combination with every other adaptation.

Evaluation of impacts and of adaptation options

A series of large factorial simulation experiments was conducted, in which each of the 5 x 25 GrassGro farm systems was simulated with 30 years of weather from the historical record and from the downscaled weather for each of 4 GCMs at 2030, 2050 and 2070 (i.e. 13 climates). Each combination was modelled at a wide range of stocking rates, and the optimal sustainable stocking rate (as defined above) was identified by interpolating between the simulation results. All 1625 comparisons (location x enterprise x GCM x year) were made at the optimal stocking rates.

The first simulation experiment used unmodified soils, pastures, livestock and management. It was used to evaluate the impact of the projected climates on pasture production, consumption of forage by livestock, the conversion of consumed forage into meat and wool and the income and operating profit.

A second series of simulation experiments was then carried out, in which a single attribute of each modelled grazing system was altered to introduce one of the 8 kinds of adaptation, and the effect on productivity and profit assessed (once adjusted to a new optimal sustainable stocking rate) for each of the . Multiple levels of some of the adaptations were trialled (increased soil fertility at 2 site-specific levels, introduction of lucerne at 20% and 40% of land area, and confinement feeding at threshold levels for livestock removal of 1000, 1500 and 2000 kg/ha). The “relative effectiveness” of each adaptation was computed as:

$$\text{Relative Effectiveness} = \frac{\text{(Profit with adaptation) - (Profit without adaptation)}}{\text{(Historical Profit) - (Profit without adaptation)}}$$

In the third set of simulation experiments, adaptations were combined in different ways in an attempt to find grazing systems that were well-adapted to future climates. In this work the focus was placed on identifying robust systems, i.e. combinations of adaptations that would return grazing systems to sustainable profitability both across the range of possible futures represented by the GCMs and over the whole of the 2030-2070 period. With 8 distinct adaptation types (plus stocking rate), there were at least 255 different combinations that could have been evaluated; the limited available computing resources meant that only a subset of these possibilities could be examined. Accordingly, the adaptation combinations reported below are not necessarily “optimal” but are rather “best examined” grazing systems.

Capacity building & support for local impacts and adaptation analyses

Developing a network of model users

13 members of the partner *Southern Livestock Adaptation 2030* projects, from organizations in 5 States, were trained in the use of GrassGro version 3 during the life of the project. Approximately 20 GrassGro users were also provided with training in the concepts underlying climate change impacts R&D and the use of GrassGro for climate change analyses. Significant time was devoted to ensuring that once trained, these participants in partner projects could use GrassGro with confidence; activities toward this aim included carrying out validation studies against local experimental data sets (and upgrading GrassGro in response).

Participation in regional climate impacts and adaptation studies

Project team members travelled to SA, WA and Tasmania to assist partner projects with the development of GrassGro “farm systems” that could be used as the basis of regionally-specific climate change impact analyses. We participated directly in 2 WA regional workshops and one in Tasmania.

Extensive support was provided to partner project teams via remote (telephone and internet) channels. Support activities included:

- Interpretation of agronomic or physiological principles underlying key outputs;
- Suggesting ways to modify GrassGro farm systems so that reference simulations were better aligned with expected or measured outcomes;
- Assistance with customization of output reports;
- Interpretation of statistical measures, including those used to derive box-plots, long-term percentiles and other variability metrics; and
- Acting as the *de facto* source of downscaled climate information for the SA, WA and Victorian state-based projects plus some of the NSW participants;

Expanding the applicability of the models – parameter set development

CO_2 responses

The equations in the GRAZPLAN pasture growth model that describe plant responses to increased atmospheric CO_2 were derived in a previous project from an analysis of the published literature. In order to test how well these modifications predict real-world pasture response to CO_2, we used the GRAZPLAN pasture model – including its N response logic – to simulate a cutting experiment in which pasture swards (subterranean clover and phalaris monocultures and their mixture) were grown at Canberra in elevated CO_2, in warmer temperatures and in the combination of the two (Lilley *et al.* 2001).

Native grass pastures

There is a substantial area of central and northern New South Wales where native pastures containing C_4 perennial grasses are an important part of the feedbase. If the GrassGro decision support tool was to be used for climate change impacts and adaptation studies in these regions then this pasture type needed to be available in its underlying pasture growth model. In the NPICC temperate pastures database (Pearson *et al.* 1997), redgrass (*Bothriochloa macra*) is recorded as the most common native C_4 species; we therefore developed a parameter set for the GRAZPLAN pasture growth model that represented this species.

Pasture parameter development proceeded by a combination of literature review together with validation/calibration simulations against datasets from grazing experiments. Two grazing trial data sets were acquired (one at Armidale and one at Barraba, NSW) for the purpose. In order to accurately reflect management activities, all experiments were modelled using the AusFarm software (Moore 2001). Apart from the management rules, the model configurations that were used were compatible with the GrassGro decision support tool, i.e. the water balance model in GrassGro was used and responses of growth to soil fertility were modelled by using a common "fertility scalar" for all pasture species in each plot.

Introduced perennial C_4 grasses

Kikuyu (*Pennisteum clandestinum*) is the most widely used introduced C_4 prennial gras in southern Australia according to Pearson et al. (1997). Development of a parameter set for kikuyu was carried out using similar techniques to the development work for redgrass, using 3 experimental data sets (2 cutting experiments from coastal NSW and a grazing trial at Albany, WA).

<u>Communication and governance</u>

Regional producer workshops were the centrepiece of communication activities in *Southern Livestock Adaptation 2030*. Two other communication channels, which aimed to reach different potential audiences for R&D findings, were also part of the program's design:

- Short reports that cater to producers who are not motivated to attend a workshop, but are seeking an introduction to climate change adaptation in their region; and
- A workshop designed to communicate program findings to policymakers and other industry stakeholders.

In conjunction with the *Southern Livestock Adaptation 2030* program coordinator and the NSW partner project, we developed a prototype of a software system that delivered context-specific information on climate change adaptation to readers over the Internet. This system consisted of a set of related HTML pages that allowed users to navigate to the region or enterprise in which they were interested; a database server that managed the short reports (including tying them to a specific author, whose photograph was displayed); a facility to attach audio content to short reports, again so as to make the user's experience more personal; ancillary Web pages for more general information about climate change and its effects on grazing systems; and a draft work flow for preparing the short reports in an efficient fashion. This prototype was used as the basis for a contract that was let by *Southern Livestock Adaptation 2030* to implement a production version of the short reporting system.

As part of a wider *Southern Livestock Adaptation 2030* program team, Andrew Moore played an active role in organizing the policy-oriented workshop, which was held on 18 May 2012 in Canberra and was attended by 30 people. He also made a presentation on "Research findings – broadacre impacts and adaptations" to the workshop.

