Appendix 8. Adaptations to climate change across southern Australia in 2030, 2050 and 2070

Introduction

Previous modelling studies indicate that expected climate changes are likely to reduce the productivity of improved pastures at a number of locations in southern Australia (Appendix 1; Cullen et al. 2009), and that the stocking rates that can be sustained will decrease disproportionately owing to increased risk of low ground cover (Alcock et al. 2010). Simulation results in the current project (Appendix 7) have demonstrated that major declines in pasture and livestock production will be widespread across southern Australia under the climates projected by a number of GCMs. Management for improved ground cover and more efficient conversion of pasture growth into production are therefore likely to be required in order for southern Australian livestock producers to adapt to climate change.

In this study we investigate the potential for a range of management and genetic changes, singly and in combination, to enhance the profitability and sustainability of livestock production across southern Australia under projected future climates at 2030, 2050 and 2070. The GRAZPLAN modelling tools have been applied to evaluate potential effectiveness of adaptation strategies under future projected climate (under the SRES A2 scenario) on pasture and livestock production of 25 representative farms across Southern Australia carrying 5 different grazing enterprises.

Methods

Selection of adaptation options for analysis

A wide variety of livestock adaptation options have been suggested for sustainable pasture and livestock production, such as alterations to rotation of pastures; grazing times; timing of reproduction; forage and animal genetics; integration within mixed livestock/crop systems including using adapted forage crops; reassessing fertilizer applications; and supplementary feeding (Daepp et al. 2001, Adger et al. 2003, Batima et al. 2005, Howden et al. 2007). We have selected candidate adaptations based on their likely fit with future rainfall patterns (e.g. a greater proportion of rainfall during summer) and their capacity to either reduce the frequency of low ground cover or else to increase livestock conversion efficiency.

The options that we have examined are shown in Table A8.1.

- Increasing soil nutrient levels will increase plant growth and so should improve

Table A8.1. 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	

ground cover levels.

- Legume residues have weaker structure compared to grass species and so degrade more rapidly over summer; a shift in pasture composition toward legume dominance under climate change can therefore be expected to make soil erosion risk greater unless stocking rates are reduced to compensate. Managing pastures for lower legume content might therefore allow higher stocking rates in future climates, at the cost of reduced production per animal.
- Introducing summer-active pastures such as lucerne to the feedbase, or increasing the proportion of lucerne where it is already used, is potentially an attractive option because rainfall is expected to shift toward the summer season in future decades. There is also good evidence that increased atmospheric CO_2 concentrations are likely to favour legumes over grasses in temperate pastures (e.g. Clark *et al.* 1997).
- “Confinement feeding”, i.e. placing animals in a feedlot during summer and autumn when pasture mass is low, has been considered as an adaptation scenario to conserve ground cover.

A number of possible adaptations through improved livestock genetics were examined, on the premise that using animals with lower maintenance requirement or higher feed conversion efficiency would mitigate the consequences of a lower amount of consumable pasture growth. The options that we considered were:

- Increasing animal size. Maintenance energy requirements vary with the 0.75 power of body weight while intake increases roughly linearly. Larger animals should therefore use a smaller proportion of the energy in consumed forage for maintenance, leaving more energy for growth, wool production or reproduction. This genotypic attribute of an animal breed is represented in the GRAZPLAN ruminant model as the “standard reference weight” of a breed, i.e. the weight of a mature, empty female in average body condition.
- Increase in wool production at constant body size. This adaptation option implies a redirection of animals’ energy and protein intake toward wool production. It is represented in the model as the ratio of the “potential fleece weight” to the standard reference weight.
- Increased reproduction rate. Overall reproduction (marking) rate is the product of fertility (proportion of females falling pregnant), fecundity (number of offspring conceive per pregnant female) and the survival rates of foetuses and of newborn lambs or calves. In southern Australian livestock systems, the great majority of ewes and cows conceive each year and survival from conception to birth and of newborn calves is also high; the greatest scope for genetic improvement therefore lies in fecundity and in perinatal survival in sheep. We have focussed on fecundity as an adaptation option, as it would apply to both sheep and cattle enterprises. Most of any reproductive rate increase in both sheep and cattle will have to appear as an increase in the proportion of twins or triplets.
- Increase in sire body size relative to dam size. This option is limited to enterprises where terminal sires are used. It result in larger offspring and should increase the overall energetic efficiency of the system. However the usefulness of this change is limited by the risk of dystokia; if the foetus becomes too large, birth becomes difficult and the death rate of lambs or calves increases.

A key difference between genetic adaptations and the feedbase and livestock management adaptations is that the former need to be implemented slowly over time. In the other words, we needed to consider gradual improvement of genetic over time, using rates of progress that should be achievable given our knowledge of rates of genetic improvement during the last 20-30 years.

Modelling analyses

The GRAZPLAN grassland and animal simulation models (Moore *et al.* 1997, Freer *et al*.1997; www.csiro.au/grazplan), were applied as implemented in the GrassGro decision support tool (Moore *et al.* 1997), in order to simulate the potential effects of adaptations under future projected climate on pasture and livestock production. The models simulate four effects of increased CO_2 concentration: a direct CO_2 fertilization effect, reduced transpiration due to partial stomatal closure, decreased specific leaf area, and decreased leaf nitrogen content. A range of effects of changes in soil moisture and temperature are also covered by the models.

The same set of 25 locations was used as for the impacts study described in Appendix 7; details can be found in Appendix 11. At each location, 5 grazing enterprises (self-replacing Merino ewes, crossbred ewes, self-replacing Angus beef cattle, Angus steers and Merino wethers) were modelled. 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 (livestock replacement, the timing of the reproductive cycle, the sale of young stock and thresholds for supplementary feeding) were described separately for each enterprise x location combination. A “historical” scenario was simulated over the years 1970-1999 as a reference period. Climates projected by 4 GCMs (CCSM3, ECHAM5/MPI-OM, GFDL-CM2.1 and HadGEM1) under the SRES A2 scenario at 2030, 2050 and 2070 were downscaled into daily weather data sequences using a technique adapted from that of Zhang (2007). CO_2 concentrations of 350 p.p.m for historical climate and 451, 532 and 635 p.p.m at 2030, 2050 and 2070 were assumed. A factorial simulation experiment was conducted in which the factors were climate scenario and date (1 + 4 x 3 levels), location (25), livestock enterprise (5), adaptation strategy and stocking rate.

For each combination, a range of 9-15 stocking rates was modelled. Physical and financial outputs from the grazing system were stored from each simulation run. A long-term rate of operating profit/income was calculated as the gross margin less overhead costs, an operator allowance and a further adjustment for the capital cost of the livestock required at each stocking rate with a 7% interest rate. An optimal sustainable stocking rate was selected as that which gave highest profit while keeping the frequency of low ground cover (cover < 0.70) below a location-specific threshold; all results are reported at this stocking rate.

