Appendix 4. Will managing for climate variability also manage for climate change? A southern Australian grazing system as an example

Introduction

In writing about policy options for climate change adaptation in agriculture, Pannell (2010) has argued that farmers faced with a changing climate will successfully adapt their systems by means of successive small, short-term changes in management practice:

> "At any point in time, farmers will use those practices that suit current perceived conditions. Farmers would respond to change as it occurred, rather than responding to predicted changes. Even for adaptations that would take some years to implement, the pace of climate change is predicted to be easily slow enough for pre-emptive action to be unnecessary in many cases" (Pannell 2010).

Built into this argument, and therefore into the policy conclusions drawn from it, are two key propositions:

- *The feasible rate of on-farm practice change is faster than the rate at which changing climate will alter the production environment*. For cropping enterprises, this is self-evident since most decisions relating to a crop are taken in the year of production or the year before. Whether it holds for livestock production in southern Australia is not as clear, however, since livestock enterprises are inherently less agile. There are several reasons for this: the genetic base (both livestock and perennial pastures) represents a significant capital investment and so the transaction costs involved in changing genotypes are greater; changes in the age structure or a herd or flock will generally persist for 4-6 years; there are feedbacks between management and the vegetation (e.g. Cayley *et al.* 1999, Hill *et al.* 2004) that can affect future production; and the lags between decisions and production outcomes are longer – especially in cattle production – with the result that uncertainties at the point of decision are typically greater.
- *Farmers' perceptions of their current conditions will be sufficient to allow them to adjust their management strategies.* Here a rather different kind of question arises: what ways of arriving at a perception of "current conditions" – for example placing different weights on past experience and on projections of expected future conditions – might be most effective in adapting to a changing climate?

This study explores these two questions for a case study livestock enterprise by analysing four alternative policies for adapting two of the key profit drivers in grazing systems: stocking rate and the timing of the reproductive cycle. The four adaptation policies considered are:

- "Traditionalist" policy: maintain the optimal stocking rate and joining date from the 1970-2009 period.
- "Incremental" policy: make a small change in either stocking rate or joining date each year, based on relative profitability over the last 5 years. This policy is closest to the spirit of the approach to climate change adaptation described by Pannell (2010), in that it is both incremental (frequent, small adjustments) and backward-looking (the manager is guided by experience).
- "Step-change" policy: every 15 years, choose the stocking rate & joining time that optimized net profit over the previous 15 years. This policy is also backward-looking, but it differs from the incremental policy in consisting of infrequent, larger adjustments.

- “Forecast” policy: set stocking rate & joining time each year as functions of an accurate forecast of long-term expected pasture production. This policy is also incremental but is forward-looking, in that only the expected future is taken into account.

In previous studies of the impacts of, and adaptation to, climate change by livestock producers (Topp and Doyle 1996, Cullen *et al.* 2009, Alcock *et al.* 2010), climate at a single future date (e.g. 2030 or 2050) has been considered. This analysis is different, since it considers alternative ways of adapting a livestock production system to a climate that is undergoing continuous change over time, as done by Kirschbaum (1999) for forestry production.

When the climate at a single future date has been the focus, it has been possible to assess variability in the future climate by downscaling multiple years of weather from a single realization of a global circulation model (GCM). This is not possible when continuously-changing climates are the objects of study. Accordingly, in this analysis the uncertainties due to year-to-year and decade-to-decade variability have been taken into account by using multiple realizations of projected climate from each of two GCMs. Another new feature of this study is that the costs and prices in financial calculations are not left constant. Instead, each possible future climate is assigned its own set of varying prices and costs, so that the interaction between business and price risks is considered.

Methods

A dual-purpose sheep production system (Merino ewes producing first-cross lambs) was considered in this study. Sheep grazed annual grass-clover pastures at Lucindale, South Australia. Policies for setting stocking rates and joining dates were examined; overstocking was penalized via a requirement for confinement feeding in order to preserve ground cover.

Simulation models. The GRAZPLAN simulation models of the dynamics of grazed temperate grasslands (Freer *et al.* 1997; Moore *et al.* 1997) were used in this study. These models are widely employed within Australia for purposes of research (e.g. Clark *et al.* 2003; Mokany *et al.* 2010) and also in decision support for producers (Donnelly *et al.* 2002 and references therein; Warn *et al.* 2006). Owing to the complexity of the management system under consideration (in particular the need to vary stocking rates and joining dates over the course of a simulation), the AusFarm software (www.grazplan.csiro.au; Moore 2001) was used to carry out the simulations.

The behaviour of the GRAZPLAN models will respond to changes in climate and atmospheric CO_2 concentration in a variety of different ways. The GRAZPLAN pasture model accounts for four effects of increasing CO_2 concentration: reduced transpiration due to partial stomatal closure, a direct CO_2 fertilization effect, decreases in specific leaf area and decrease in leaf nitrogen content (Moore and Lilley 2010). Changes in rainfall at a location will mainly affect the dynamics of the models via the water balance. Effects of changes in soil water content on pasture growth rate and the decomposition of litter are represented in the pasture model. The key effects of increasing temperatures across southern Australia – at least for increases up to about 3°C – are also accounted for by model equations describing effects of increased temperatures on vapour pressure deficit, seed dormancy release, germination, plant phenology, rates of assimilation, respiration and decline in the digestibility of herbage (Moore *et al.* 1997), reductions in animal intakes on hot days, decreased energy expenditures by livestock in winter and lower peri-natal mortality of lambs (Freer *et al.* 1997).