Andrew Moore also acted as a member of the program steering committee of *Southern Livestock Adaptation 2030*. He attended all meetings of this committee.

Results

<u>Literature review: natural selection in Australian pastures under climate change</u>

Significant levels of genetic variation are known to occur in both native and introduced pasture species in Australia. Variation for a range of climate-relevant traits

Table 2. Relative change in long-term average annual profit after undertaking each of a set of adaptation options under shorter growing seasons, relative to a 1970-1999 historical baseline with no adaptation, at seven locations across southern Australia. Cells shaded in green denote an improvement of 2% or more relative to no adaptation under shorter growing seasons; cells shaded in red denote a decline in profit of 2% or more relative to no adaptation under shorter growing seasons.

Adaptation option	Hamilton	Goulburn	Wagga Wagga	Katanning	Cowra	Lucindale	Mt Barker
Confinement feeding (2000 kg /ha)							
Confinement feeding (1500 kg/ha)							
Confinement feeding (500 kg/ha)							
1 Nov mating, first joining at 6 months							
1 Nov mating, first joining at 18 months							
1 Nov mating, first joining at 30 months							
1 Dec mating, first joining at 6 months							
1 Dec mating, first joining at 30 months							
Early annual grass added to the pasture							
Very early annual grass added to the pasture							
Increased pasture fertility							

is known to exist in a range of Australian pasture species. These traits are known to be heritable and responsive to selection in some introduced species, but the heritability or potential response to selection of these traits in Australian native pasture species is unknown. The extent of variation for traits associated with drought and heat tolerance is not known, except in a restricted set of introduced species such as *Phalaris aquatica* and *Lolium rigidum*.

Paleobotanical evidence suggests that climate-driven evolution does not, in general, result in the broadening of species' physiological niches; changes in species' distributions should therefore broadly track changes in climate. On the other hand, theoretical and contemporary evidence indicates that local adaptation could potentially alleviate some of the adverse effects of climate change, especially in range-core areas where plant population sizes and genetic variation are large.

<u>Adaptations for shorter growing seasons</u>

Confinement feeding was the most generally applicable adaptation option under shorter, more intense growing seasons; starting confinement at a threshold of 1500 kg/ha improved profit at 6 of the 7 locations in the simulation study. Adding early-flowering annual grass to the pasture improved profit by at least 2% of historical levels at 3 of the 7 locations. At the prices assumed, the mating time options were not effective adaptation options for dealing with shorter but more intense growing seasons. Multiple management adaptations were advantageous at locations with relatively longer growing seasons, such as Hamilton, Goulburn and Mount Barker. Adaptation strategies at sites with relatively short duration seasons such as Lucindale and Katanning appear more limited.

Most reductions in profit were a result of the necessity to reduce stocking rates to meet the minimum ground cover constraints. Strategies that allowed the greatest resting of pastures (e.g. confinement feeding with a high threshold) were generally most beneficial, since they allowed recovery of pasture growth and restoration of ground cover. The results of this preliminary study led us to place considerable emphasis on adaptation options that would reduce the frequency of low ground cover in the main adaptation study. More details of this analysis can be found in Appendix 3.

Will managing for climate variability also manage for climate change?

Different realizations of the same GCM showed large differences in decadal average rainfalls. Despite reducing rainfall, total pasture production at Lucindale was predicted to rise at first under both GCMs, with most of the increase in the winter; however the end of the pasture growing season became earlier. Clover contents were also predicted to increase over time. The use of a confinement feeding rule in the management policy allowed stocking rates to be maintained (in most cases) at or above historical-optimum levels, so that long-run average profitability under unchanged management rose gradually until about 2060 and then declined.

Pannell's (2010) contention that on-farm practice change can keep pace with a changing climate was clearly borne out by this case study. The long-term shifts in profitability over time were quite small relative to the year-to-year variability. On average, all four adaptation policies – including no change – produced risk-adjusted profit levels over 2010-99 that were higher than that of the 1990-2010 base period. None of the four adaptation policies consistently outranked all others in terms of risk-adjusted profit. The "forecast" policy was quite robust, improving on no adaptation in 7 of 8 climate+price scenarios, but it usually only provided a modest increase in risk-adjusted average profit. The "incremental" policy did better – often much better – in half the cases but was not resilient to uncertainty in future climate. This study is reported more fully in Appendix 4.

An unexpected finding was that for the "incremental" adaptation policy and the ECHAM5/MPI-OM projected climate, major differences arose between realizations of the same changing climate. It appears that intra-decadal variation around the same mean climate and prices can result in very different trajectories under incremental changes in management.

Medium-term climatic variability and its effects on pasture and livestock production

Taken across southern Australia as a whole, the 14-year period from 1997 to 2010 was drier than any of the 7 preceding periods starting in 1899, and this was reflected in the modelled pasture production; the area-weighted average rainfall and ANPP for the 1997-2010 period were both 10% below the 1899-1996 average. The 1899-1912 and 1927-40 periods also showed lower average annual NPP across southern Australia than the other 5 periods, but at the sub-continental scale it is necessary to look back 70 years to find a sustained period of reduced potential pasture growth such as that experienced recently. However, the spatial average conceals considerable spatial variation: across the South Australian locations, area-weighted average pasture growth was 22% lower in 1997-2010 compared to the 1899-1996 average, while in NSW and Tasmania (Launceston) the corresponding decline was only 4%. For NSW, however, the period of reduced pasture growth in 1997-2010 followed on from the most productive of the eight 14-year periods in 1983-1986.

While there was considerable location-to-location variation, there was a general tendency for the profitability of grazing enterprises to decrease over the 1899-2010 period in Western Australia and to increase and then decrease in Victoria and much of South Australia (Figure 1). In most of New South Wales, the period from 1899-2010 saw steady increases in profitability (at Armidale, this trend continued to 2010); as a result, for the New South Wales locations the profitability of the 1997-2010 period, while much lower than that of the preceding 14 years, was generally inside the range encountered in the historical weather record.