Otherwise, the climate change adaptations described above were incorporated into the GRAZPLAN models as follows:

Higher soil fertility	The “fertility scalar” in each modelled paddock was increased to reflect an overall increase in soil fertility. The initial values of the fertility scalar varied from location to location in line with local practice; fertility scalars were increased by 0.1 units (on a 0-1 scale) up to a maximum of 0.95. At some locations, a further increase in fertility scalars (usually in low-fertility native pastures) was also examined.
Management to remove annual legumes	The pasture in each modelled paddock was modified to remove either all annual legumes other than lucerne (including white clover at Ellinbank) or else all legumes including lucerne.
Sowing a portion of land to lucerne	Either 20% or 40% of land from the most-productive soil class was separated into an extra paddock that contained a

pastures	pure lucerne pasture. Where the pastures at a location already included a lucerne component (for example at Wellington), this new lucerne paddock was in addition to the existing lucerne. Rooting depths of the lucerne pasture were set to be somewhat deeper than that of grasses.
Increased breed standard reference weight (SRW)	The breed standard reference weight and (where relevant) the potential fleece weight and sire standard reference weight were adjusted upward to reflect increases of 0.5% per year starting in 2010, i.e. a 10% increase in 2030, a 20% increase in 2050 and a 30% increase in 2070. As in the impacts study, the same genotype was used for each enterprise x date at all locations.
Increased wool production at constant SRW	The potential fleece weight of sheep breed was adjusted upward to reflect increases of 0.5% per year starting in 2010. The same genotype was used for each enterprise x date at all locations.
Increased sire SRW	This adaptation was only applied to the crossbred ewe enterprise, as the other breeding enterprises assumed self-replacing flocks and herds in which sire and dam genotypes were the same. The standard reference weight of rams was adjusted upward to reflect increases of 0.5% per year starting in 2010. The same genotype was used for each date at all locations.
Increased conception rate	The underlying genetic parameters governing conception rate in the GRAZPLAN model were adjusted so as to give conception rates (averaged across locations) that increased by 0.005 lambs/ewe/year in the Merino ewe enterprise, 0.0075 lambs/ewe/year in the crossbred ewe enterprise and 0.0025 calves/cow/year in the beef cow enterprise. These parameters were then applied at each location, in combination with system-specific mating dates, to derive reference conception rates for each location x enterprise x date.
Confinement feeding in summers with low pasture mass	A supplementary feeding rule was introduced to each grazing system in which all livestock were removed from pastures and fed a maintenance ration in a feedlot whenever total pasture mass fell below either 2000, 1500 or 1000 kg/ha. Animals were returned to grazing when total green herbage mass exceeded 500 kg/ha. All three threshold biomasses for livestock removal were trialled for each location x enterprise x date combination.

Adaptations were evaluated in terms of their “relative effectiveness”, computed as:

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

By examining the effectiveness of adaptations in terms of income rather than profit, we are taking an “industry” view of adaptation; a “producer” view would focus more on profitability.

Combinations of adaptation strategies were also examined, because a single option may not be able to recover all declines in productivity of the pasture and livestock system. 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. A small set of combinations of adaptations was modelled for every location x enterprise x date; these combinations were selected to concentrate on adaptations with high relative effectiveness in recovering the impact of climate change on the total value of livestock production across southern Australia. In addition, a single "locally-relevant" combination of adaptations was selected for each location x enterprise combination by (i) computing the average relative effectiveness of each adaptation option over the years 2030, 2050 and 2070, (ii) selecting higher fertility if its average relative effectiveness was positive, (iii) adding the genetic adaptation with highest average relative effectiveness if this was positive, and (iv) adding the most effective of the remaining 3 adaptations if it also had a positive average relative effectiveness.

Results

Single climate change adaptations at 2030, 2050 and 2070

Significant increases in operating profit were estimated under the higher fertility adaptation strategy relative to with no adaptation at most of the 25 locations, with the result that its overall relative effectiveness was high (Table A8.2). Adding lucerne to the feedbase (generally at 40% of land area) had the second largest effect overall (Table A8.2), with increased conception rate in third place. The "zero legume" adaptation, on the other hand, was estimated to have little positive effect. This suggests that even under future climates, the higher nutritive value of legumes outweighs the disadvantage of more rapid ground cover loss. The results for this adaptation varied widely between locations, GCMs and future dates, however; for example, legume removal was estimated to have a relative effectiveness of 0.80 at Cummins in 2030. Adaptations that increased meat production had a larger overall relative effectiveness than increasing wool production at constant body size; this result is consistent with the current relative values of wool and meat production in southern Australia.

The relative effectiveness of the feedbase-related adaptations and of confinement feeding decreased over time from 2030 to 2070 (Table A8.1). For the genetic adaptations, there was a tendency for relative effectiveness to increase from 2030 to 2050 and then to stabilize between 2050 and 2070.

Figures A8.1 to A8.3 expand on Table A8.1 by showing the range of relative changes in income ($/ha) of the different adaptation options across the 25 locations, for each combination of enterprise and date. Again, higher soil fertility had the highest positive

Table A8.2. 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 location x enterprise combinations where they increased profit at the sustainable optimum stocking rate. Values are averages over 4 GCMs and value-weighted averages over 25 locations and 5 livestock enterprises.

	2030	2050	2070
Higher soil fertility	0.62	0.67	0.44
Add lucerne to the feedbase	0.45	0.50	0.41
Increased conception rate	0.15	0.32	0.31
Increased livestock size	0.11	0.27	0.28
Confinement feeding	0.22	0.26	0.18
Increased ram size	0.07	0.16	0.16
Increased fleece weight	0.03	0.06	0.05
No annual legumes	0.01	0.01	0.01

Figure A8 1. Boxplots showing the relative change of income/ha at the optimal sustainable stocking rate from the historical baseline at 2030 for five livestock enterprises, for grazing systems in which a range of climate change adaptation options have been implemented. Each boxplot shows the distribution of income changes across 25 locations, after averaging over the climates predicted by 4 GCMs. Unlike Table A8.1, this figure shows the results of each adaptation when it is implemented, regardless of whether or not it is effective in recovering profitability. A value of 0 means that average income/ha is the same as for the historical period. N.A = no adaptation, F = increased soil fertility, C.F.1000 = 1000kg/ha confinement feeding, C.F.1500 = 1500kg/ha confinement feeding, C.F.2000 = 2000kg/ha confinement feeding, Z.L = Zero legume, L.20% = 20% lucerne, L.40% = 40% lucerne, I.B.S = increased body size, H.C.R = higher conception rate, I.P.F.W = increased potential fleece weight, S.R.W = increased standard reference weight

