Comparative analysis of climate change adaptation options across the southern Australian livestock industry

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Abstract. Climate change is predicted to have a substantial negative effect on the productivity of grasslands across southern Australia (Moore and Ghahramani 2013). We used the GRAZPLAN biophysical simulation models to assess several possible grassland management and animal genetic improvement adaptations under SRES A2 climate change scenario. Simulations spanned the five dimensions of geography, time, global circulation models, enterprise, and adaptations. Impact of climate change was predicted to reduce profitability of livestock industry by 46%, 58%, and 72% at 2030, 2050 and 2070, respectively. Increasing soil fertility could return the average profitability of five livestock enterprises to its historical level at 54%, 50%, and 25% of locations in 2030, 2050, and 2070. Increasing the proportion of Lucerne in pasture was effective for 35%, 22%, and 15% of locations in 2030, 2050, and 2070. Increasing fleece growth rates was the most effective genetic adaptation that could return profitability of sheep enterprises to its historical level for 24%, 52%, and 28% of locations in 2030, 2050, and 2070. Removing annual legumes in an attempt to preserve ground cover by replacing annual grass and larger sire body size were less effective options. The incremental adaptations we examined could significantly increase profitability of the enterprises at 2030. However, at many locations in drier regions it appears unlikely that a single adaptation can return profit to the historical level. In most of the high rainfall zone, systemic adaptation using a combination of grassland management and animal genetic improvement could return livestock systems to historical profitability in 2030 and 2050.

Keywords: Climate change, systemic adaptation, modelling, livestock, agricultural system.

Introduction

Climate changes caused by anthropogenic increases in greenhouse gases such as CO_2 will affect southern Australia along with the rest of the globe (Moore and Ghahramani 2013). In addition to declines in pasture production, the other predicted challenges for the broadacre grazing industries under climate change are decreases in forage quality, drought (Howden *et al.* 2007) and a greater risk of soil erosion and degradation due to decline in ground cover. Reduced productivity of improved pastures of southern Australia will lead to a decrease in the stocking rates that can be sustained owing to increased risk of low ground cover. Dryland pastures supporting extensive beef, sheep meat and wool production occupy a third of southern Australia's farming zone. These livestock production systems are highly sensitive to climatic variation, because they depend almost entirely on pasture for forage. Given the diversity of current climates, soils and pastures that are found across southern Australia, and the spatial variation in projected climate changes (CSIRO 2007), it can also be expected that the impacts of changing climates on pasture production will differ across space. In this study, therefore, we used the GRAZPLAN simulation models of grasslands (Moore *et al.* 1997) and livestock production to examine the potential adaptations to livestock production systems to enhance the profitability and sustainability of livestock production across southern Australia under projected future climates. Our research area includes diverse environments in which climates and pasture species are found with analogues in many temperate parts of the world, *e.g.* New Zealand, South America, South Africa and southern Europe.

Methods

The GRAZPLAN grassland simulation models (Moore *et al.* 1997) were used to model the responses to changed climate and atmospheric CO_2 concentration of temperate pastures at 25 representative locations across southern Australia (Moore and Ghahramani 2013). Grassland-livestock interactions were simulated as a biophysical system including climate inputs, soil moisture, plant growth, plant response to CO_2 concentration, pasture management, ruminant feed intake, nutrition, and reproduction.

At each location, one or more representative soils and grassland types were modelled as being grazed by each of 5 livestock enterprises (Merino and crossbred ewe, wether, beef cattle, and steer). Statistical Areas Level 2 within study area (SA2s, Australian Bureau of Statistics 2011) were classified into a set of 25 regions with approximately equal gross value of agricultural production (GVAP; Australian Bureau of Statistics 2008, 2012a, 2012b). SA2s were grouped according to their average annual rainfall and land use (*i.e.* the proportions of GVAP attributable to cropping, sheep and cattle production).