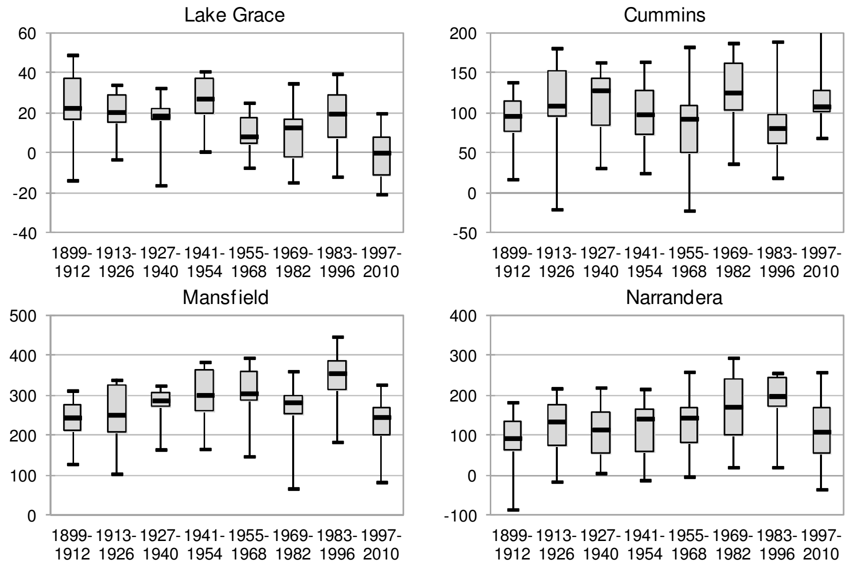


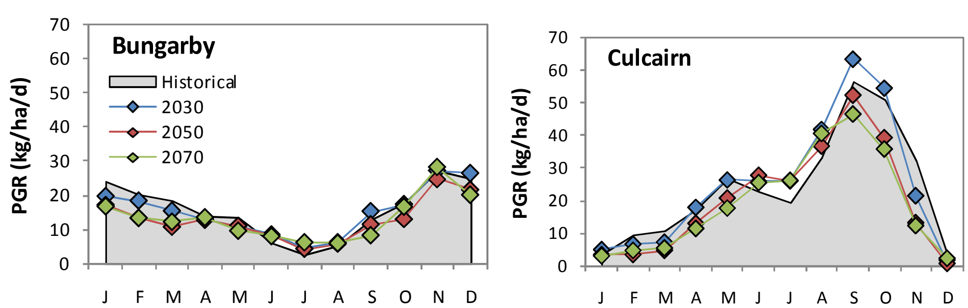
Figure 1. Boxplots showing modelled annual operating profit of a Merino ewe enterprise over 7 periods from 1899 to 2010 at 4 locations across southern Australia. The scales for each location are different so as to show the differences between periods more clearly. The management of each modelled grazing system is identical in each period within each location, except that the optimal sustainable stocking rate for each period has been selected.

There was no evidence that the variability of modelled ANPP or profitability (measured as the standard deviation) had increased, either over the historical record or in the 1997-2010 period in particular.

<u>Impacts of climate change across southern Australia in 2030, 2050 and 2070</u>

The preliminary study for southern NSW is reported more fully in Appendix 6. Projected climate changes were highly consistent across the eight locations (which ranged from the Moss Vale in the Southern Highlands to Culcairn in the eastern Riverina). By 2070, three of the four GCMs projected, lower annual rainfall at most of the locations. Projected changes in total rainfall largely determined the changes in pasture growth (aboveground net primary productivity) at all eight locations. At the majority of sites, a given relative change in rainfall was predicted to produce an approximately proportionate change in pasture growth. At Bungarby in the Southern Tablelands, however, each 1% change in annual rainfall induced roughly 1.4% change in pasture growth.

Figure 2. Modelled long-term average monthly pasture growth rates (PGR) at Culcairn, NSW and Bungarby, NSW for climates projected by the UKMO-HADGEM1 model under the SRES A2 emissions scenario. Historical (1970-1999) growth rates for each month are shown as grey shaded areas for comparison. The progressive shortening of the growing season and an increase in winter growth rates can be seen clearly. Corresponding plots for six other sites can be found in Appendix 1.



The direction of changes in stocking rate, livestock income and profitability was largely determined by the direction of change in rainfall. Stocking rates declined by a larger relative amount than rainfall; income per DSE remained fairly stable, so that changes in gross income were similar in all cases to changes in stocking rate. Owing to the effect of fixed and overhead costs, profit declined faster in relative terms than income. Levels of deep drainage varied widely from location to location; changes in drainage under altered climates were primarily driven by changes in rainfall. None of the projected climate changes altered the overall quality of pasture consumed enough to shift the expected production of methane per DSE, so that projected changes in livestock methane emissions per hectare were almost entirely driven by the changes in the sustainable optimum stocking rate.

The main climate change impacts analysis (Appendix 7) showed significant differences between the GCMs at each future date. For example, under projections from the CCSM3 model the total (area-weighted) pasture ANPP in the study area was modelled to decrease by 7% in 2050 and 8% in 2070, while for GFDL-CM2.1 total pasture ANPP was estimated to decrease by 20% in 2050 and 34% in 2070. Changes in rainfall were the main determinant of the modelled ANPP changes at most locations, and the sensitivity of ANPP to changes in rainfall was greater in lower-rainfall environments. There was, therefore, a strong tendency for locations with lower annual rainfall to show larger decreases in annual ANPP, particularly in Western Australia.

For the majority of location x projected climate combinations, the optimal sustainable stocking rates were lower than the historical value. In the vast majority of enterprise x location x projected climate combinations – especially in 2050 and 2070 – the proportion of pasture growth that was consumed was lower than in the historical simulation, i.e. utilization rates declined as well as pasture production.

Changes in the climate within each location had relatively little effect on the conversion of consumed pasture into product and hence income. As a result, the changes in long-term average profit from Merino ewe enterprises (Figure 4) were driven by the amount of pasture that can be consumed without reducing ground cover below threshold levels. By 2050 Merino ewe production in most regions is predicted to produce substantially less income in most regions under at least 3 of the 4 GCM projections; under the climate projected by the most favourable GCM (CCSM3) the average reduction in annual income over all regions was 24% in 2050 and 23% in 2070, while for GFDL-CM2.1 the corresponding reductions in income were 44% and 57%.

When averaged over all GCMs and livestock enterprises, operating profit at the sustainable stocking rate decreased by 38% in 2030, 48% in 2050 and 67% in 2070. These decreases are much greater than the corresponding reductions in pasture ANPP (18%, 21% and 30% respectively). A somewhat unexpected result is the large size of the overall profitability decline by 2030; previous studies (including our preliminary analysis) have concentrated on south-eastern Australia where effects on profit to 2030 are relatively smaller (Figure 4).

At 6 low-rainfall locations (Dalwallinu, Lake Grace, Esperance, Kyancutta, Lameroo and Birchip) stocking rates and hence pasture consumption were reduced to negligible levels in a number of projected climates. For these combinations of location and projected climate, the ground cover constraint cannot be met even at minimal stocking rates, i.e. there is no feasible grazing system with the present-day feedbase.

Figure 3. Modelled changes in aboveground net primary productivity of pastures across southern Australia resulting from climate changes projected by 4 GCMs under the SRES A2 scenario. Values shown are changes relative to ANPP in the 1970-1999 base scenario. ANPP values are averaged over the 5 livestock enterprises at their optimal sustainable stocking rates.