Grazing system. A breeding flock of Merino ewes (breed standard reference weight 55 kg, reference greasy fleece weight 5.0 kg with 70% clean yield) was modelled. These ewes grazed annual pastures (a mixture of annual ryegrass, subterranean clover and capeweed). A set of 5 identical paddocks was available to be grazed; the duplex soil in each paddock was assumed to have a sandy loam topsoil and a clay subsoil with high bulk density (Table A4.1) that limited the rooting depth of all species to 400mm. As a result the plant-available water holding capacity of the soil was only 50 mm.

Table A4.1. Soil properties used in the simulations of a dual-purpose sheep production system at Lucindale

	Topsoil	Subsoil
Depth to base of horizon (mm)	300	800
Bulk density (Mg/m^3)	1.50	1.80
Wilting point (m^3/m^3)	0.08	0.15
Field capacity (m^3/m^3)	0.22	0.23
Saturated hydraulic conductivity (mm/hr)	100	1.0

Stocking rate and joining date varied between simulations and over time within some of the simulation runs. (In this analysis, “stocking rate” denotes the number of ewes per hectare in the flock – including weaner replacements and yearling ewes – immediately after old ewes are cast for age, and “joining date” refers to the start of a 42-day joining period rather than to the average date of conception.)

Ewes were first joined at 17 months of age. A proportion of the ewes was joined to rams of the same breed each year, so as to produce sufficient replacement ewes to maintain the current stocking rate. The youngest ewes in the breeding flock were selected for mating to Merino rams in order to minimize the risk of losses due to dystocia. The remaining ewes were joined to Dorset rams (breed standard reference weight 60 kg, reference greasy fleece weight 3.8 kg with 70% clean yield). Ewes that conceived in each oestrus cycle during joining period were simulated separately, as were their lambs. All male lambs were castrated shortly after the youngest lambs were born and weaning took place when the average age of lambs was 14 weeks. All weaner sheep not kept as replacement ewes were sold as soon as they reached a live weight of 50 kg, or else on 31 December.

All ewes and weaners were shorn on 25 November each year. Each 30 November, enough ewes were sold out of the oldest age cohorts in the flock to bring the size of the ewe flock back to the current stocking rate, i.e. stocking rate changes were implemented by varying the number of ewes that were culled from the flock. The age structure of the ewe flock therefore varied through time in simulations where the stocking rate was allowed to change.

Each week, animals were moved between the 5 paddocks so as to ensure that the best available forage was provided to crossbred weaners (if present), the next-best forage to Merino weaners, then successively to the maiden ewes, the weaners kept as replacements and the remainder of the ewes. In order to preserve the soil resource, any paddock with a ground cover less than 0.75 was closed to grazing. At times when all paddocks were closed to grazing, all stock were removed to a feedlot and fed wheat to maintain their current body condition. When sheep were in the pasture paddocks, the standard maintenance feeding rule used in the GrassGro decision support tool was used: if the body condition of a group of sheep at pasture fell below the thresholds shown in Table A4.2, then all sheep in that class of stock were fed (in their paddock) in order to prevent the body condition of the thinnest group from falling further.

Table A4.2. Condition score thresholds used to trigger maintenance feeding in the paddocks

Start of time period	Replacement ewe weaners	Other ewes	Other Weaners
Weaning	1.5	1.5	2.0
30 days before start of joining	2.0	2.0	2.0
Start of joining	1.5	1.5	2.0
Day 120 of average pregnancy	1.5	2.0	
Average lamb birth date	1.5	2.0	

Weather data and climate change projections. An historical daily weather dataset for Lucindale Post Office for the years 1961-2009 was obtained from the SILO database (Jeffrey *et al.* 2001, http://www.longpaddock.qld.gov.au/silo). These weather data were used in conjunction with monthly output from two global circulation models (GCMs) under the SRES A1B emissions scenario to generate time sequences of changing climate over the period 2010-2099.

Output from the CCSM3 (Collins et al. 2006) and ECHAM5/MPI-OM (Roeckner et al. 2003) models was used for this purpose. These two GCMs (and the A1B scenario) were selected because data from multiple runs were publically available; by evaluating each adaptation policy over an ensemble of GCM runs, the inherent uncertainty in the projected climates could be taken into account. Note well that the weather inputs used here differ in nature from those used in previous impacts and adaptation studies with the GRAZPLAN models (e.g. Alcock *et al.* 2010). In this study, each weather input file represents a climate that changes over time from 2010 to 2099; the previous studies have considered the year-to-year variability projected for specific future date (e.g. 2030).

Daily weather data sequences matching each projected climate (2 GCMs x 4 model runs per GCM) were constructed using a downscaling technique adapted from that of Zhang (2007). Briefly, the technique uses ranked monthly values from the historical weather record and outputs from a global circulation model to develop a locally-specific “transfer function” that maps the GCM-predicted monthly value to a location-specific monthly value. The resulting time sequences of monthly weather values are detrended when a weather sequence corresponding to the climate for a particular time is required, as in this study. Finally, a stochastic weather generator (Hansen and Mavromatis 2001) is used to convert the monthly time course of weather to daily values. Full details of the technique are given by Moore (2008). Atmospheric CO_2 concentrations were increased in the course of each simulation using a polynomial function fitted to the ISAM reference atmospheric CO_2 concentrations for the A1B emissions scenario (Houghton *et al.* 2001; Figure A4.1).