Climate projections for 2030, 2050 and 2070 derived from the Coupled Model Intercomparison Project (CMIP3) global climate models (GCM; CCSM3, ECHAM5/MPI-OM, GFDL-CM2.1 and UKMO-HadGEM1) were downscaled to daily weather sequences by modified algorithm of Zhang (2007) and used as an input to simulations. Each grazing system was therefore simulated under historical climate (1970-99, 350 ppm CO_2) and a range of projected climates (451, 532 and 635 ppm CO_2 at 2030, 2050 and 2070). For each location x livestock enterprise x climate combination, stocking rates were varied an optimal sustainable stocking rate (OSSR). The OSSR was determined to maximise operating profit while keeping the frequency of days with ground cover <0.7 below location-specific thresholds in order to protect from water erosion risk. Grassland management adaptation options to reduce periods of low ground cover and animal genetic improvement adaptations based on historical genetic improvements (Gregory *et al.* 1997; Safari *et al.* 2007; Jeyaruban *et al.* 2009), were determined in order to increase the efficiency of forage consumption. The following adaptation options were evaluated and adjusted to minimize the frequency of days with ground cover of less than 0.7: (1) higher soil fertility (Ghahramani and Moore 2012); (2) confinement feeding in poor years; (3) increasing the proportion of lucerne to pasture in response to a predicted shift to a more summer dominant rainfall scenario under climate change; (4) increased animal body size; (5) higher conception rate; and (6) increased potential fleece weight.

A factorial simulation experiment was conducted in which the factors were climate scenario (1 + 4 climate models x 3 CO_2 concentrations), location (25), livestock enterprise (5), and adaptation option (6, some of which included multiple levels). For each combination, a range of stocking rates was modelled and physical and financial outputs from the grazing system were stored from each simulation run. For each year of each simulation, an operating profit, *OP* ($/ha) was calculated as following:

$$OP=INCOME-(COST_{var}+COST_{fert}+COST_{stock}+COST_{operator}) \qquad (1)$$

where *INCOME* is the total income ($/ha) from meat and wool of the enterprise; $COST_{var}$ is the variable costs ($/ha) of the enterprise, including costs of animal husbandry, supplementary feed, shearing, purchase and sale of livestock (including rams or bulls) and sale of wool; $COST_{fert}$ is the cost ($/ha) of the P fertilizer required to maintain soil nutrient status, $COST_{stock}$ is the marginal capital cost of livestock ($/ha), and $COST_{operator}$ is an operator allowance (the equivalent cost of the farmer's labour). For operating profit, relative effectiveness was calculated as:

$$RE_P = (OP_A-OP_N)/(OP_H-OP_N) \qquad (2)$$

where OP_A denotes long-term average operating profit under a projected climate when an adaptation has been implemented, OP_N is operating profit under that climate without any adaptation, and OP_H is operating profit during the historical period (1970-1999). In circumstances where $P_N \geq P_H$, the relative effectiveness cannot be calculated.

Results

Average annual rainfall differed widely among the four GCM projections. The GFDL-CM2.1 model showed the largest decrease of annual rainfall across the study area (10%, 11%, and 24% in 2030, 2050, and 2070 respectively) while 0%, 1% and 3% increases were projected by CCSM3 for 2030, 2050 and 2070. Annual mean temperature increase was similar under all examined GCMs and the mean projected temperature increase averaged across the study area and all GCMs was 1.0°C, 1.5°C, and 2.4°C in 2030, 2050 and 2070. Average annual rainfall was predicted to vary widely among GCMs. Declines in annual rainfall increased over time. Winter rainfall decreased continuously from 2030 to 2070. Climate change impacts on annual net primary productivity (ANPP) varied widely among GCMs; the average declines from historical climate were 9% in 2030, 7% in 2050 and 14% in 2070. Declines in ANPP were larger at lower-rainfall locations. Western Australian locations tended to have larger decreases in estimated ANPP (*e.g.* at Lake Grace, the average decrease in ANPP estimated for 2070 by the four GCMs was 50%) whereas Launceston (Tasmania) was predicted to have an increase in ANPP. In the absence of adaptations, modelled operating profits at OSSR (averaged over the GCMs) decreased steadily from the historical climate to 2070 at all locations except Launceston. Operating profit (at constant prices) fell by an average of 27% in 2030, 32% in 2050 and 48% in 2070. Profit declines were most marked at drier locations, with operating losses expected at 9 of the 25 locations by 2070. Differences between livestock enterprises were smaller than differences between locations and dates.