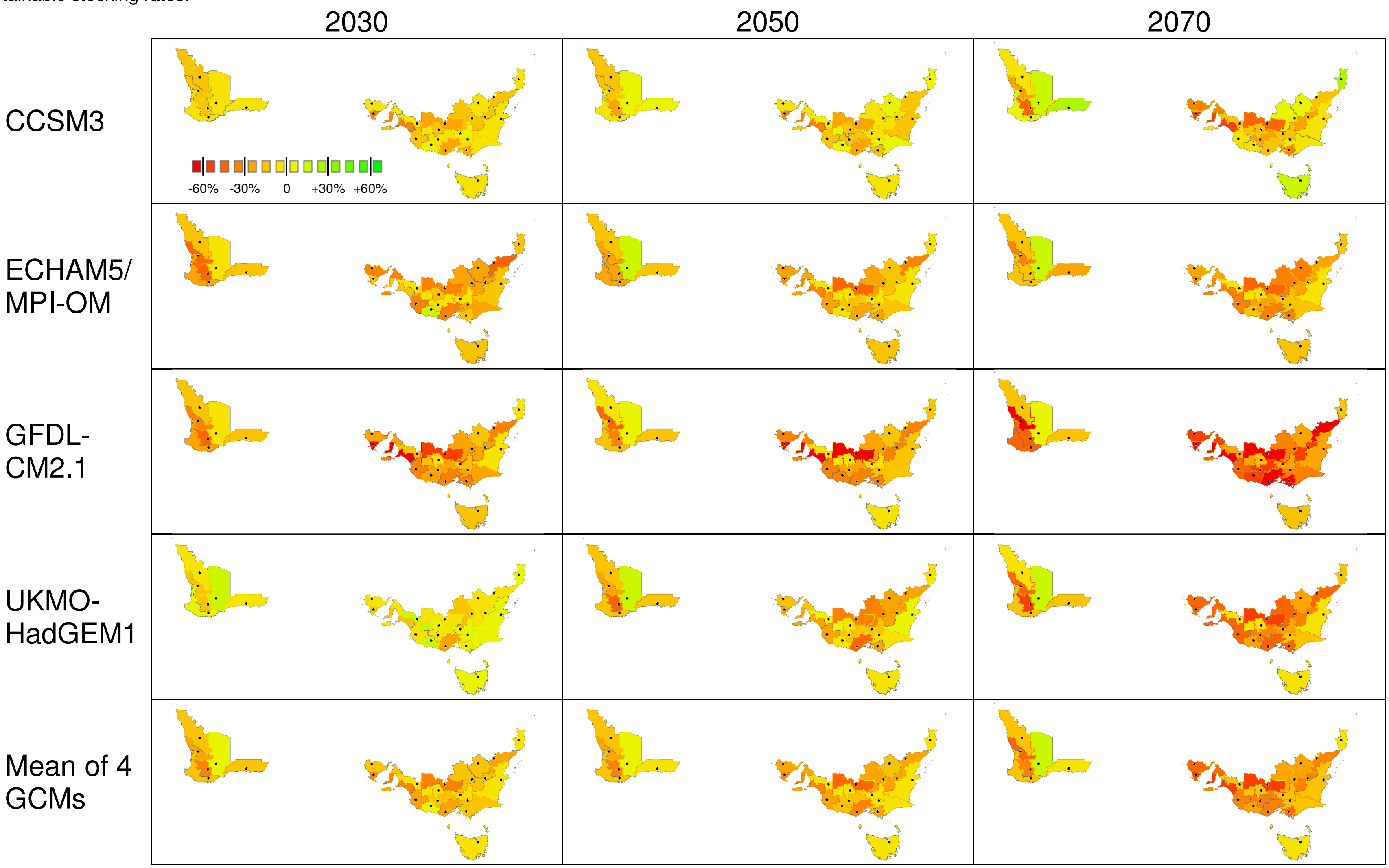


Figure 4. Modelled changes in long-term average operating profit from Merino ewe enterprises modelled across southern Australia resulting from climate changes projected by 4 GCMs under the SRES A2 scenario. Values shown are changes relative to average annual profit modelled for the 1970-1999 base scenario. All profits are computed at the optimal sustainable stocking rate for the relevant scenario. Note that the shading scale is different to that in Figure 3.

