Appendix 1. A review of prior work relating to adaptation of southern Australian livestock production to climate change

This short review is intended as a summary of investigations into the impacts of climate change on, and adaptation to climate change by the southern Australian livestock industries prior to the commencement of the Climate Change in Southern Australian Livestock Industries project in September 2009. The focus of this document will be on paddock- and farm-scale changes; the physiological aspects of plant and animal responses to likely climate changes have been reviewed elsewhere (e.g. Ainsworth & Long 2005, Soussana & Lüscher 2007, Marai *et al.* 2007, Moore *et al.* 2008).

<u>Review and overview articles</u>

There are a number of review articles addressing climate change impacts on the Australian livestock industries (Harle *et al.* 2007, Howden *et al.* 2008, Stokes *et al.* 2010, Miller *et al.* 2010). These papers are all high-level summaries that cover entire industries: they therefore contain little quantitative information about climate change impacts. As Stokes *et al.* (2010) put it, "a rigorous analysis of the regional variation in impacts of climate change on grazing lands still needs to be conducted".

These four reviews focus on livestock production in the pastoral zone, with a secondary focus on dairy production (mainly in the chapter by Miller *et al.* 2010). Much less attention is paid to meat and wool production in the high-rainfall and cereal-livestock zones. For example in the book chapter by Stokes *et al.* (2010) on broadacre grazing, over half the text is devoted to issues of specific relevance to rangelands even though only ~15% of the economic value of broadacre livestock production comes from the pastoral zone. This imbalance seems to reflect the history of research investment into studying climate change impacts and also the relative land area.

Pasture growth. The view of changes to pasture growth rates put forward in these reviews – at least to 2030 – is that impacts on broadacre pasture supply will be "noticeable, although not dramatic" (Harle *et al.* 2007) and will be mainly driven by rainfall changes, which are in turn uncertain given the current state of knowledge. As Miller *et al.* (2010) point out, if climate projections of reduced rainfall in southern Australia come to pass then availability of irrigation water will reduce.

Livestock production. All four reviews place greatest emphasis on the likelihood of increasing heat stress on beef cattle (as studied by Howden *et al.* 1999) and on increasing water requirements for stock (Howden & Turnpenny 1997). Both these issues are of especial relevance in the rangelands. Livestock water infrastructure in southern Australia is almost certain to meet any increased demand (supply of livestock water from dams is much more likely to act as a constraint). While the incidence of days of high temperature-humidity index will clearly increase in southern Australia, both cattle and sheep can adapt their behaviour – especially their times of grazing – and so reduce the effect of higher temperatures on their energy balance. The overall importance of heat stress in future southern Australian climates once behavioural adaptations and the annual cycle of energy supply are taken into account, and the relative importance of heat stress to cattle and sheep, are questions needing further examination.

Natural resource management. The main NRM issue raised in these reviews is the risk of increased soil erosion, based on projections of increased rainfall intensity and the possibility of more variable annual rainfall producing more frequent episodes of

Table A1.1. High-priority adaptation options for producer action proposed by Stokes *et al.* (2010) for the broadacre livestock industries and by Miller *et al.* (2010) for dairy production. A priority ranking of 1 is higher. In some cases similar actions on the two lists have been combined; a small number of non-specific statements have been omitted.

Climate change adaptation option	Priority ranking for:	
	Broadacre	Dairy
Use seasonal climate forecasting in decision-making	1	1
Provide extra shade	2	1
Select animal lines that are resilient to higher temperatures	2	2
Improved on-property water use efficiency of irrigation		1
Select drought-tolerant pasture cultivars		1
Fodder conservation and conserved fodder use strategies		1
Forward contracting supply of supplementary feedstock		1
Agist stock during unsuitable conditions		1
Progressive recalculation of safe stocking rates	1	
Improve on-property water management	2	
Greater use of strategic spelling	2	
Improve nutrient management using sown legumes and P fertilizer where appropriate	2	
Modify timing of mating, weaning and supplementation based on seasonal conditions	2	

low ground cover. This question is already receiving considerable attention in CCASALI.

Industry-level issues. Harle *et al.* (2007) devote attention to the possibility that industry production of wool under changing climate and technology will be driven by land use changes driven by differential changes in productivity of wool relative to other agricultural enterprises (cropping, beef and lamb production) even more than the changes in productivity within wool enterprises themselves. Heyhoe *et al.* (2007) assumed for the purposes of an economic analysis that wheat productivity would be more sensitive to rainfall changes than wool and beef productivity, although they did not report the basis of this assumption.