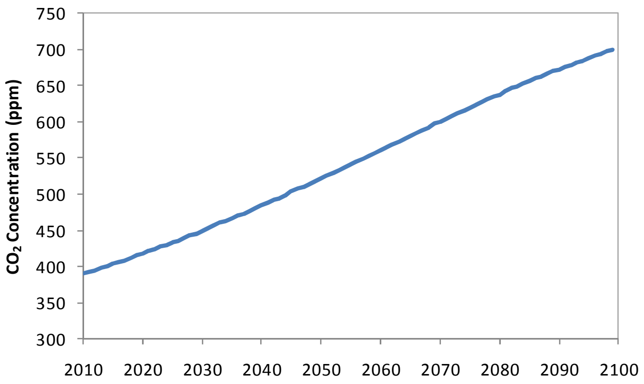


Figure A4.1. Atmospheric carbon dioxide concentrations for the A1B emissions scenario that were used in simulations of the Lucindale ewe production system under all projected climates.

Financial calculations. All financial calculations used a July-June year. The following production-related outputs were collected for each year of each simulation: numbers of ewes and lambs shorn and their average clean fleece weight, number of each class of lamb sold (male and female x crossbred and Merino) and their average weight at sale, number of ewes mated and total amount of supplement fed (in kg fresh weight). From this information, an annual profit (Y, \$/farm) was calculated as

$$\begin{aligned} Y = \; & \left(1 - VC_{sale,wool}\right) \cdot [\, F_{wool} \cdot P_{fleece} \cdot (NSH_{ewe} \cdot CFW_{ewe} + NSH_{mlamb} \cdot CFW_{mlamb}) \\ & \qquad + F_{wool} \cdot F_{xbred} \cdot P_{fleece} \cdot NSH_{xlamb} \cdot CFW_{xlamb} \,] \\ & + \left(1 - VC_{sale,stock}\right) \cdot [\, NS_{mlamb} \cdot (P_{lamb} \cdot F_{dress} \cdot LW_{mlamb} + P_{skin}) \\ & \qquad + NS_{xlamb} \cdot (P_{lamb} \cdot F_{dress} \cdot LW_{xlamb} + P_{skin}) \\ & \qquad + NS_{ewe} \cdot (P_{ewe} \cdot F_{dress} \cdot LW_{ewe}) \,] \\ & - C_{shear,ewe} \cdot NSH_{ewe} - C_{shear,lamb} \cdot (NSH_{mlamb} + NSH_{xlamb}) \\ & - FC_{sale,stock} \cdot (NS_{mlamb} + NS_{xlamb} + NS_{ewe}) \\ & - C_{husb,ewe} \cdot N_{ewe} - C_{husb,lamb} \cdot (NS_{mlamb} + NS_{xlamb}) \\ & - C_{ram} \cdot F_{ram} \cdot NM_{ewe} - C_{supp} \cdot SUPP - C_{pasture} \cdot AREA - C_{operator} \cdot AREA \end{aligned}$$

where NSH_{ewe}, NSH_{mlamb} and NSH_{xlamb} are the numbers of ewes, Merino lambs and crossbred lambs shorn; CFW_{ewe}, CFW_{mlamb} and CFW_{xlamb} are the clean fleece weights (kg/head) of these three classes of stock; NS_{ewe}, NS_{mlamb} and NS_{xlamb} are the numbers of each class of stock sold each year; LW_{ewe}, LW_{mlamb} and LW_{xlamb} (kg) are their average live weights at sale; N_{ewe} is the number of ewes present immediately after replacement; NM_{ewe} is the number of ewes mated; $SUPP$ (tonne) is the total amount of supplementary feed provided to livestock over the year; $AREA$ is the property area; P_{fleece} (\$/kg) is the price of clean fleece wool in the current year; P_{lamb} (\$/kg) is the carcass price for lambs in the current year; P_{ewe} (\$/kg) is the carcass price for mutton in the current year; C_{supp} (\$/tonne) is the price of supplementary feed in the current year; and the remaining constant prices and costs are set out in A4. 3.

The prices received for wool (average price over ewes and lambs, \$/kg clean fleece), lambs, (\$/kg dressed weight), cull sheep (\$/kg dressed weight) and supplementary feed (\$/kg fresh weight for wheat) varied from year to year. For simulations carried out over the historical record, historical price data from ABARES were deflated to Jun 2010 dollars; wool quality of purebred Merino sheep was assumed to result in the Eastern Market Indicator price. For each realization of each GCM, a synthetic sequence of these four prices was generated using the weakly stationary generating process of Matalas (1967). This generating process is also used in commonly-

Table A4.3. Constant costs, prices and multipliers used in the financial calculations for the Lucindale ewe enterprise.