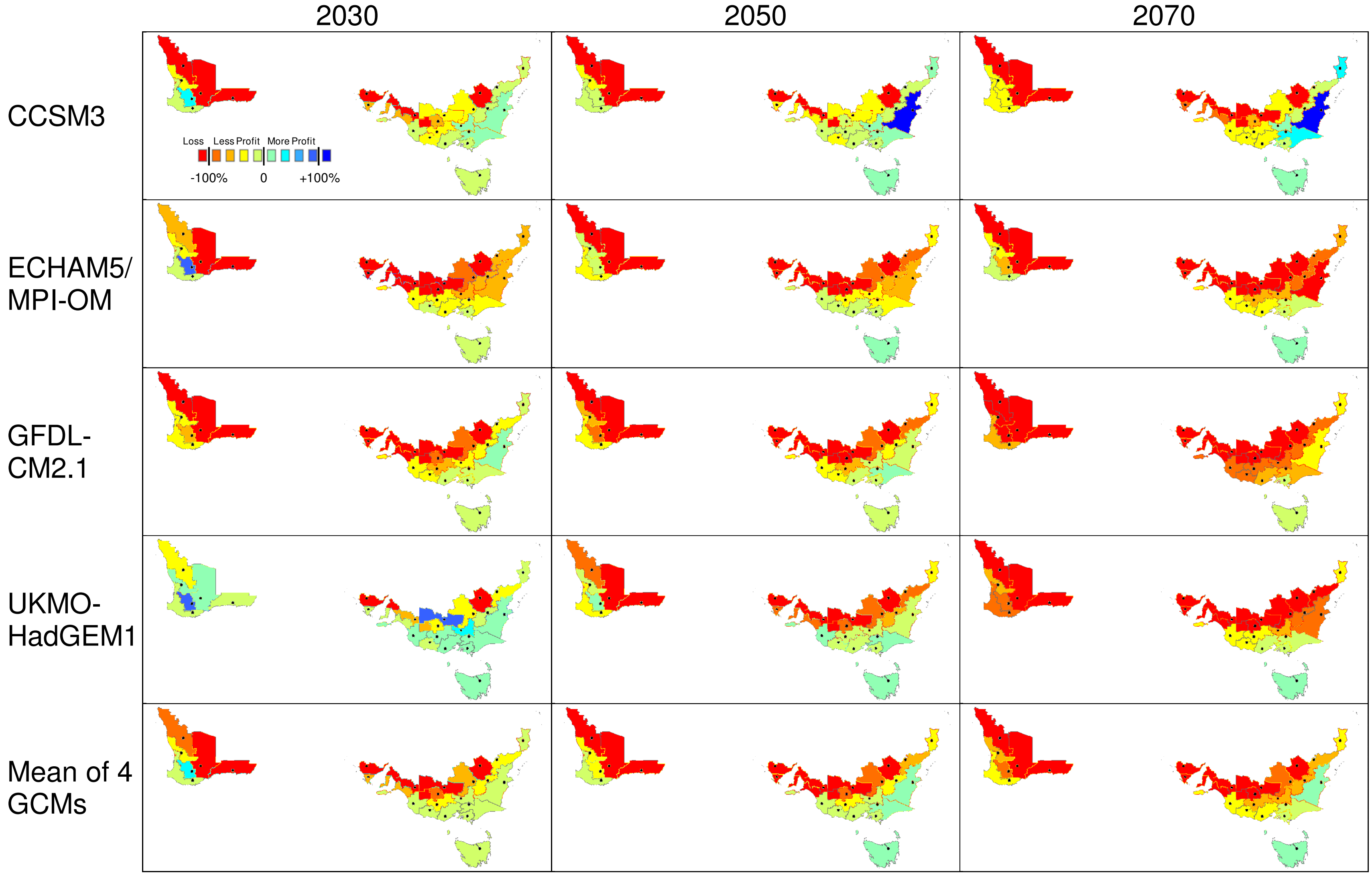


Table 2. Relative effectiveness of a range of different potential adaptations in recovering the impact of climate change on the total value of livestock production across southern Australia (0.0 = no benefit; 1.0 = a return to the 1970-99 baseline value of production). Adaptations were only applied to those location x enterprise combinations where they increased profit at the sustainable optimum stocking rate. Values are averages over 4 GCMs.

	2030	2050	2070
Higher soil fertility	0.62	0.67	0.44
Sowing a portion of land to lucerne pastures	0.45	0.50	0.41
Increased conception rate	0.15	0.32	0.31
Increased breed standard reference weight	0.11	0.27	0.28
Confinement feeding in summers with low pasture mass	0.22	0.26	0.18
Increased sire standard reference weight	0.07	0.16	0.16
Increased wool production at constant standard reference weight	0.03	0.06	0.05
Management to remove annual legumes	0.01	0.01	0.01

Adaptations to climate change across southern Australia in 2030, 2050 and 2070

Relative effectiveness of individual adaptations

Increasing soil fertility was the most generally applicable adaptation option (Table 2); under the financial assumptions that were used, it was cost-effective for nearly all location x enterprise combinations. When averaged over all locations and GCMs, this adaptation option recovered up to two-thirds of the profitability losses due to climate change.

The next most effective adaptation option overall was sowing a portion of the land area to lucerne pastures. This option differed from higher soil fertility, however, in that it was effective at some locations (the high- and medium-rainfall parts of Western Australia and Goulburn) and not at others (for example Launceston). Similarly, confinement feeding was effective only at particular locations such as Colac and Mount Barker. The best genetic option to pursue differed from location to location and enterprise to enterprise. Because the genetic improvement adaptations involved continual improvements over time, they maintained their effectiveness in 2070 to a greater extent than modifications to the feedbase or to livestock management.

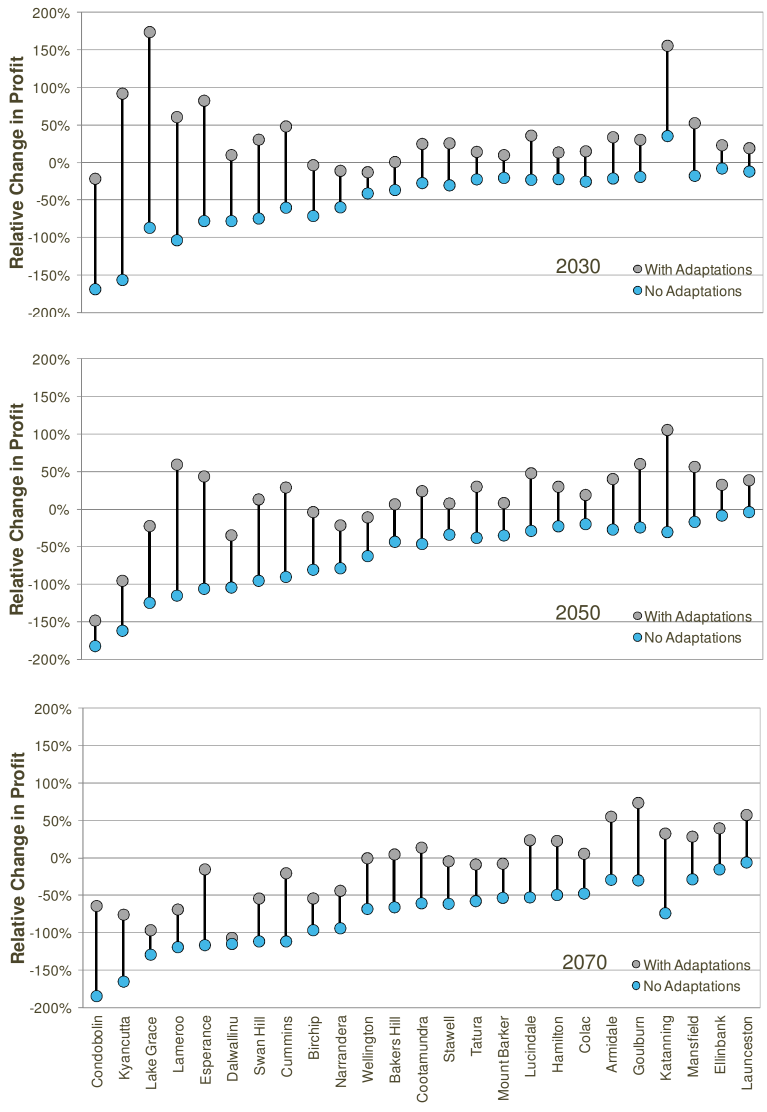
The single most important point to emerge from Table 2, however, is that no single adaptation strategy can be expected to be fully effective in returning all future southern Australian livestock production systems to historical levels of productivity.

Combinations of adaptations

The results of simulations implementing combinations of adaptations for the Merino ewe enterprise are compared with simulations with no adaptations in Figure 5. The actual combinations of adaptations represented in Figure 5 are very different from location to location. At 2030, the best combination of adaptations that we have been able to identify is sufficient in nearly all cases to return these grazing systems to their 1970-99 levels of profitability; there is a tendency for the locations at which climate change impact is greatest to show the greater effectiveness of the adaptations that have been examined.