Adaptation options. Each of the four review articles provides a list of possible adaptation options. The book chapters by Stokes *et al.* (2010) and Miller *et al.* (2010) are the first to attempt to prioritize the wide range of adaptations that are possible for the broadacre and intensive livestock industries respectively (Table A1.1). The highest-priority common item is the idea of using seasonal climate forecasting (adapted to take climate trends into account) as a way of managing for climate change incrementally. The other common items relate to avoiding or tolerating the projected increases in heat stress. It is noticeable that the dairy priorities place more emphasis on managing the supply of feed than do the broadacre priorities; this most likely reflects the greater level of inputs into dairy production.

Experimental studies

Small-scale experiments. Roger Gifford & co-workers have carried out a series of experimental studies into the responses of temperate pastures to increased CO_2 and/or temperature in microcosms (Lutze & Gifford 1998a, 1998b, 2000) or temperature gradient tunnels (Lilley *et al.* 2001a, 2001b, Volder *et al.* 2004). These experiments involved very high atmospheric CO_2 treatments of 690-750 ppm and (in the tunnels) temperature increases of 3-4°C, and were carried out under conditions of continuously high water availability. Under these conditions the enhancement of total shoot growth by CO_2 alone was species-specific, ranging from 0-11% for phalaris (*Phalaris aquatica*) monocultures, 14-29% for *Danthonia racemosa* monocultures and 19% for subterranean clover (*Trifolium subterraneum*) monocultures. In a phalaris/clover mixture, however, biomass production of clover increased by 31% and that of phalaris by 40% in the mixture (Lilley *et al.* 2001a). Volder *et al.* (2004) found strongly seasonal responses to increased temperature and CO_2 in phalaris. These responses were generally reduced by warming; a 3.4° temperature increase reduced clover biomass production in monoculture by 28% at ambient CO_2 and by 9% at elevated CO_2, despite the low winter temperatures at the experimental location (Canberra).

The fact that these experiments were all continuously irrigated will have tended to reduce the relative response of biomass production to CO_2, as the "water-sparing" effects of stomatal closure at high CO_2 (e.g. Ferretti *et al.* 2003) would have had no scope to allow later onset of water stress. Lutze & Gifford (1998b) found clear evidence of this effect in their study.

The differing responses of phalaris growth to increased CO_2 in monoculture and in mixture in the experiment of Lilley *et al.* (2001a) suggest the existence of a nitrogen supply interaction. Lutze *et al*. (1998b), however, did not find a trend in the CO_2 fertilization effect across three sharply different levels of N supply to *D. racemosa* microcosms.

Free-air CO_2 enrichment (FACE) experiments. Two FACE experiments have been conducted in environments of direct relevance to southern Australia. Newton *et al.* (2006) report a FACE study on a diverse pasture (containing C_3 and C_4 grasses, legumes and forbs) in New Zealand, while Hovenden *et al.* (2008a, 2008b, 2008c) are carrying out a FACE experiment on a *Themeda triandra*-dominant but botanically diverse native pasture in Tasmania.

Newton *et al.* (2006) found no statistically significant difference in long-term pasture yield between FACE rings grown at ambient CO_2 and 475 ppm, but the measured difference (about 8%) is consistent with the experimental studies described above once the smaller size of the CO_2 treatment (475ppm) is taken into account. They did find an increase in photosynthetic rates under increased CO_2, but there was also an increase of allocation of carbon belowground. N content of individual species declined, but this was offset by an increase in the proportion of legumes in the pastures under increased CO_2. Newton *et al.* (2006) also found evidence that N and P became progressively less available over time under increased CO_2 in this long-term experiment – this phenomenon, termed "progressive nutrient depletion", has been observed by other workers (Luo *et al.* 2004).

Hovenden *et al.* (2008a) reported no increase in biomass production when a CO_2 concentration of 550 ppm and a 2.1°C warming were imposed on a native pasture. Little response to CO_2 would be expected in a plant community that is dominated by a C_4 grass with limited water stress but the lack of a temperature response is somewhat surprising. The site does appear to be nutrient-poor, however. They found some evidence for progressive nutrient depletion under enhanced CO_2, but the measured decreases in inorganic N availability were reversed when warming was also applied. Hovenden *et al.* (2008b) found marked changes in phenology, especially flowering date, in response to temperature increases (but not CO_2 increases), thereby confirming one of the main expected responses of pastures to increased temperature.

The interactions between CO_2, water and nutrient supply in pastures are clearly complex and need further teasing out. In particular, the likelihood of progressive nutrient limitation becoming a major factor in field situations under simultaneous CO_2, temperature and soil moisture changes needs to be evaluated.