Among adaptations, only the increased soil fertility, via phosphorus addition, significantly increased ANPP. This option increased ANPP by 12.8% in 2030, 12.7% in 2050, and 13.3% in 207. The effect of the adaptations on long-term average annual income and operating profit differed widely among enterprises, locations, GCMs, and over time. Overall, higher soil fertility was the adaptation that produced the greatest increase in annual income and operating profit. This adaptation was the most effective means to reverse the decline in profitability in the majority of high rainfall regions. Increased soil fertility could return profitability of enterprise (averaged across all five enterprises) relative to the baseline historical period (1970-1999) to 54%, 50% and 25% of locations in 2030, 2050, and 2070. Increasing the proportion of lucerne in a pasture was effective at 35%, 22% and 15% of locations in 2030, 2050 and 2070. Confinement feeding could substantially increase long-term average annual income, but was not effective in term of profitability. The effectiveness of all the simulated

Table 1: Relative effectiveness of adaptations in recovering the impact of climate change on profitability of *Merino ewe* enterprises at 4 locations (where 0.0 = no benefit; 1.0 = a return to the historical period, >1 benefit higher than reference period). Note that values don't represent spatial dominance of adaptations: F, Increased soil fertility (best of multi-trophic levels); L, Increased proportion of lucerne in pasture (best of multi-trophic levels of 20% and 40% level); B, increased body size; FW, increased potential fleece weight; HC; higher conception rate, 2×= synergies of the most profitable grassland management and the most profitable genetic improvement. Values are averages over 4 GCMs.

	F	F	L	L	B	B	FW	FW	HC	HC	Best 2×	Best 2×
Location	2030	2050	2030	2050	2030	2050	2030	2050	2030	2050	2030	2050
Colac	0.5	4.9	1.1	4.9	0.4	5.6	0.7	12.5	0.2	1.7	1.7	18.4
Goulburn	6.5	11.1	0.6	0.6	0.7	2.0	1.4	5.4	0.3	0.8	6.7	16.2
Bakers Hill	1.1	0.8	0.3	0.1	0.6	0.6	0.9	1.2	0.3	0.4	2.2	2.2
Kyancutta	0.4	0.0	0.4	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.5	0.2