This picture changes at 2050 and 2070. At these dates the magnitude of climate change impacts on profitability generally becomes greater, and the degree of recovery of profitability from adaptation at the highly-impacted locations (mostly at the dry margin of the cereal-livestock zone) becomes smaller, so that major reductions in profitability remain even after adaptation of the grazing systems.

Figure 5. Change in profitability of Merino ewe enterprises at 25 locations across southern Australia under projected future climates before (blue circles) and after (grey circles) the introduction of the best-available, locally-specific combination of adaptation options. Profitability values are averages over 4 GCMs and are given as changes relative to profit 1970-99 climate, so that 0% denotes historical levels of profitability and values below -100% denote4 systems that operate at a long-term average loss. Locations have been arranged in decreasing order of climate change impact on profitability (averaged over 203, 2050 and 2070).



At the same time the relative amount of technical adaptive capacity at less-impacted locations increases somewhat; as a result, at locations such as Katanning, Goulburn or Mansfield there is a margin of capacity available to cope with other possible future shocks such as a decline in the terms of trade or a disease outbreak.

It should be emphasised, however, that the combinations of adaptations shown in Figure 5 together imply major shifts in the management of livestock farms: a general increase in the intensity of inputs of fertilizer, widespread and long-term adoption of systematic livestock genetic improvement, and a significant increase in the proportion of perennial pastures in the landscape. The potential implementation difficulties associated with each of these changes are significant. For example, increasing soil fertility in mixed farming areas may require a shift in overall land use toward pastures in order to maintain or increase soil organic matter levels, and the widespread adoption of lucerne may be limited by soil constraints.

Nonetheless, our simulation results suggest that some of these adaptations we ahve examined – especially locally-specific genetic improvements and management for increased soil fertility – are likely to be widely cost-effective under current climate, i.e. they are "no-regret" adaptation options that can be advocated immediately.

Expanding the applicability of the GRAZPLAN models

CO_2 responses

Lilley *et al.* (2001) measured enhanced herbage production in the clover under elevated [CO_2], and reduced growth at warm temperature, while there were no treatment effects on herbage biomass in phalaris. The results of the simulations with GRAZPLAN were broadly consistent with these results. The model predicted growth of clover monocultures well for ambient and elevated CO_2 at field temperature (Figure 7), so supporting the CO_2 response functions in the GRAZPLAN model. However, the model over-predicted clover growth at higher temperatures. In the experiment, was no effect of CO_2 or warming on growth of phalaris in monoculture; the GRAZPLAN simulations produced the same result, predicting that the experimental plots were nitrogen-limited.

In contrast to the monoculture, herbage production of phalaris in mixture was enhanced by both elevated [CO_2] and temperature. GRAZPLAN simulations were similar in trend but smaller in magnitude than the observed data. Overall, the results of this test of the CO_2 response functions are promising; testing against further data sets is needed, however.

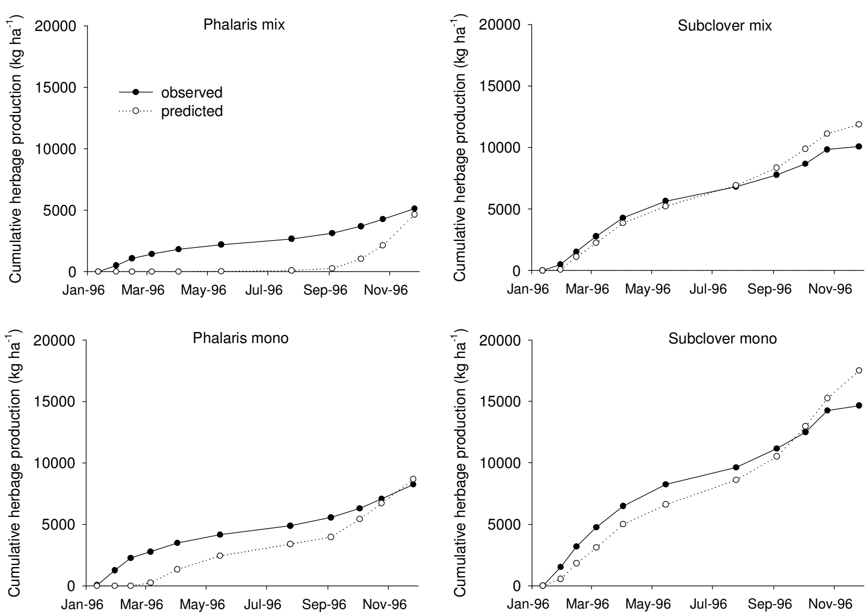
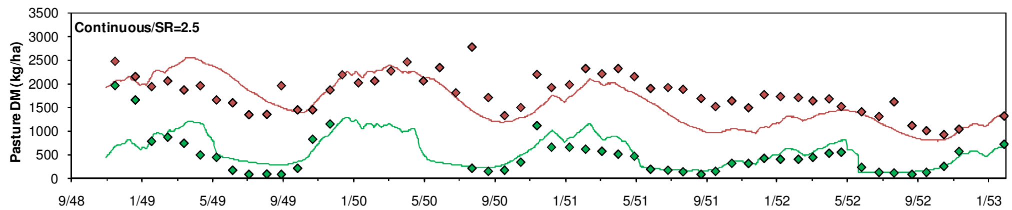


Figure 7. Observed cumulative herbage biomass (greater than 7 cm height) over time measured by Lilley *et al.* (2001) and predicted with GRAZPLAN between December 1995 and November 1996 in the elevated [CO_2] warm temperature treatment.

Figure 8. Simulation of an unfertilized redgrass-dominant pasture at Armidale, NSW stocked at 2.5 dry sheep/ha between October 1948 and October 1952. (a) Actual (symbols) and modelled (lines) green and total herbage mass, (b) actual (LHS) and modelled (RHS) botanical composition by weight at 12 measurement dates Note that the data set does not distinguish between grass species, so that the grey bars the proportion of grass (i.e. redgrass+*Austrodanthonia*).

(a)



Native grass pastures

The dynamics of herbage mass in the Armidale grazing experiment were quite successfully modelled (green mass: RMSD = 204 kg/ha; total mass: RMSD = 398 kg/ha), with the characteristic high ratio of dead to green *Bothriochloa* being successfully captured (Figure 8). The simulation of botanical composition was pleasing: the modelled pasture retained all four functional groups and the annuals correctly appeared as only small components of the pasture. There was, however, a systematic pattern of under-prediction of sheep weight change in spring each year.
Results of the validation simulations for the Barraba experiment were not as good as for the Armidale experiment; the general patterns of herbage availability were reproduced but the RMSD for pasture mass was 1066 kg/ha. The relationship between measured and modelled pasture masses did not depart significantly from the 1:1 line, however. Discrepancies in live weight change predictions showed similar month-to-month variation to the Armidale experiment.