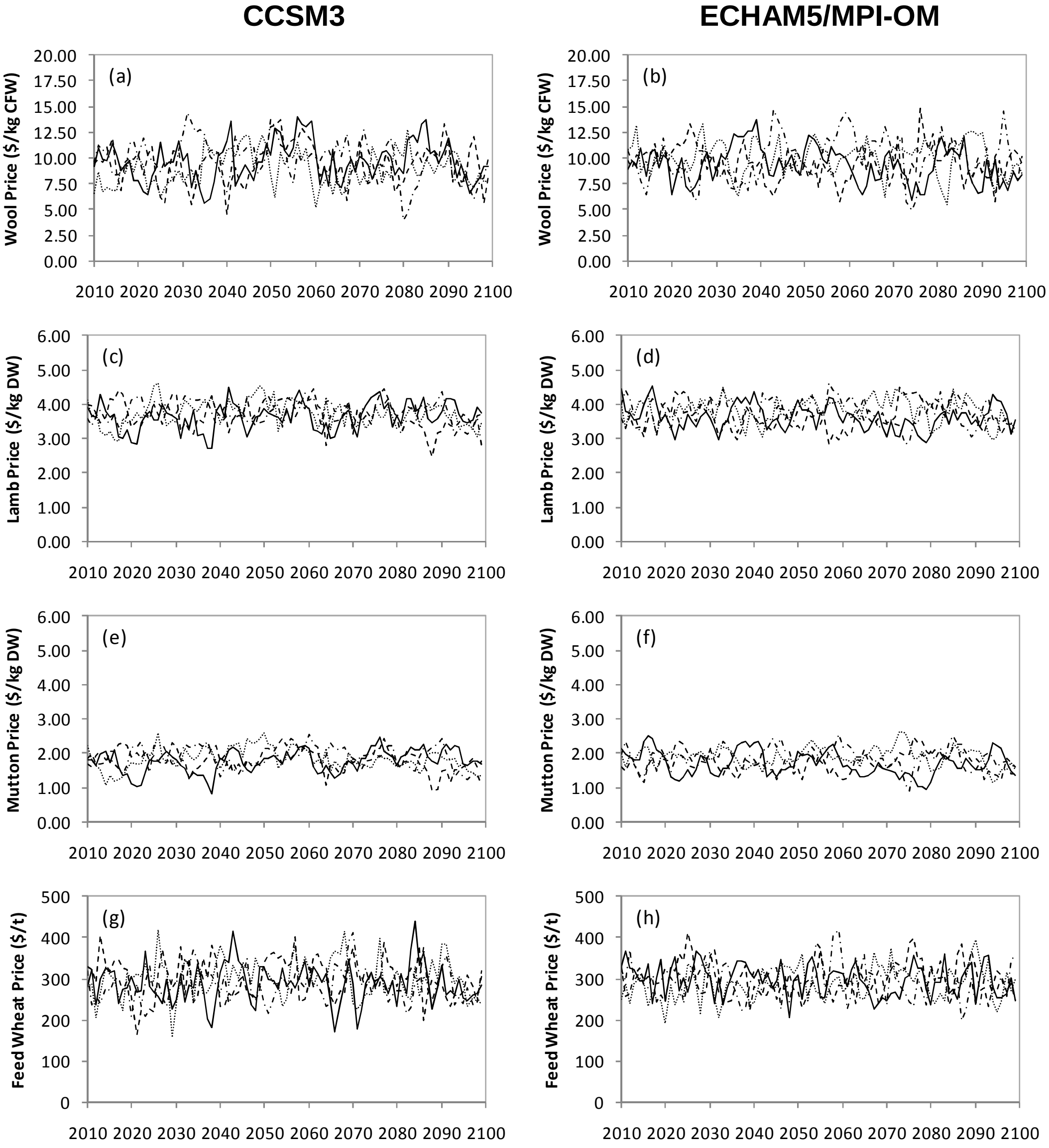
Variable	Meaning	Value	Unit
P_{skin}	Lamb skin price	5.00	\$/head
$C_{shear,ewe}$	Cost of shearing ewes	4.50	\$/head
$C_{shear,lamb}$	Cost of shearing lambs	4.00	\$/head
$VC_{sale,wool}$	Variable costs of wool sales (commissions etc)	0.04	\$/\$
$VC_{sale,stock}$	Variable costs of livestock sales	0.08	\$/\$
$FC_{sale,stock}$	Fixed costs of selling stock	2.00	\$/head
$C_{husb,ewe}$	Annual husbandry cost for ewes	3.80	\$/head
$C_{husb,lamb}$	Husbandry cost for lambs (birth to sale)	2.00	\$/head
C_{ram}	Purchase cost for rams	1000	\$/head
$C_{pasture}$	Cost of pasture management	35.00	\$/ha
$C_{operator}$	Operator labour allowance	100.00	\$/ha
F_{ram}	Rams purchased per ewe per year	0.04	–
F_{xbred}	Ratio of fleece price for crossbred lambs to fleece price for Merino rams	0.90	–
F_{wool}	Ratio of average wool price to fleece price	0.85	–
F_{dress}	Dressing proportion (carcass:live weight ratio)	0.41	–

Table A4.4. 2001-2009 average price levels (expressed in June 2010) dollars of key prices and costs, their coefficients of variation over 1983-2009 and correlations over 1983-2009. Values are calculated from Bureau of Agricultural Economics/Australian Bureau of Agricultural and Resource Economics data.