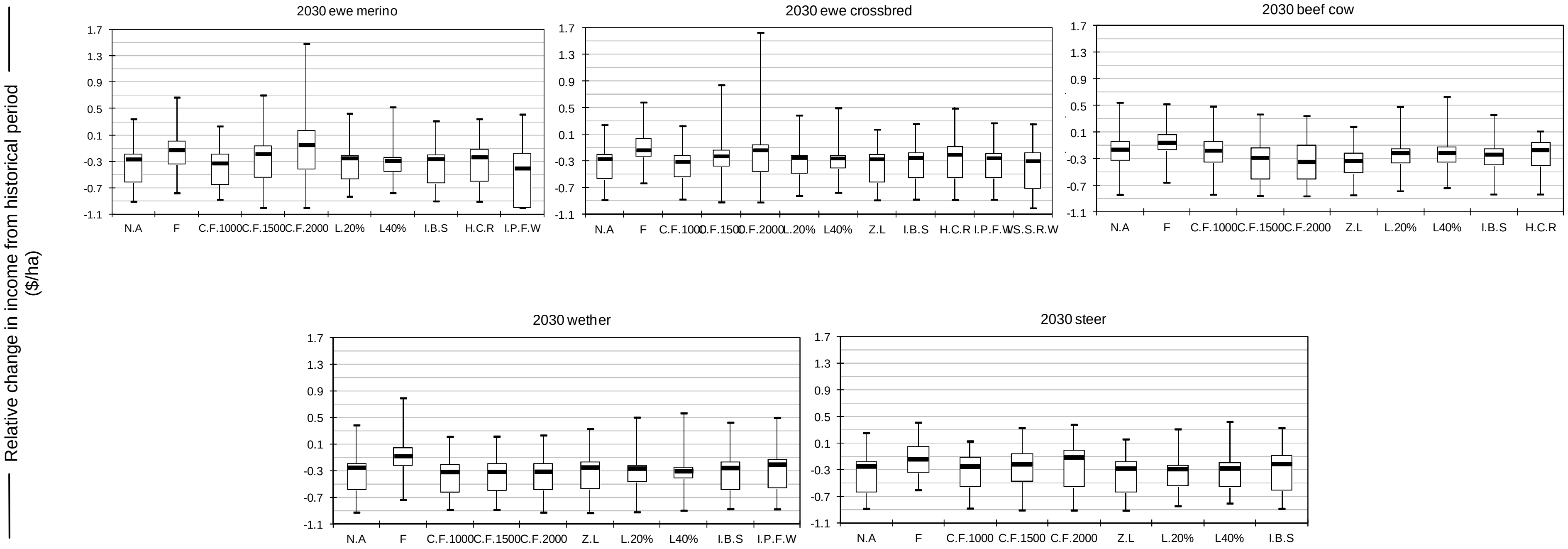


Figure A8 2. Boxplots showing the relative change of income/ha at the optimal sustainable stocking rate from the historical baseline at 2050 for five livestock enterprises, for grazing systems in which a range of climate change adaptation options have been implemented. Each boxplot shows the distribution of income changes across 25 locations, after averaging over the climates predicted by 4 GCMs. Presentation is as in Figure A8.2.

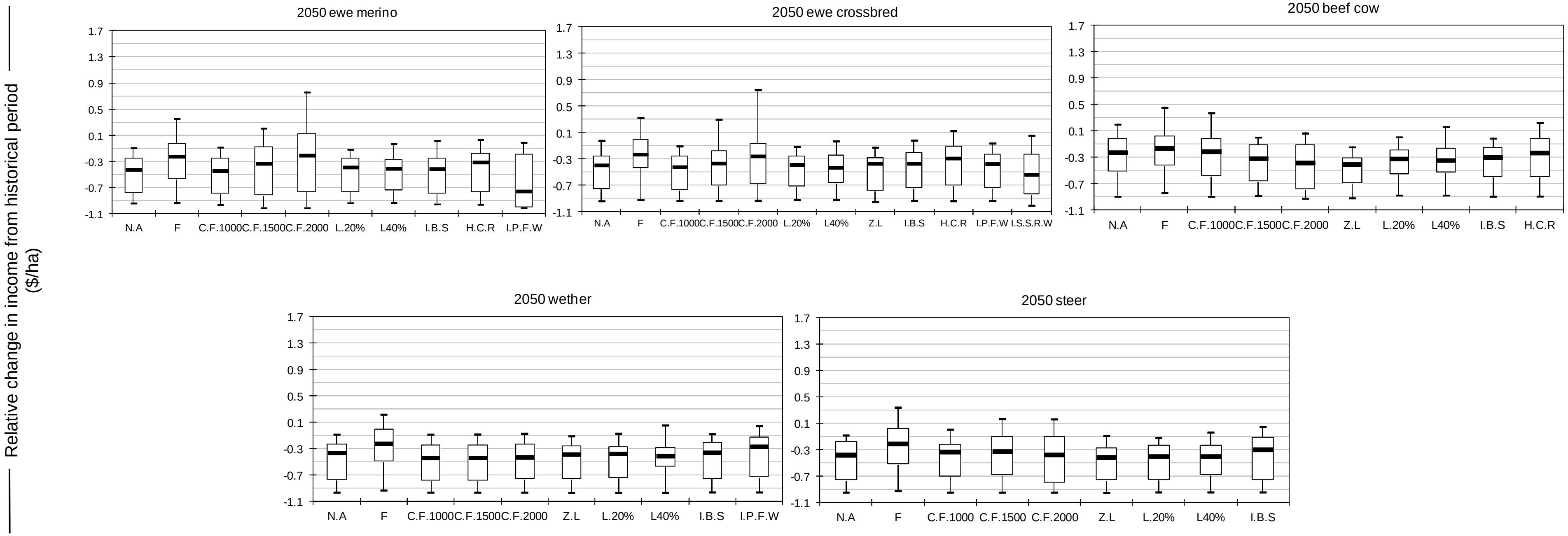
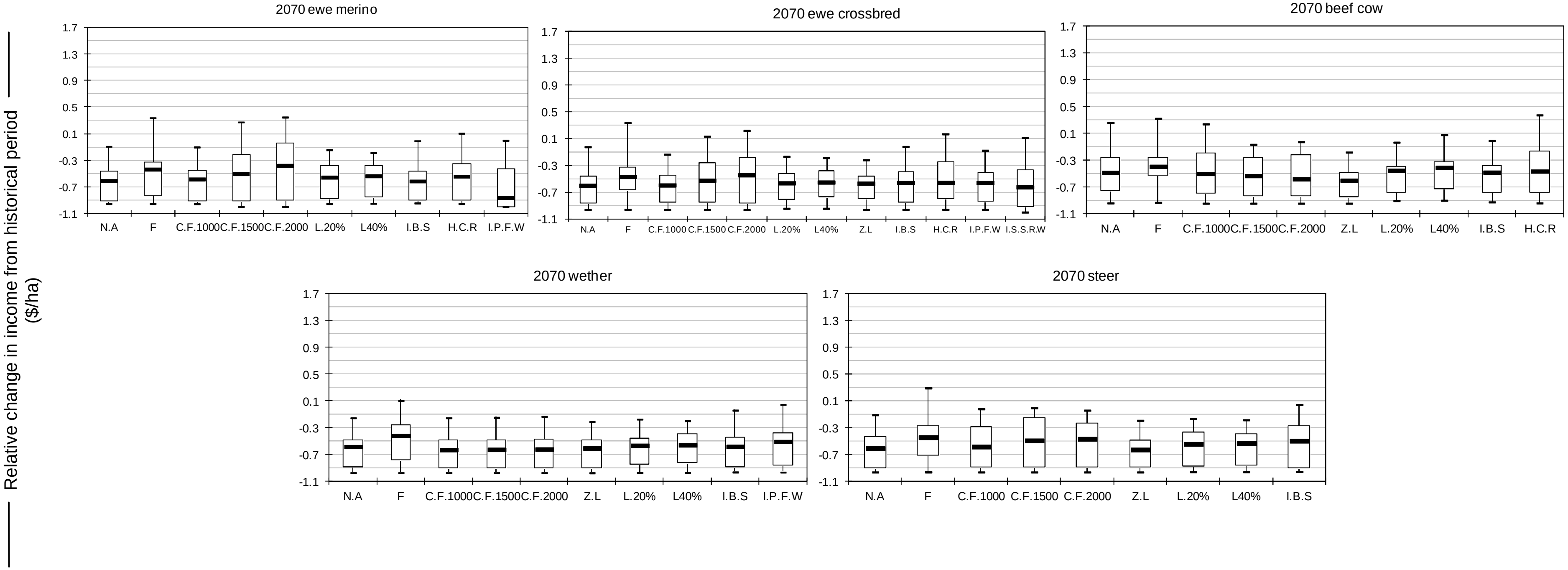


Figure A8.3. Boxplots showing the relative change of income/ha at the optimal sustainable stocking rate from the historical baseline at 2070 for five livestock enterprises, for grazing systems in which a range of climate change adaptation options have been implemented. Each boxplot shows the distribution of income changes across 25 locations, after averaging over the climates predicted by 4 GCMs. Presentation is as in Figure A8.2.