The redgrass parameter set remains a work-in-progress. However it received a good level of acceptance from NSW Department of Primary Industries staff at a GrassGro training workshop in June 2011, and so a decision was taken to release it for use in *Southern Livestock Adaptation 2030*. It has since been used in NSW regional workshops and in the work presented in Appendices 7 and 8.

Introduced perennial C_4 grasses

Development of a kikuyu parameter set proceeded to a point where it be used to successfully simulate growth rates of cut kikuyu swards on the Central Coast of NSW, but performance of the new parameter set in mixtures at Albany was unsatisfactory. This parameter set was therefore not used in the main impacts and adaptation studies. Work to further improve the kikuyu parameter set will continue.

Discussion and Conclusions

Overall, this project has met its objectives and it has played a vital role in the undoubted success of the *Southern Livestock Adaptation 2030* RD&E program.

<u>Knowledge to underpin ongoing engagement about climate change adaptation</u>

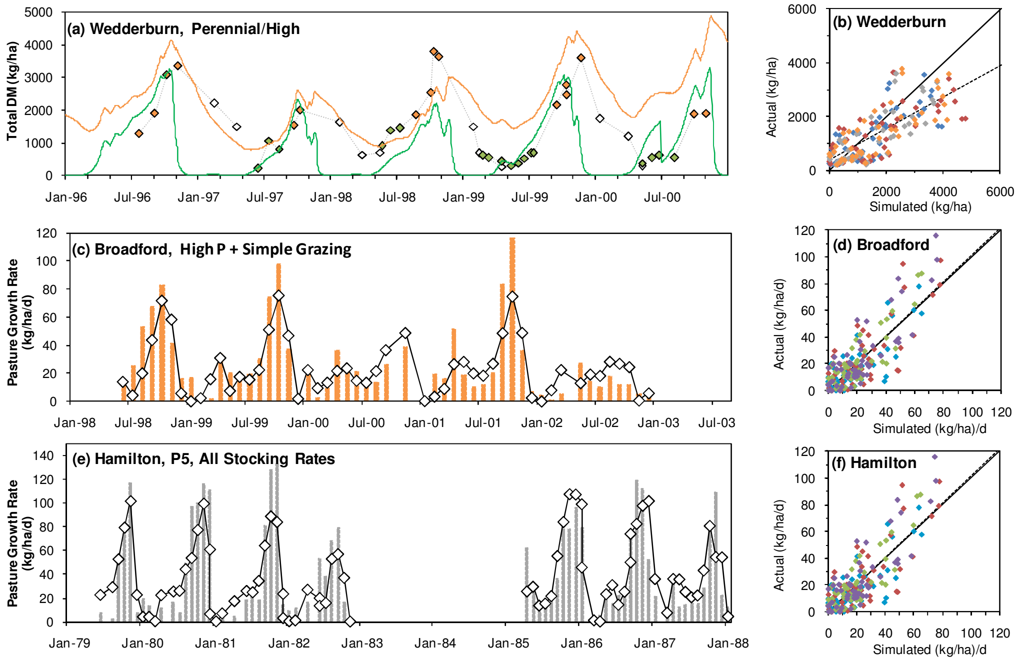
This project has carried out the first systematic analysis of the likely magnitude and rate of climate change impacts on the economic productivity of the southern Australian livestock industries. This work is ground-breaking: no other agricultural climate change study has simultaneously addressed the dimensions of geography, industry segment, time, natural resource management constraints and climate projection uncertainty while considering multiple adaptation strategies singly and in combination.

Despite the enormous complexity of our research question, a set of key messages emerges from the mass of modelling results:

- In the absence of adaptation, the magnitude of climate change impacts will be large; the potential exists for a significant decrease in the total value of livestock production.
- Based on the available projections, there is a real prospect of substantial impacts on pasture growth in the next twenty years.
- Declines in production and profitability can be expected to be significantly larger than declines in total pasture growth (which has been the focus of most previous research). This differential is caused by the need to leave herbage unconsumed to protect the soil resource, and is probably exacerbated by increased variability in future climates.
- Climate change impacts, and hence the need for adaptive responses, are greatest in the lower-rainfall parts of the cereal-livestock zone and tend to be less severe in the south-eastern parts of the high-rainfall zone.
- Taken across southern Australia, all broadacre livestock enterprises are likely to be strongly affected by projected future climates. It appears that impacts on beef breeding will be somewhat smaller in relative terms than the impacts on other enterprise types; these differences are unlikely to be large enough to make beef cattle more economically attractive than other enterprises, however.
- The uncertainty associated with these projected changes in livestock production is large – and is caused by uncertainty in rainfall projections – but the above trends are discernable nonetheless.
- A range of different adaptations, based on currently-available technologies, are potentially effective in ameliorating the impacts of projected climate changes. The most important of these are:
  - increasing soil fertility, so increasing the water use efficiency of pasture growth;
  - ongoing genetic improvement of livestock;
  - introduction or increased use of summer-active perennials (particularly lucerne);
  - in some locations, the use of confinement feeding to protect ground cover.
- No single adaptation will be completely effective adapting the broadacre livestock industries to climate change. In most situations, a combination of adaptive responses will be required.
- It is likely that in 2030, combinations of adaptations can be found to return most livestock production systems to profitability. By 2050 and 2070, on the other hand, our findings suggest that the lower-rainfall parts of the cereal-livestock zone will require either new technologies, a complete re-thinking of the feedbase or else sustained price increases in order for livestock production to remain viable.

Publication of these results in the scientific literature has been slower than intended. Owing to difficulties with recruitment and retention of staff (the latter a symptom of the demand for agricultural scientists with systems analysis skills), the postdoctoral fellowship in this project was filled for only 19 months of a planned 3 years. Dr Jenny Carter was brought into the project team to work on the CO_2 response studies & Mr Scott McDonald to provide technical assistance with the main impacts and adaptation study, but this response did not fully compensate for the gap in the postdoctoral fellowship. The main aspect of the project which suffered from the resulting under-

Figure 9. Selected results of validation simulations at three Victorian locations with the modified pasture parameter sets developed during the project (a, c, e) Time courses of pasture mass (Wedderburn) or pasture growth rate (Broadford and Hamilton) compared against measured data for one of the experimental treatments at each site. (b, d, f) Comparison of actual vs modelled pasture mass or growth rate across all modelled treatments in each experiment.



staffing was the publication of our findings. Publication will be pursued actively during the remainder of the project's life (to 30 June 2012) and beyond.