Commodity	Mean	C.V.	Correlation (r) with		
			Lamb	Mutton	Wheat
Merino wool (\$/kg clean fleece)	9.57	0.21	0.20	0.25	0.32
Lamb (\$/kg dressed weight)	3.69	0.11		0.86	0.14
Mutton (\$/kg dressed weight)	1.80	0.18			0.15
Feed wheat (\$/tonne)	291	0.15			

employed weather generators (e.g. Hansen & Mavromatis 2001). It produces a stochastic sequence of multiple variables which is stationary in time (i.e. the long-run expected mean does not change) and in which both the correlations between the variables and their lag-1 autocorrelations are preserved. Detrended ABARES price index values from 1982-3 to 2008-9 were used to derive the necessary correlation information and coefficients of variation, and the average real price of the four commodities over 2001-09 was used to set the expected long-run average price levels (Table A4.4). The resulting price sequences are shown in Figure A4.2.

Figure A4.2. Synthetic price sequences for 2010-2099, used in conjunction with four realizations of each the CCSM3 (a, c, e, g) and ECHAM5/MPI-OM (b, d, f, h) global circulation models.



Risk-weighted profit measure. A risk-averse manager was assumed. Risk aversion was taken into account by adding a weighted "conditional value-at-risk" to the average annual profit over a period of N years when ranking combinations of stocking rate and joining date, to obtain a "risk-adjusted profit", *Z* ($/ha):

$$Z = \frac{1}{AREA} \cdot \left(\frac{1}{N} \sum_{i=1}^{N} Y_i + \beta \cdot \frac{1}{\alpha \cdot N} \cdot \sum_{i: Y_i \leq Y_\alpha} Y_i \right)$$

The conditional value-at-risk at a nominated level *α* is the average of the profits obtained in the worst proportion *α* of years. The risk-adjusted average profit measure effectively gives extra weight to poor years when computing the average return over a period. Values of *α*=0.20 and *β*=0.50 have been used here, i.e. a 150% weighting to the 20% of years with lowest profits.

Simulation under historical climate. A simulation experiment was conducted in which the Lucindale ewe grazing system was simulated over the years 1970-2009 for all combinations of 5 joining times (15 Nov, 15 Dec, 15 Jan, 15 Feb, 15 Mar) and 12 stocking rates (from 4.5 to 10.0 ewes/ha at intervals of 0.5). The combination of stocking rate and joining time that gave the highest risk-adjusted average annual profit was then selected as the "historical optimum" management policy.

"Traditional" adaptation policy. The historical optimum management policy was simulated over Jan 2010 to Dec 2099 using downscaled weather data and stochastic prices for each of the eight projected climates.

"Incremental" adaptation policy. To analyse the incremental policy, a single simulation was run over the period Jan 2010 to Dec 2099 for each of the eight projected climates. Five separate farms were modelled within this simulation; these farms were identical in all respects except for their stocking rates and joining dates. The five modelled systems were a current-best stocking rate and joining date (i.e. the current result of the incremental policy), and four alternatives obtained by increasing stocking rate by 0.25 ewes/ha, decreasing stocking rate by 0.25 ewes/ha, making joining earlier by 3 days and making joining later by 3 days. (The motivation for this approach was that the results of different policies on neighbouring farms would be part of the information available to the manager adopting the incremental policy.) The historical optimum management policy was used as the current-best policy for 2010. Immediately prior to ewe replacement in each year from 2015 onward, the five alternative policies were ranked according to their average profits over the preceding five years (without risk adjustment) and the highest-ranking policy was adopted for the coming year. As a result either a small stocking rate change or a small joining date change could be made in each year, but not both at once. Because the set of stocking rate x joining time combinations being modelled changed each year, profits for the desired combinations in the four prior years were estimated from the combinations that were actually run by fitting and interpolating quadratic functions of profit vs stocking rate and profit vs joining date.