Modelling studies

There have been three simulation modelling studies that bear on the issues being addressed by the CCASALI program: a continent-wide study of impacts on native pasture growth by McKeon *et al.* (2009), a multi-site study of impacts on improved pasture growth by Cullen *et al.* (2008, 2009) and a study of impacts and adaptation for pasture and livestock production in the Southern Tablelands of NSW (Moore *et al.* 2009). These three studies have used different simulation models, different time horizons and different approaches to the projection of future climates.

McKeon *et al.* (2009), building on an earlier study by Crimp *et al.* (2002), used the GRASP model to estimate the impacts of a suite of possible future climates on native pasture growth across Australia. McKeon *et al.* did not use projections of future climate from global circulation models, but instead applied various combinations of (a) an increase in atmospheric CO_2 to 650 ppm, (b) a temperature increase of 3°C and (c) rainfall changes of -30%, -10%, +10% and +20% that were applied uniformly across the continent. They estimated that the response of yearly pasture production to increased CO_2 at 650 ppm would be quite small in south-eastern Australia (0-10% over most of the HRZ and CLZ), with slightly higher (10-20%) response in the lower-rainfall parts of the southeastern CLZ and in south-western Australia. This low response was attributed by McKeon *et al.* (2009) to the low soil fertility that was assumed for the native pastures that were the subject of their analysis. The sensitivity of pasture production to rainfall changes was estimated to be roughly 1.5:1 over most of the continent, with the exception of south-eastern Australia where the assumed nutrient limitation reduced this sensitivity. A 3°C temperature increase was estimated to have a neutral or small positive effect on native pasture production in the south-eastern HRZ, a small negative effect (0-10%) over much of the CLZ and a stronger negative effect in the warmest parts of the CLZ (e.g. Eyre Peninsula).

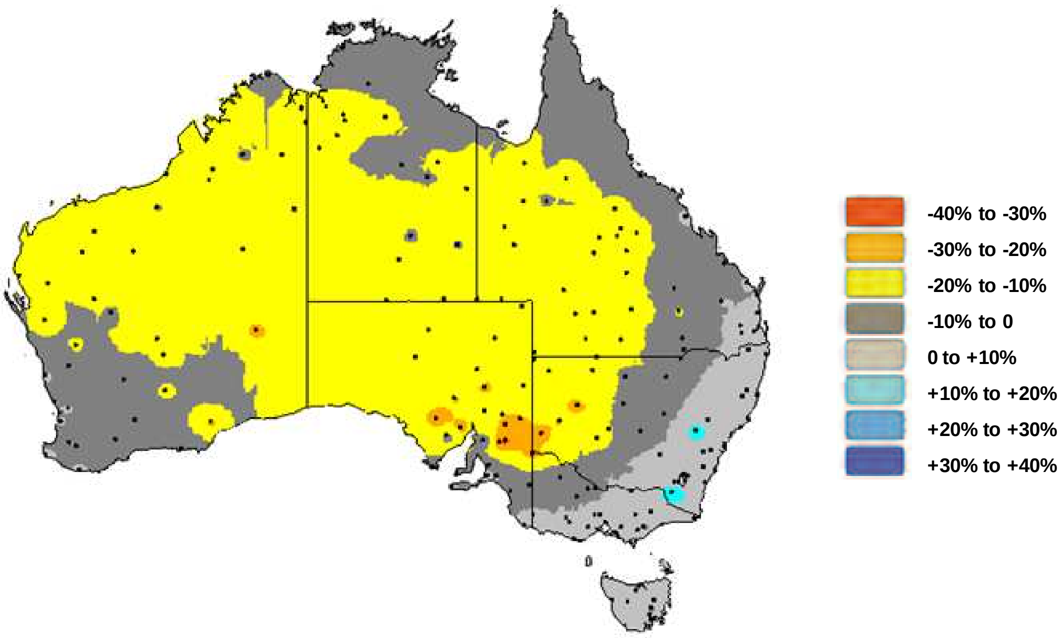

Figure A1.1. Relative changes in annual pasture shoot net primary productivity estimated by McKeon *et al.* (2009) using the GRASP simulation model for a future climate with 650 ppm atmospheric CO_2 concentration, a uniform temperature increase of 3°C and a uniform rainfall decrease of 10%.