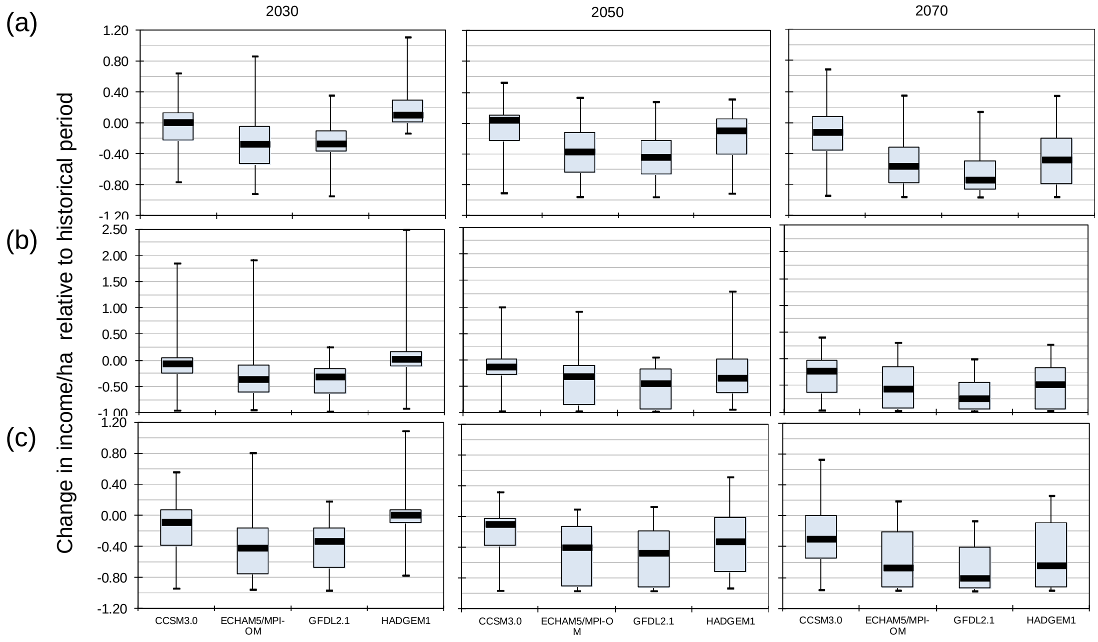


effect in recovering climate-change-induced declines in income. Under average of all GCMs, the smallest variation and consequently the smallest uncertainty of income recovered by fertility was modelled for beef cow enterprises at 2030. Confinement feeding with a threshold for confinement of 2000 kg/ha introduced greater variability between locations, particularly for the two ewe enterprises, but this variation decreased at 2070. The standard deviation across locations of the relative change in income increased from 2030 to 2050 and then deceased at 2070 in the no adaptation case, and this pattern was also followed when the following adaptations were implemented: adding 20% of lucerne to the feedbase, increased body size, increased ram size, increased fleece weight, and confinement feeding with a 1000 kg/ha threshold. For the higher conception rate adaptation, the standard deviation between locations increased sharply from 2030 to 2070, indicating that the effectiveness of this adaptation was diverging over time across locations. The pattern of response was the same but smaller for higher soil fertility. The standard deviation between locations of change in income decreased from 2030 to 2070 for three of the adaptation options (zero legume, adding 40% of lucerne to the feedbase and confinement feeding with a 1000 kg/ha threshold), indicating that the effectiveness of this adaptation was converging over time across locations.

Effectiveness of adaptations: uncertainty under different GCMs

Adaptation effectiveness differed widely among GCMs, presenting a challenge to our ability to estimate climate change impact and adaptation capacities. However, as shown in Figure A8.4 for changes in income in ewe crossbred enterprises, the differences between locations within a specific GCM are much greater than the differences in average response between GCMs. Overall the rank order of the impact of climate change projected by different GCMs was little altered by implementing single GCMs: income was reduced most under climates projected by GFDL2.1, then ECHAM5/MPI-OM and HadGEM1 with the smallest impacts estimated for climates projected by CCSM3.0. The exception was HADGEM1: its relative ranking changed from 2030 to 2070 as the climate conditions it projected became increasingly severe (Figure A8.4).

Figure A8.4. Variation of relative income change ($/ha) for ewe crossbred enterprises across Southern Australia under four GCMs at 2030, 2050 and 2070 after implementation of three climate change adaptation options Each boxplot shows the distribution of income changes across 25 locations. (a) higher soil fertility, (b) confinement feeding (2000 kg/ha threshold, note different scale), (c) higher conception rate.



Relative effectiveness of single adaptations over locations and time

Table A8.3 and Figure A8.5 show that when averaged over the four GCMs, in ewe crossbred enterprises, higher soil fertility and increased conception rate had the highest calculated relative effectiveness in areas with high rainfall; adding lucerne to the feedbase had the highest relative effectiveness in areas with lower rainfall. Increasing body size or fleece weight, were, in general, effective in drier areas. Locations where confinement feeding or increased ram size were effective were scattered across Southern Australia (Figure A8.5). Increased ram size was most effective at Launceston and its positive effect increased over time. Removing annual legume had the lowest overall effectiveness and was only effective at a few locations. (Figure A8.5). It should be noted, however, that the values shown in Table A8.3 and Figure A8.5 are averages over four GCMs; the effectiveness of adaptation options differed between GCMs (Figure A8.4).

Table A8.3. Relative effectiveness of a range of different potential adaptations in recovering the impact of climate change on the total value of livestock production at 25 locations across southern Australia (0.0 = no benefit; 1.0 = a return to the 1970-99 baseline value of production). For this table, adaptations were applied whether or not they increased profit at the sustainable optimum stocking rate. Values are averages over 4 GCMs. Where different levels of an adaptation were trialled, the best option has been selected for each location.