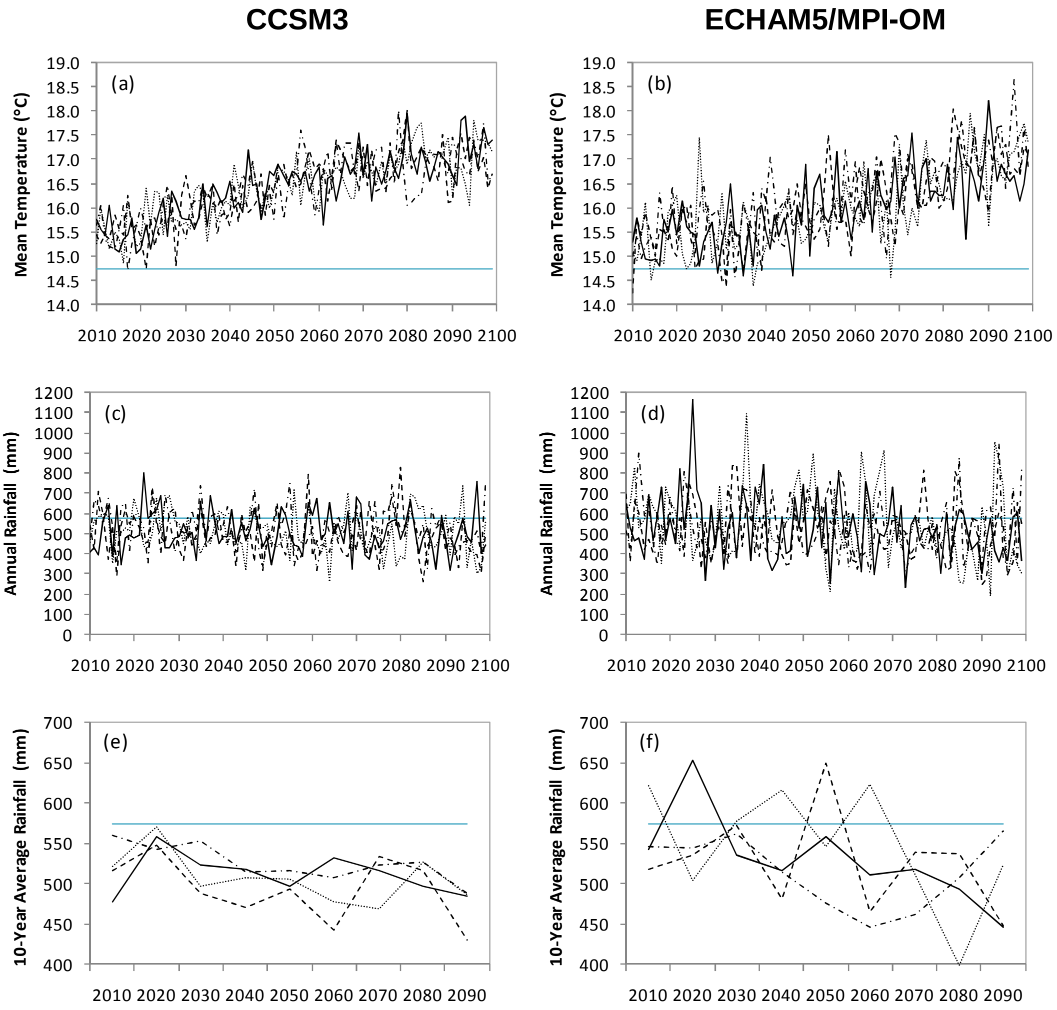
"Step change" adaptation policy. The step-change policy was analysed over the period Jan 2010 to Dec 2099 for each of the eight projected climates. Within each projected climate, the 90 years from 2010 to 2099 were divided into six 15-year periods and a single combination of stocking rate and joining date was selected for each period. For 2010-2024, the historical optimum management policy was selected. The management policy for the subsequent five periods was chosen as follows:

1. The previously-selected management policies for periods more than 15 years before the start of the period under consideration were simulated.
2. From the resulting common starting point (15 years before the start of the period), a simulation experiment was run with a range of combinations of joining time (in half-month intervals) and stocking rates (in steps of 0.5 ewes/ha). The exact set of policies examined varied from period to period to ensure that the policy with the highest risk-adjusted average profit for each climate and period was located.
3. The management policy highest risk-adjusted average profit for the previous 15 years was selected as the policy to be adopted *in the new 15-year period*. For example, the management policy for 2040-2054 was selected because it had the highest risk-adjusted average profit during 2025-2039.

Once the management policy for each of the six periods had been selected, a final simulation with the selected set of stocking rates and joining dates was run over the whole 90-year period.

"Forecast" adaptation policy. For this policy, a two-step procedure was followed. First, the annual above-ground net primary productivity (ANPP) of the pastures modelled for each year under the step-change adaptation policy was collated for each of the eight projected climates, and the average ANPP in each year over the four realizations was computed for each of the two GCMs. A quadratic regression was then fitted for each GCM, relating expected ANPP to year. Second, the optimal stocking rates, optimal joining dates and average pasture ANPP for each GCM x realization x 15-year period (i.e. 2 x 4 x 6 = 48 values) were collated. The optimal stocking rates and optimal joining dates were each regressed against ANPP. Linear regressions were found to be adequate. A single simulation was then run in which the expected ANPP for each year was calculated from the GCM-specific regression of ANPP versus year, and the expected optimal stocking rate was calculated from the common relationship between ANPP and stocking rate. Because there was no significant relationship between joining date and pasture ANPP, joining dates were left at the historical optimum value.

Figure A4.3. Annual mean temperatures, annual rainfalls and decadal average rainfalls of projected weather sequences at Lucindale that were downscaled from four realizations of the CCSM3 (a, c, e) and ECHAM5/MPI-OM (b, d, f) global circulation models over 2010-2099. Blue lines show the historical average value (over 1970-2009) for comparison.



Results

Projected climates. Annual mean temperatures and rainfalls under the eight projected climates are shown in Figure A4.3, along with decadal rainfall averages. Temperatures increase steadily between 2010 and 2099 for both GCMs under the assumed emissions scenario (SRES A1B), with increases for CCSM3 and ECHAM5/MPI-OM respectively of about 1.8°C and 1.2°C at 2055 and 2.3°C and 2.5°C at 2099 (i.e. CCSM3 exhibits faster warming than ECHAM5/MPI-OM in the first half of the period and slower warming in the second half). Average rainfall decreases by about 15% from historical levels by 2099 for both GCMs. Different realizations of the same GCM show large differences in decadal average rainfall, especially for ECHAM5/MPI-OM.