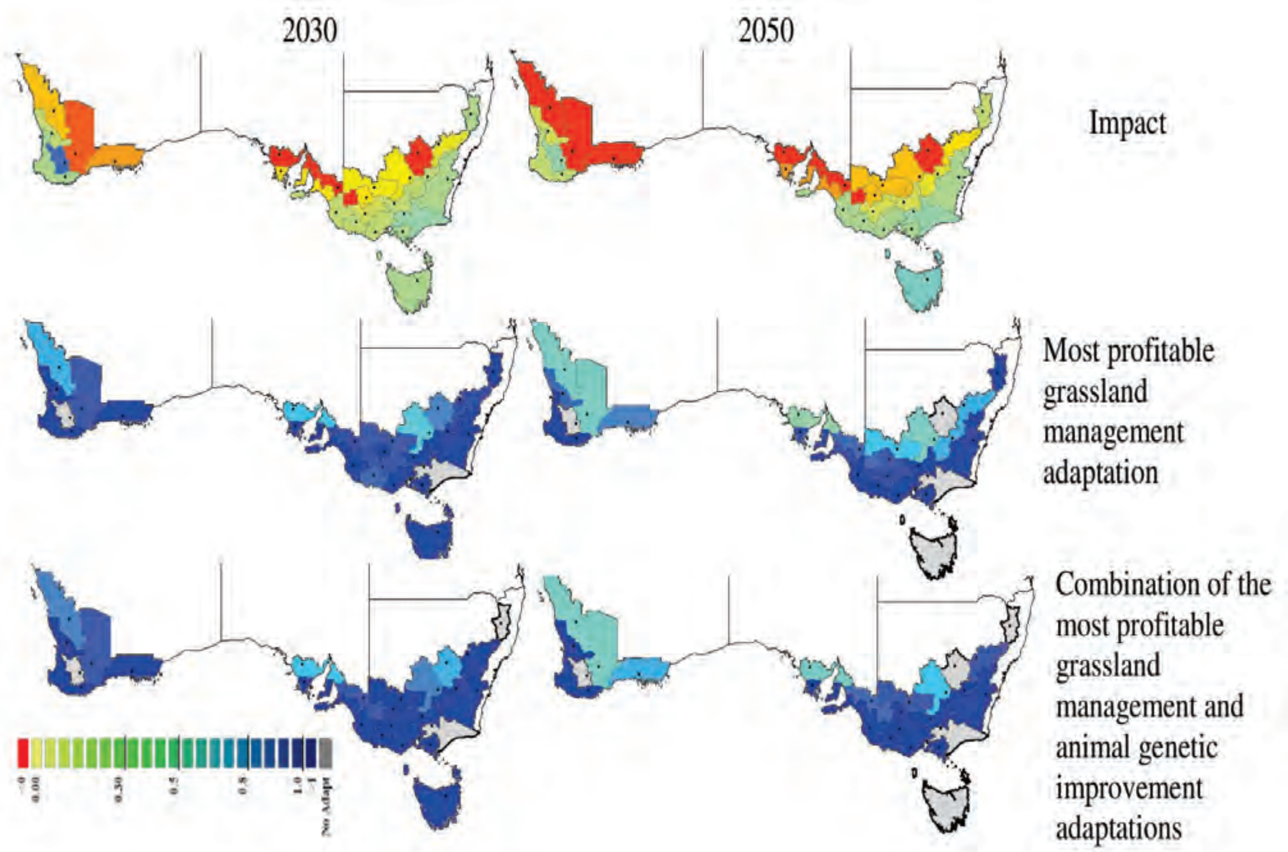

Figure 1. Synergic effectiveness of combining the most profitable grassland management and the most profitable genetic improvement in *Merino ewe* enterprises. (0.0 = no benefit; 1.0 = a return equivalent to the historical period, >1 benefit higher than reference period). Adaptations were applied whether or not they increased profit at the sustainable optimum stocking rate. Values are averages over 4 GCMs. Regions shown in gray pattern were estimated to have higher operating profit under climate change than historical period without adaptation (in legend, presented as No adapt).

options except lucerne decreased over time from 2030 to 2070.

The grassland management adaptations that we examined can be implemented relatively quickly and provide a short-term output. In contrast, animal genetic improvement has been assumed to take place gradually over time. The greatest effect of animal genetic improvement is predicted for 2050; after this year animal genetic improvement effectiveness estimated to decrease because of predicted severe climatic conditions. Increasing fleece growth rates was the most effective genetic adaptation at 24%, 52%, and 28% of locations in 2030, 2050, and 2070. Increased body size was the second most effective option and was predicted to return profitability of livestock industries (averaged among all enterprises) to that of the reference period at 21% of locations in 2030, 0.46% of locations in 2050, and 021% of locations in 2070. The most profitable option varied over time at a given location due to site's specific climate change impacts over time. In 2030, examined single incremental adaptations could significantly increase profitability of the enterprises over a majority of the high rainfall zone. At many locations in drier regions it appears to be unlikely that a single adaptation can return profit to the historical level. As shown in Figure 1, in Merino ewe enterprises, synergistic effect of systemic adaptation by combination of grassland management and animal genetic improvement could return livestock systems to the historical profitability in 2030 and 2050, but mainly in the high rainfall zone. Effectiveness of systemic adaptation by combining grassland management and animal genetic improvement is presented for 4 selected locations in Table 1. Synergies of the systemic adaptation by combing the individual options would increase profitability;

Conclusion

For the majority of southern Australia, it appears unlikely that a single adaptation can return farm profitability back to historical levels. For the majority of high rainfall zone, systemic adaptations using a combination of grassland management and animal genetic improvement may return livestock systems to historical profitability in 2030 and 2050. However, drier regions would need more systemic adaptations or transformational options. Applying more systemic adaptations could result in higher profitability than the historical baseline period.

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