	Higher soil fertility			Increased conception rate			Add lucerne to the feedbase			Increased body size		
	2030	2050	2070	2030	2030	2050	2070	2050	2070	2030	2050	2070
Western Australia												
Dalwallinu	0.26	0.12	0.00	0.05	0.04	0.02	0.01	0.04	0.00	0.16	0.06	-0.01
Bakers Hill	0.73	0.37	0.17	0.45	0.16	0.12	0.07	0.38	0.15	0.49	0.46	0.27
Lake Grace	0.29	0.01	0.01	0.00	0.00	0.03	0.04	0.01	0.02	0.34	0.01	0.00
Katanning	-1.35	1.63	0.30	-0.99	-0.06	0.25	0.04	0.59	-0.01	-5.53	4.45	0.78
Esperance	0.35	0.07	0.00	0.22	0.01	0.02	0.00	0.00	0.00	0.19	0.07	0.00
Mount Barker	0.33	0.10	0.12	0.58	0.21	0.14	0.12	0.51	0.33	1.58	0.93	0.66
South Australia												
Kyancutta	0.29	0.00	0.00	0.00	0.01	0.01	0.01	0.00	0.00	0.04	-0.01	-0.01
Cummins	0.93	0.56	0.43	0.38	0.04	0.03	0.02	0.17	0.07	0.44	0.21	0.06
Lucindale	1.16	1.01	0.44	1.20	0.11	0.12	0.13	1.37	0.75	1.48	1.57	0.81
Lameroo	0.71	0.69	0.28	0.02	0.01	0.01	0.01	0.00	0.00	0.07	0.01	0.00
Victoria												
Birchip	0.72	0.58	0.34	0.13	0.03	0.01	-0.01	0.07	0.01	0.20	0.10	0.00
Colac	0.27	0.26	0.14	0.31	0.10	0.24	0.15	0.56	0.37	1.15	1.12	0.64
Stawell	0.40	0.42	0.22	0.17	0.03	0.06	0.07	0.27	0.07	0.64	0.55	0.26
Swan Hill	1.04	0.61	0.11	0.54	-0.01	0.02	0.03	0.08	-0.01	-0.09	-0.04	-0.02
Tatura	0.57	0.52	0.28	0.27	0.09	0.12	0.01	0.42	0.25	0.61	0.57	0.22
Mansfield	2.38	2.83	1.66	1.26	0.39	0.72	0.42	1.82	0.90	0.69	0.23	0.45
Hamilton	0.40	0.33	0.12	0.38	0.13	0.21	0.13	0.55	0.40	0.73	0.89	0.39
New South Wales												
Armidale	-8.29	20.02	13.59	-0.54	3.08	0.38	0.20	8.52	6.51	7.05	10.67	-8.53
Condobolin	0.43	0.10	0.40	0.05	0.01	0.01	0.01	0.00	0.00	-0.01	0.00	0.00
Cootamundra	0.75	0.40	0.25	-0.06	0.09	0.06	0.07	0.02	-0.01	0.53	0.34	0.15
Goulburn	1.43	1.20	0.73	0.51	0.14	0.20	0.32	0.54	0.57	0.46	0.48	0.31
Narrandera	0.40	0.23	0.14	0.07	0.03	0.03	0.03	0.12	0.02	0.33	0.19	0.03
Wellington	0.52	0.24	0.23	0.28	0.05	0.03	0.06	0.09	0.13	0.19	0.06	0.08
Tasmania												
Launceston	1.59	2.73	1.92	0.72	0.18	0.47	0.48	1.90	2.17	1.27	2.28	2.52

Table A8.3 *continued*

	Confinement feeding			Increased ram size			Increased fleece weight			No annual legumes		
	2030	2050	2070	2030	2050	2070	2030	2050	2070	2030	2050	2070
Western Australia												
Dalwallinu	0.11	0.05	0.00	0.01	0.01	0.00	0.02	0.01	0.00	-0.07	-0.04	0.00
Bakers Hill	-0.03	-0.02	0.02	-3.87	-1.86	-0.77	0.08	0.08	0.06	0.07	-0.01	0.04
Lake Grace	0.44	0.06	0.04	-0.02	0.02	0.02	0.03	0.01	0.02	-0.18	-0.01	-0.01
Katanning	-1.01	0.88	0.32	-0.05	0.24	-0.01	-0.10	0.19	0.08	0.27	-0.28	-0.04
Esperance	0.53	0.28	0.13	0.01	0.02	0.00	0.01	0.00	0.00	-0.02	-0.01	0.00
Mount Barker	0.52	0.36	0.29	0.43	0.41	0.39	0.09	0.07	0.00	-0.06	-0.03	0.07
South Australia												
Kyancutta	0.12	0.02	0.01	0.00	0.01	0.01	0.00	0.00	0.01	0.00	0.00	0.00
Cummins	0.38	0.12	0.12	0.01	-0.01	0.01	0.06	0.02	0.02	0.55	0.24	0.14
Lucindale	0.22	0.16	0.16	0.46	0.69	0.43	0.07	0.09	0.11	-0.31	-0.28	-0.17
Lameroo	0.11	0.27	0.01	0.00	0.00	0.00	0.01	0.00	0.00	-0.13	-0.01	-0.01
Victoria												
Birchip	-0.02	0.08	-0.02	-0.14	0.08	0.01	0.01	0.01	-0.02	-0.09	-0.04	-0.02
Colac	0.19	0.15	0.04	0.03	0.10	0.05	0.05	0.16	0.12	0.11	0.08	0.05
Stawell	-0.07	-0.07	0.00	0.09	0.17	0.04	0.04	0.09	0.07	0.07	0.01	-0.01
Swan Hill	0.31	0.20	0.07	0.29	-0.01	-0.05	0.08	0.04	0.00	-0.15	-0.10	-0.02
Tatura	0.10	0.06	0.03	0.30	0.35	0.15	0.05	0.05	0.06	0.02	0.06	-0.01
Mansfield	-0.52	-0.45	-0.10	0.91	1.51	0.56	0.33	0.40	0.37	-0.18	-0.12	-0.21
Hamilton	0.01	0.03	0.10	0.05	0.10	0.06	0.08	0.15	0.06	0.08	0.01	0.04
New South Wales												
Armidale	9.76	-13.25	-11.00	40.44	-56.57	-36.84	5.67	-4.85	-4.13	9.97	-15.25	-11.14
Condobolin	0.12	0.00	0.08	0.00	0.00	0.01	0.00	0.00	0.01	0.02	-0.01	-0.01
Cootamundra	0.13	0.12	0.16	0.04	0.01	0.04	0.07	0.03	0.04	0.05	0.03	0.02
Goulburn	-0.08	-0.06	-0.01	0.06	0.06	0.13	0.11	0.11	0.22	-0.05	-0.05	-0.09
Narrandera	0.02	0.09	0.08	0.04	0.08	0.00	0.04	0.02	0.03	-0.07	0.04	0.01
Wellington	0.27	0.16	0.17	0.24	0.05	0.05	0.04	0.04	0.04	0.65	0.46	0.50
Tasmania												
Launceston	-0.38	-0.56	-0.21	0.59	1.64	1.80	0.10	0.39	0.43	0.00	-0.52	-0.57

Figure A8.5. Relative effectiveness of single adaptations in recovering the impact of climate change on total income from crossbred ewe production at 25 locations across southern Australia (0.0 = no benefit; 1.0 = a return to the 1970-99 baseline value of production). Adaptations were applied whether or not they increased profit at the sustainable optimum stocking rate. Values are averages over 4 GCMs. Where different levels of an adaptation were trialled, the best option has been selected for each location.