A combination of 650 ppm CO_2, 3°C temperature increases and a 10% rainfall decrease (Figure A1.1) can be thought of as a plausible 2070 future in southern Australia. In this scenario, the CO_2 fertilization and rainfall effects roughly cancelled out across southern Australia, so that the overall productivity response was similar to the response to a 3°C temperature increase alone.

Cullen *et al.* (2008, 2009) used the SGS Pasture model to evaluate the impact on pasture growth rates of climate changes projected for a range of Australian locations in 2030 and 2070 by the CSIRO Mark 3.0 global circulation model (GCM) under 3 SRES emissions scenarios (B1, A1B and A1FI). The CSIRO Mark 3.0 GCM predicts modest rainfall changes to 2030 (-9% to +1% depending on location & emissions scenario) and Cullen *et al.* (2008) found correspondingly minor impacts on pasture production. For 2070, however, changes to pasture growth patterns were predicted to be larger. The nature of these changes varied from south to north. At Elliott in Tasmania, 2070 pasture growth was predicted to be higher than current levels despite significant reductions in annual rainfall. At Albany, Wagga Wagga, Terang, Hamilton and Ellinbank, Cullen *et al.* (2008) predicted higher winter and early spring growth rates but a shorter growing season in 2070. At Barraba in northern New South Wales, there was little rainfall change and the balance of pasture composition shifted in favour of C_4 grasses. In irrigation areas, the irrigation water requirement was estimated to increase by up to 10% in 2070, with the greatest increase in northern Victoria.

Cullen *et al.* (2009) also report a modelled CO_2 fertilization response of 24-29% at 550 ppm for C_3 grass-based pastures in southern Australia and 17% at 550 ppm for a mixed C_3/C_4 pasture at Barraba. This estimate of the CO_2 fertilization effect is much higher than that proposed by McKeon *et al.* (2009); the Barraba pasture is of the type considered by McKeon *et al*.

Moore *et al.* (2009) used the GRAZPLAN simulation models to examine impacts of climate change to 2030 on sheep and cattle production systems in the Southern Tablelands of NSW. They considered a much smaller geographic area than McKeon *et al.* (2009) or Cullen *et al.* (2008), but extended their analysis in three directions: (i) by considering the effects of pasture growth changes on the profitability and sustainability of livestock production, (ii) explicitly considering changes to stocking rate and mating date as adaptations to the climate changes, and (iii) attempting to take into account the uncertainty in projected future climates by employing projections from four GCMs. The CSIRO Mark 3.0 model used by Cullen *et al.* (2009) was not one of the four GCMs. Realistic livestock management systems for sheep and cattle were modelled at two locations within the region (Bookham and Goulburn) with differing weather and soils.

Moore *et al.* (2009) found that differences between emissions scenarios (SRES A1, A1B and B1) at 2030 were relatively small, in agreement with Cullen *et al.* (2008). Pasture growth rates in 2030 were projected to increase in winter by all four GCMs when management was held constant. Three of the four GCMs predicted decreases in both autumn and spring pasture growth rates, while one GCM (CCSM 3) predicted little change during these seasons (Figure A1.2). The climate projections from two GCMs implied higher annual pasture growth in 2030 and two lower growth. Overall, the pattern of higher winter growth and shorter growing seasons identified for many sites by Cullen *et al.* (2008) was also found by Moore *et al.* (2009). The key finding of this study, however, was that increased frequency of low ground cover meant that sustainable stocking rates fell – quite sharply for some GCM x emission scenario combinations. As a result, even after adaptation of joining dates, optimal stocking rates under 2030 climate were lower than currently-optimal practice. This was

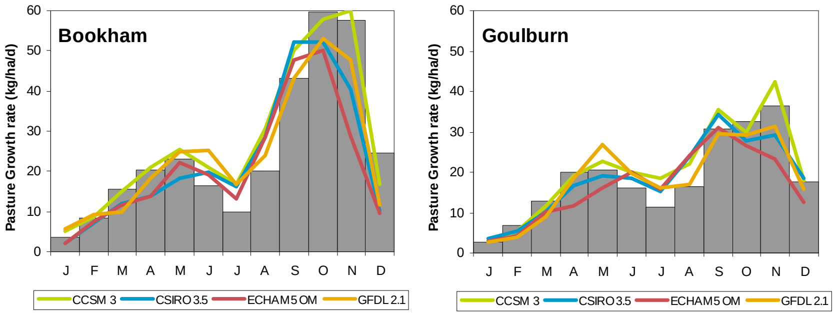

Figure A1.2. Long-term monthly average pasture growth rates projected by Moore *et al.* (2009) for Bookham and Goulburn, NSW, in 2030 for four global circulation models under the A2 emissions scenario. Grey bars show the 1971-2000 average monthly pasture growth rates for comparison.

somewhat compensated by higher weaning rates in sheep production systems, but nonetheless profitability in 2030 was much lower than the magnitude of the pasture growth changes might have suggested.