Figure A4.4. Modelled pasture production responses to a changing climate over 2010-2099 in a dual-purpose ewe production system at Lucindale, when the historical optimum stocking rates (7.5 ewes/ha) and joining date (15 Jan) are used. (a, b, c) Average monthly pasture growth rates under climate projected by the CCSM3 (◆) and ECHAM5/MPI-OM (◆) global circulation models for three 30-year successive periods, compared with the average modelled pasture growth rates for 1970-2009 (■). (d, e) Modelled trends in annual above-ground net primary productivity and the proportion of ANPP due to clover growth from 2010 to 2099 under climate projected by the CCSM3 (–) and ECHAM5/MPI-OM (–) global circulation models, compared with the 1970-2009 average (–). All projected values are averaged over 4 realizations of each GCM.

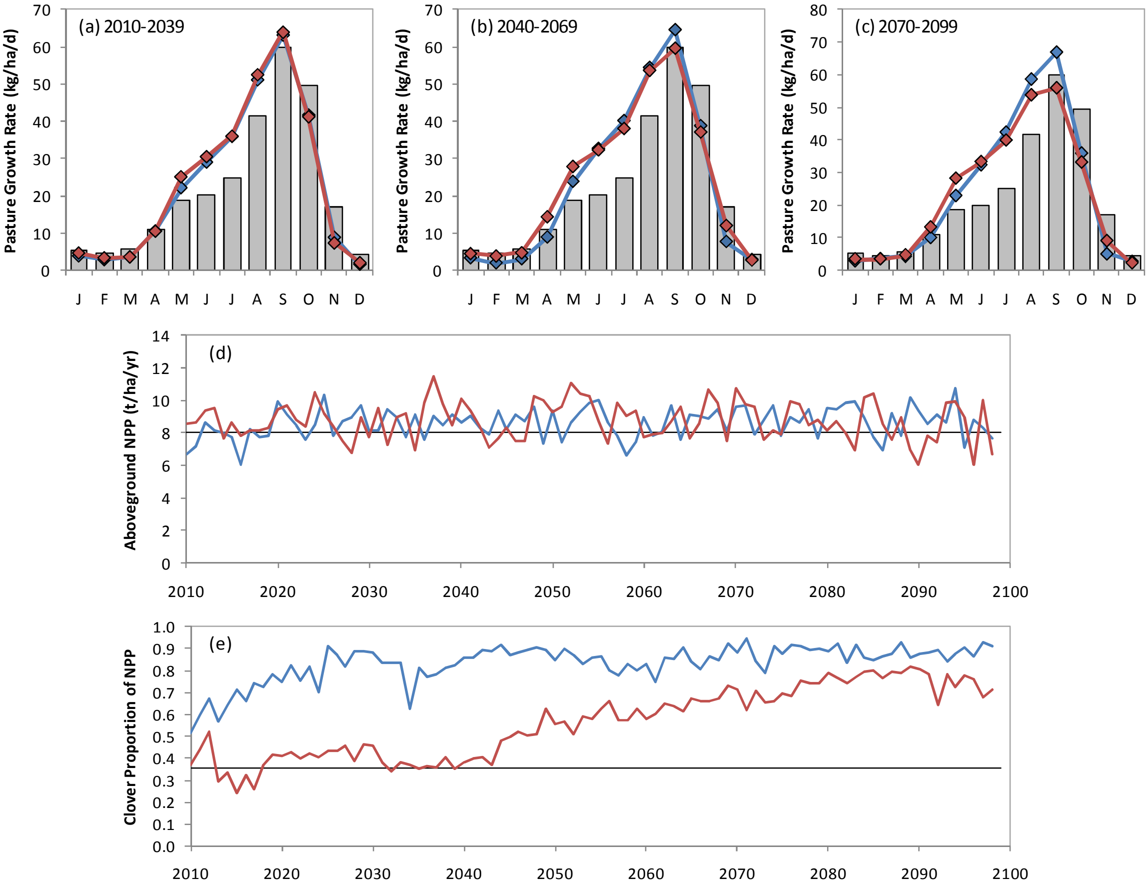
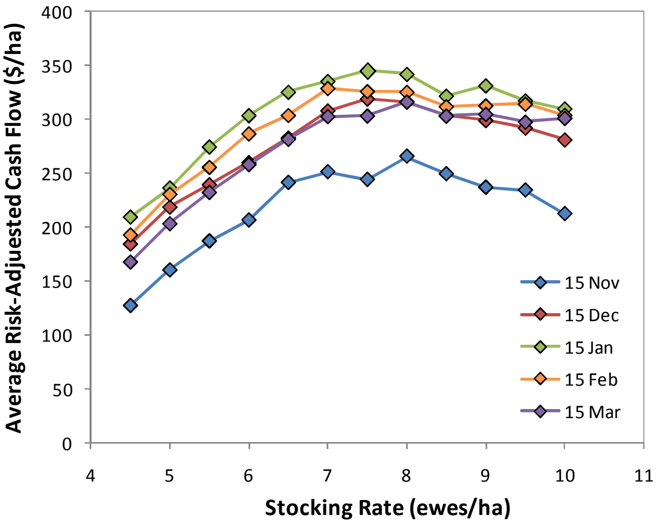