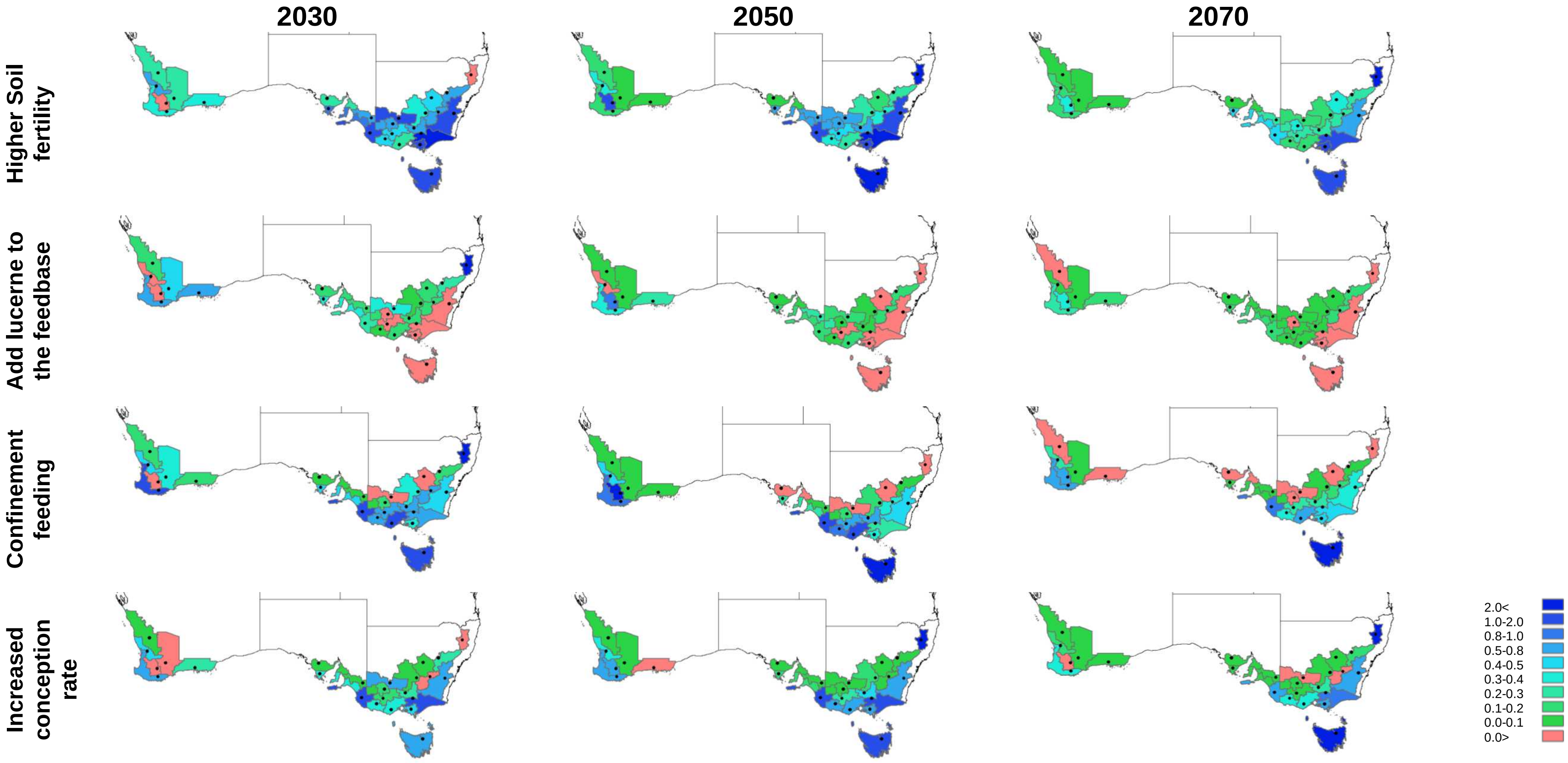


Figure 8.5 *continued*

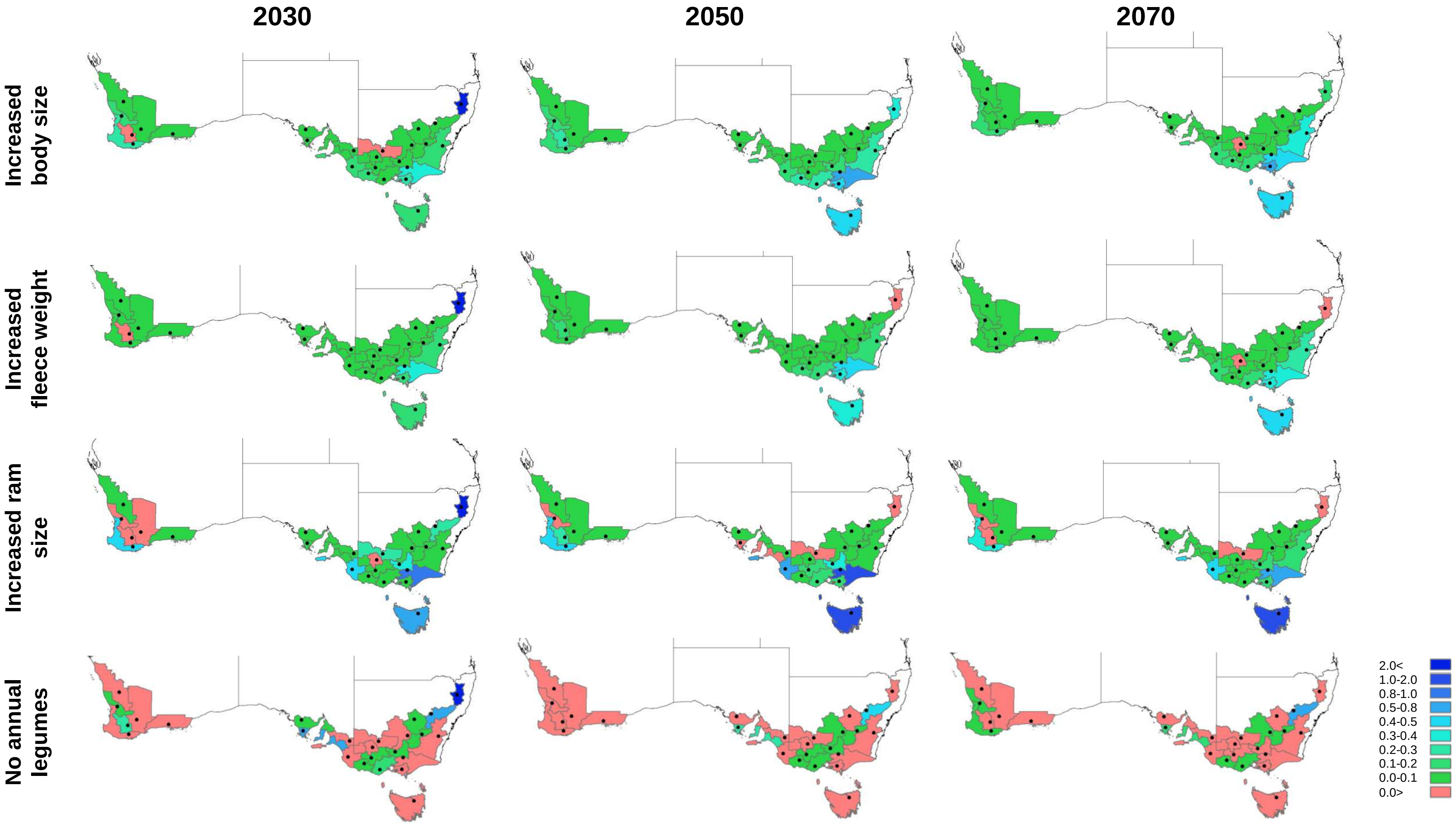
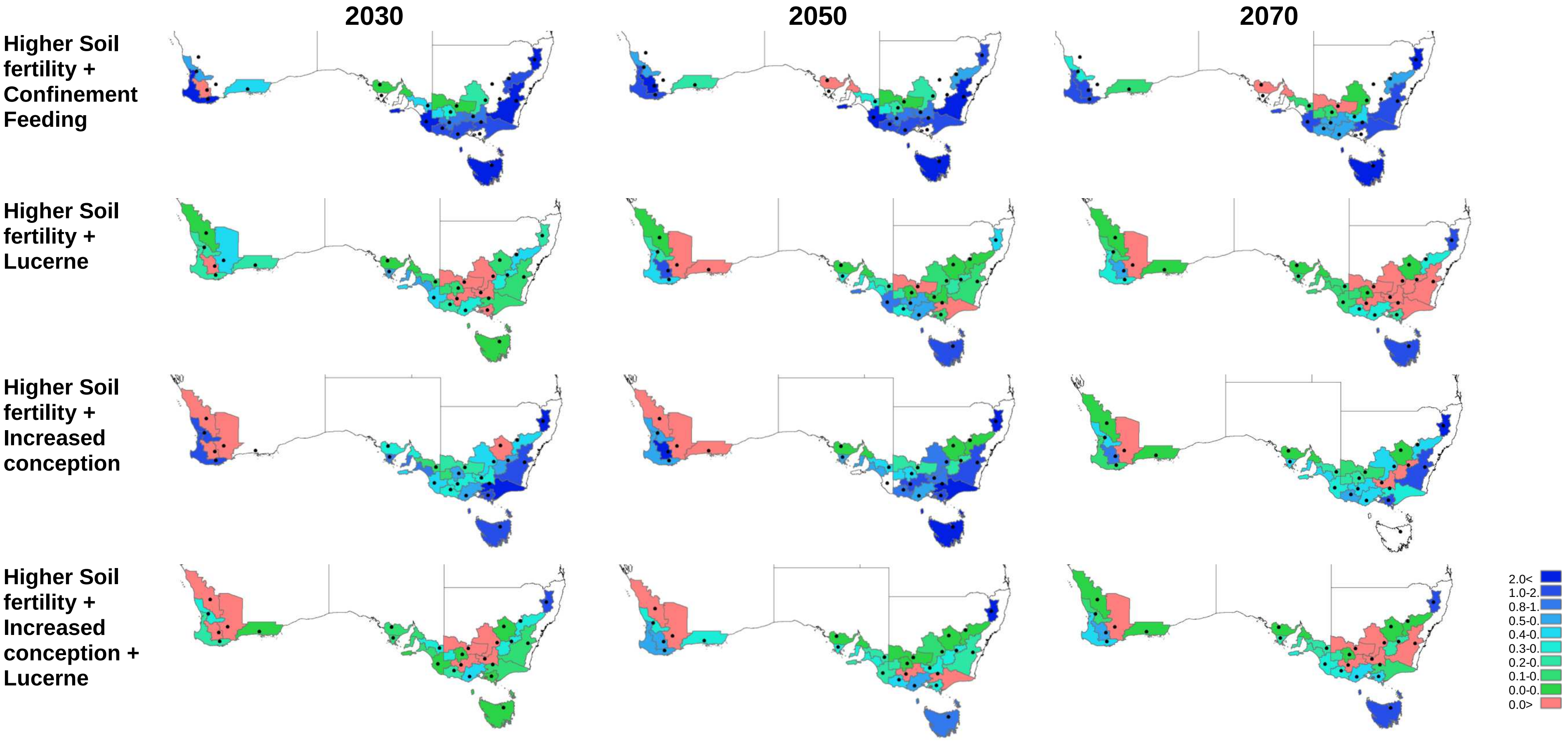


Figure A8.6. Relative effectiveness of four combinations of adaptations in recovering the impact of climate change on the total value of Merino ewe production at 25 locations across southern Australia (0.0 = no benefit; 1.0 = a return to the 1970-99 baseline value of production). Adaptation combinations were applied whether or not they increased profit at the sustainable optimum stocking rate. Values are averages over 4 GCMs. See Table A8.4 for details of the adaptation combinations.



Combination of adaptation strategies

The effect of a combination of adaptation strategies will not be simply the sum of the individual effects, because of complex interactions among biophysical and economical factors. As an example, Table A8.4 and Figure A8.6 show the relative effectiveness of four combinations of adaptations for Merino ewe enterprises. At 2030, at least one of these four combinations is more effective than the best single adaptation at 4 of the 25 locations (Lucindale, Goulburn, Bakers Hill, and Armidale); this expands to 6 and 10 of the 25 locations at 2050 and 2070 respectively. For these four combinations of adaptations, overall relative effectiveness was greater at 2050 than at 2030 or 2070. The combinations of higher soil fertility with confinement

Table A8.4. Relative effectiveness of four combinations of adaptation options for Merino ewe enterprises in recovering the total value of livestock production at 25 locations across southern Australia (0.0 = no benefit; 1.0 = a return to the 1970-99 baseline value of production). For this table, adaptations were applied whether or not they increased profit at the sustainable optimum stocking rate. Values are averages over 4 GCMs. The smallest increase in soil fertility, sowing of lucerne on 20% of land area and confinement feeding with a threshold pasture mass of 2000 kg/ha have been used in the results presented here.