<u>Research questions arising from this review</u>

Impact of climate change on the livestock industries

- *Size of the CO2 fertilization effect.* The CO2 fertilization effect estimated for southern Australian pastures by the various studies reviewed above ranges from small (<10% at 650 ppm as modelled by McKeon *et al.* 2009) to sizeable (34% at 690 ppm as measured by Lilley *et al.* 2001a). Neither of these studies was intended to reflect the majority of southern Australian pastures. Obtaining a better understanding of the CO_2 fertilization effect – and especially the way it varies with climate and nutrient supply – is a research topic that would repay investigation. As part of such an analysis, it would be important to test the ability of our simulation models to capture the dynamics of the chamber and FACE experiments reviewed in section 3.
- *The possibility of evolutionary response by pastures to changing climate.* Common pasture species such as *Lolium rigidum* show considerable genetic variation in phenology (McLean & Watson 1992) and it may be that natural selection from changing climate will act as an "automatic stabiliser" on pasture productivity. It should be possible to explore at least some aspects of this issue (e.g. the size of the selective pressure) with existing models.
- *Impact of changed climate on livestock water supply.* Livestock water was a significant management issue for some producers during dry years in 2002-08. It may be possible to infer some useful information about likely changes to the water balance of livestock dams – and hence the risk of extended periods of low livestock water availability – from the results of climate change simulations carried out for other purposes.
- *Heat stress.* Moore *et al.* (2008) concluded that "given the size of the projected rise in ambient temperature and the slow rate at which it is expected to increase, it seems likely that adaptation in selected sheep will keep pace with this rise for many years to come". Nonetheless there is scope to use existing models of heat exchange (Turnpenny *et al.* 2000) to evaluate the relative susceptibility of sheep and cattle to heat stress and to check the adequacy of the heat stress equations used in the GRAZPLAN ruminant model.

- *Uncertainty in projections induced by uncertain regional climate projections.* CCASALI clearly cannot rely on the projections of a single GCM. Dealing with the question of how to project impacts while taking the climate projections of different GCMs into account is an active topic of discussion amongst the Australian climate science community. The CCASALI project team should be active participants in this discussion, not least because we are at the front line in communicating with producers in the face of this difficulty.

Adaptations of the livestock industries to climate change

- *Management systems that cope better with shorter, more intense growing seasons.* Identifying such systems is probably the main priority for CCASALI as a whole.
- *The profit-sustainability "feasible space" and how it alters under climate change.* Mokany *et al.* (2010) have described a method for delineating a management space (in their case, combinations of stocking rate and maintenance fertilizer application rate) within which economic and environmental sustainability is likely. Shifts in the boundary of this "feasible space" due to climate, technological or economic changes can show whether broad management strategies such as low-input-low-output are put at risk of becoming unviable.
- *Differential changes in profitability of agricultural enterprises.* The review by Harle *et al.* (2007) raised this issue but the qualitative approach they employed will not assist long-term planning. The need identified by CCASALI for analysing this issue – after taking adaptation of enterprises as well as impacts on them into account – remains.
- *Seasonal forecasts as a means to gradual adaptation.* This idea was quite enthusiastically proposed by both Stokes *et al.* (2010) and Miller *et al.* (2010). CCASALI could evaluate this concept, by comparing the profitability and sustainability of a forecast-responsive producer (under changing and variable climate) to that of one who manages to the long-term trend only. Care would need to be taken to properly cost the prices and costs encountered by a producer who regularly changed stocking rate.
- *The role of C_4 grasses.* A shortening of the main pasture growing season in south-eastern Australia, as suggested by both Cullen *et al.* (2009) and Moore *et al.* (2009), implies a lengthening of the intervening dry seasons, making summer-growing species a riskier proposition. At the same time, however, increasing temperatures should increase the relative attractiveness of C_4 perennial grasses. How will this tradeoff play out in different environments, and will it be better to grow C_4 grasses separately or in mixture with C_3 competitors?
- *The potential value of selecting animals with greater resilience to high temperatures.* This was raised as an option by both Stokes *et al.* (2010) and Miller *et al.* (2010); if heat stress impacts on existing breeds can be better quantified, then the value of selection should be fairly straightforward to estimate taking into account potential tradeoffs in production.

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