<u>Awareness of program results by livestock producers</u>

At the beginning of the project, provision was made for the CSIRO project team to participate actively in regional producer workshops, in order to provide readily-accessible scientific backup (and, to some extent, to lend credibility) to the workshop leaders. In the event, our interactions with the state-based project teams took a different form, in which we mostly provided "back office" support to the achievement of the producer awareness goals. The SA, WA, Tasmanian and Victorian project teams were predominantly composed of officers who were inexperienced GrassGro users. With each of these projects we undertook an initial period of training in the "art" of modelling, and of assistance in specifying "farm systems" for use in regional impacts and adaptation work. Once we had helped our state-based colleagues to develop confidence in the performance of GrassGro, however, they found that they did not need our backup when interacting with producers. As a result, the producer workshops that we did attend (especially in Tasmania and WA) were early in each state-based project's work program. The NSW project team was largely self-sustaining, and our interactions with them were of a more advisory nature (through participation in NSW project team meetings) or focussed on more narrowly technical issues such as the development of native grass parameter sets.

The process of establishing confidence in GrassGro was not without its challenges, and it is fair to say that we spent more effort in this area than originally envisaged. The most significant confidence issue we encountered - concern about GrassGro's predictions of patterns of pasture growth in Victoria – was well-founded, however.

The interaction resulted in revisions to the standard pasture model parameter sets that were both necessary and useful (Figure 7). This issue and its resolution provide an excellent example of the way in which the practical application of simulation models can lead to the improvement of their scientific rigour.

The provision of short, context-relevant reports via the Internet is a relatively new approach to producer communication. Our design work on the technical aspects of providing short reports via the Internet was successful in that it gave the program coordinator Steering Committee confidence in the feasibility of this communication channel and an appreciation of the features that a system for report provision would need. Implementation of the system of short reports was taken up as a program-level, rather than a project-level, responsibility.

The stakeholder conference was successful in its aim of engaging a policy and industry audience with the results of *Southern Livestock Adaptation 2030*, and of this project in particular.

<u>Definition of a program for on-farm trialling of key recommendations</u>

One of the objectives of *Southern Livestock Adaptation 2030* was to define a program of on-farm trialling of key recommendations within each of the agro-climatic regions of southern Australia for implementation after 2012. Responsibility for this objective was shared across the projects in the *Southern Livestock Adaptation 2030* program. It was overtaken by events in the final year of the program, in particular the introduction of the Australian Government's Carbon Farming Initiative (CFI). As a result of the CFI and its associated R&D calls, the focus of planning for new work following on from *Southern Livestock Adaptation 2030* shifted toward mitigation of climate change rather than adaptation to it. We played an active role in planning for the livestock sector's response to the CFI, through participation in two workshops organized by MLA; the preparation of a position paper on "adaptation of wool production systems" (the brief actually covered climate variability, climate change adaptation & mitigation) for a research forum held November 2011 as part of implementing the Primary Industries Standing Committee's Wool RD&E Strategy; and the submission of proposals to the *Filling the Research Gap* component of the CFI.

<u>Development of an improved modelling capacity across a range of industry RD&E providers</u>

A "modelling capacity" must be built up from scientific understanding expressed in mathematical models, the implementation of that understanding in usable software and the development of skilled people who can apply the models and software to RD&E activities.

The most important improvement to the scientific capacity of the GRAZPLAN models has been the improvements to the pasture parameter sets that underpin them. In particular, the addition of a C_4 native perennial grass parameter set removes a long-standing constraint to the use of these models in northern NSW.

While a few improvements were made to the GrassGro decision support tool in the course of the project (particularly the reporting of ground cover), the GRAZPLAN software proved to be largely adequate to the tasks required of it both in this project and in the *Southern Livestock Adaptation 2030* program more generally.

As a result, the most important "software" output from this project is the set of consistently-defined, representative models of grazing systems (GrassGro "farm systems"). The set of farm systems developed in this project complement those prepared for regionally-specific studies in our partner projects; they abstract away from local reality to some extent, but this makes them more comparable across locations and livestock sectors. As well as providing a useful starting point for future users of GrassGro, this set of farm systems has potential to be useful in taking geographic variation into account when analysing a wide range of different questions relating to livestock production.

The most significant steps toward a capacity to model southern Australian livestock systems, however, have been in the development of a network of skilled people. Not only have three post-doctoral scientists (2 CSIRO, one University of Melbourne) started to use the GRAZPLAN models in their research, but a network of development officers and extension staff across 5 states has learned to apply these models to practical questions. Importantly, the process of engagement between the CSIRO project team and this state-based network has enabled the latter to develop confidence in the GRAZPLAN models sufficient that they wish to continue using them (as indicated by a successful proposal to the DAFF *Action on the Ground* program by our South Australian partner). As with the set of representative grazing systems, this network of people represents an opportunity to address a range of different issues in a consistent way across Australia, as envisaged by the new PISC industry RD&E strategies.

Where to from here?

The most immediate next step for our project will be to further communicate project findings, and in particular to publish in the peer-reviewed scientific literature. This will be a focus of work in the period until the formal closure of the project in June 2012. We also plan to propose our work as for presentation to the 2012 International Grassland Congress to be held in Sydney.

A second priority needing consideration is how to maintain the momentum developed in the *Southern Livestock Adaptation 2030* program in developing a network of people who can carry out relevant systems analyses for the livestock industries. At the research end of the spectrum, the new DAFF *Filling the Research Gap* program will draw on the expertise developed in this project, but an opportunity needs to be sought to put the skills of the wider group of State-based staff to good use. This should be a priority in project development for the next round of *Filling the Research Gap* and *Action on the Ground* funding proposals.

Our project was part of a highly successful integration of researcher, industry extension and producer expertise, and it was also successful in forming and maintaining links across the boundaries of 5 states. We did not, however complete the integration trifecta by establishing strong working links with companion programs in the Climate Change Research Program addressing other agricultural industries – especially the northern livestock and cropping programs. An important task, therefore, will be to compare and contrast our findings with those from these companion programs, so as to more fully understand the potential consequences of climate change for patterns of land use across our continent.

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List of Appendices

The Appendices to this Final Report present the scientific results of project MBP.0073 in greater detail. They are provided as a separate document.

1. A review of prior work relating to adaptation of southern Australian livestock production to climate change
2. Natural selection in southern Australian pastures under climate change: a brief review
3. Effectiveness of a range of grazing system adaptations in ameliorating the impacts of shorter growing seasons
4. Will managing for climate variability also manage for climate change? A southern Australian grazing system as an example
5. Medium-term climatic variability and its effects on pasture and livestock production: consequences for projections of climate change impacts
6. Impacts of climate change to 2070 at eight locations across southern New South Wales: a preliminary analysis
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10. Improving and extending the parameter sets for the GRAZPLAN pasture model
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