Higher soil fertility		Yes			Yes			Yes			Yes	
Confine’t feeding		Yes										
Add 20% lucerne					Yes						Yes	
Conception rate								Yes			Yes	
	2030	2050	2070	2030	2030	2050	2030	2050	2070	2030	2050	2070
Western Australia												
Dalwallinu	0.00	0.00	0.00	0.08	0.06	0.01	-0.61	-0.09	0.02	-0.61	-0.09	0.02
Bakers Hill	0.79	0.65	0.34	0.27	0.26	0.13	1.18	0.73	0.41	0.38	0.35	0.19
Lake Grace	0.00	0.00	0.00	0.48	-0.06	-0.09	-0.48	-0.06	-0.09	-0.48	-0.05	-0.09
Katanning	-3.52	4.91	1.22	-0.26	1.84	0.66	-1.59	2.93	0.85	-0.21	0.67	0.73
Esperance	0.41	0.29	0.17	0.20	-0.01	0.08	0.00	0.00	0.09	0.09	0.30	0.10
Mount Barker	2.32	1.51	1.05	0.24	0.41	0.35	1.42	0.71	0.17	0.28	0.60	0.42
South Australia												
Kyancutta	0.03	0.00	0.00	0.01	0.02	0.01	0.32	0.03	0.02	0.14	0.03	0.03
Cummins	0.00	0.00	0.00	0.55	0.31	0.11	0.87	0.58	0.40	0.12	0.34	0.26
Lucindale	2.47	2.46	1.21	0.47	0.87	0.15	0.45	0.00	0.32	0.06	0.23	0.36
Lameroo	0.41	0.36	0.16	0.11	0.24	0.18	0.13	0.45	0.21	0.30	0.23	0.22
Victoria												
Birchip	0.40	0.29	0.10	0.11	0.03	0.06	0.52	0.44	0.25	0.03	0.04	0.08
Colac	1.38	1.43	0.61	0.39	0.69	0.40	0.58	0.78	0.47	0.42	0.68	0.44
Stawell	0.97	0.95	0.62	-0.30	0.53	-0.15	0.36	1.16	0.47	-0.12	-0.28	-0.15
Swan Hill	0.07	0.03	-0.03	-0.06	-0.10	-0.07	0.25	0.23	0.14	-0.55	0.00	-0.07
Tatura	0.82	0.91	0.49	-0.09	0.03	-0.05	0.40	0.85	-0.10	-0.72	0.32	-0.15
Mansfield	1.54	1.64	1.09	0.16	-0.71	-0.02	2.30	2.32	0.39	0.10	-0.08	0.11
Hamilton	1.28	1.44	0.79	0.23	0.38	0.31	0.32	0.87	0.53	0.30	0.43	0.36
New South Wales												
Armidale	3.95	1.65	2.07	0.27	0.43	1.36	6.38	5.39	3.71	1.40	2.46	1.02
Condobolin	0.00	0.00	0.00	0.11	0.03	0.02	-0.02	0.04	0.04	0.09	0.03	0.03
Cootamundra	0.00	0.00	0.00	0.30	0.26	-0.11	0.76	0.25	-0.02	0.35	0.31	0.30
Goulburn	2.32	2.28	1.76	0.11	0.13	-0.78	1.46	1.25	1.27	0.19	0.26	-0.61
Narrandera	0.22	0.26	0.04	-0.07	0.18	-0.15	0.47	0.92	0.42	-0.41	0.16	-0.17
Wellington	1.15	0.76	0.62	0.42	0.03	0.38	0.40	0.07	0.44	0.31	0.03	0.01
Tasmania												
Launceston	2.26	3.97	3.57	0.04	1.09	1.09	1.20	3.28	0.00	0.04	0.92	1.48

feeding and higher soil fertility with increased conception rate were more effective than the other two combinations; surprisingly, the three-way combination of higher soil fertility, increased conception rate and adding lucerne was more effective than higher soil fertility and increased conception rate alone in only 15 of 75 possible date x location combinations; this three-way combination only out-performed the best single adaptation for Kyancutta at 2070.

Changes in profitability over time after 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 A8.7.

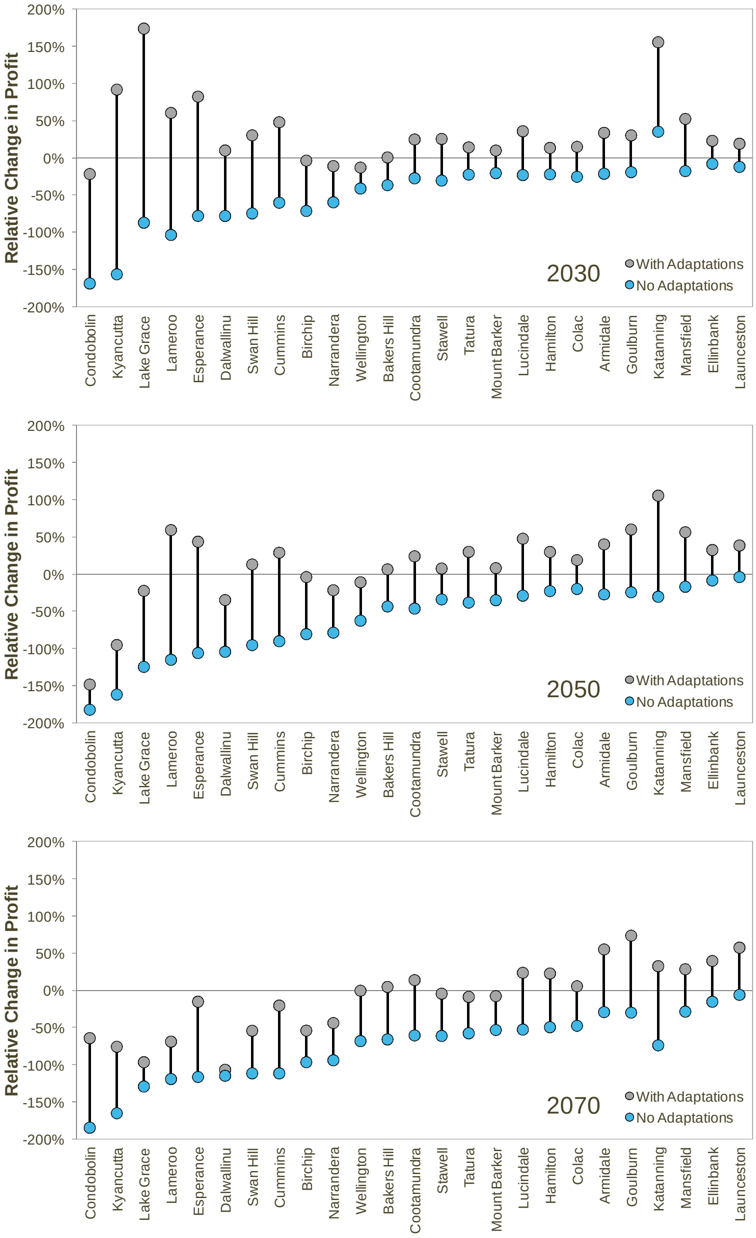


Figure A8.7. Change in profitability of Merino ewe enterprises at 25 locations across southern Australia under projected future climates before (blue circles) and after (grey circles) the introduction of the best-available, locally-specific combination of adaptation options. Profitability values are 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).

The actual combinations of adaptations represented in Figure A8.7 are very different from location to location, being selected from either the systematic combinations of adaptations (e.g. Table A8.5) or the “locally-best” combination of up to 3 adaptation options. 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.

Conclusions

Modelling different pasture management and livestock genetic adaptation options has demonstrated the effectiveness of such strategies to recover decline in pasture and livestock production. Effectiveness of adaptation strategies varied widely among locations, over time and under the four examined projected future climates. Adaptations would potentially recover decline in income under average effect of examined GCMs.

No single adaptation will be able to return income of enterprises to the historical period (1970-1999), demonstrating a requirement to combine applicable single adaptations. Applying combined adaptations would be especially helpful at later dates, when the increased negative effect of climate change means that single adaptations are likely to be less able to recover declines in production.

There were high uncertainties of applying any given adaptation approach across Southern Australia, because of high variation of rainfall, CO_2 concentration and temperature under different GCMs. This will cause challenges for implementing adaptation strategies, and require the adoption of more complex and combined adaptation strategies, which will differ among locations due to the site characteristics and projected climate.

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.

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