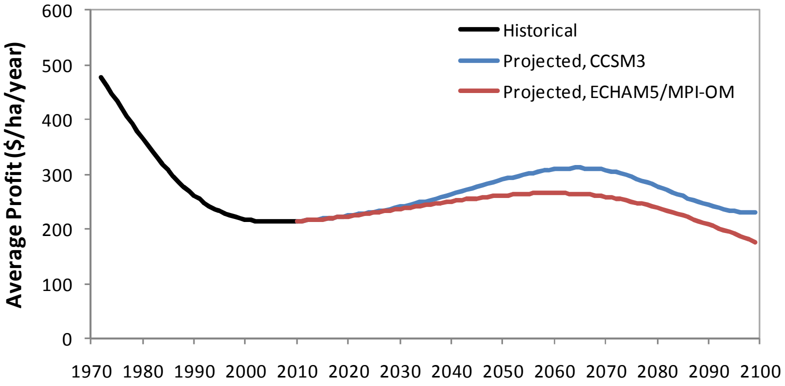
Figure A4.5. Response surface of risk-adjusted average profit of a dual-purpose ewe production system on annual pastures at Lucindale for 1970-2099 as stocking rate and joining date are varied.



Pasture growth under a changing climate. When compared with historical (1970-2009) results, the patterns of pasture growth under the projected climates show a pattern of higher winter growth rates and an earlier end to the growing season (Figure A4.4(a)-(c)). Unlike an earlier analysis at Canberra by Alcock *et al.* (2010), however, there is little if any delay in the start of pasture growth. Annual average pasture productivity increases by about 9% from 2010 to 2099 under the CCSM3-projected climate but shows no change under the ECHAM5/MPI-OM-projected climate (Figure A4.4(d)), despite the lower average rainfall projected for late in the centrury. The GRAZPLAN models predict a major shift in pasture composition, with a move to clover dominance over time.

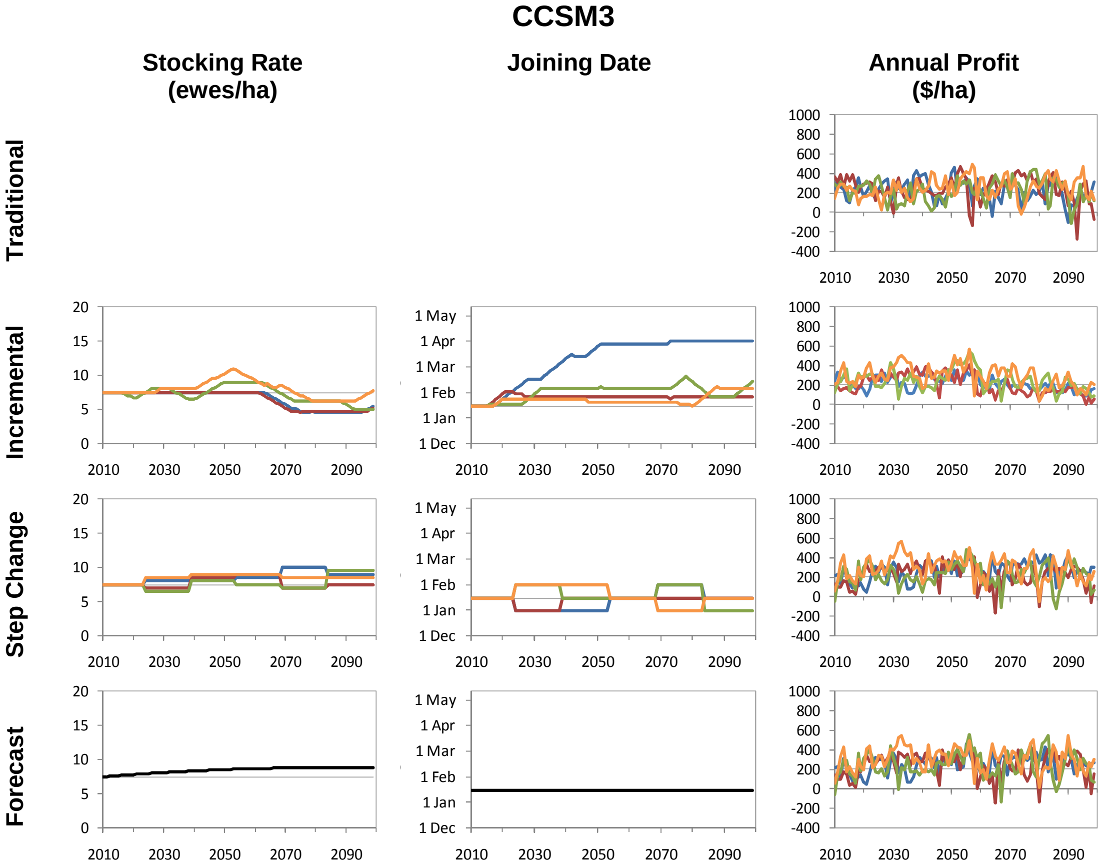
Historical optimum management policy. The combination of 7.5 ewes/ha and a joining date of 15 January gave the highest risk-adjusted profit over 1970-2009 of all management policies examined. A typical “flat-topped” profit response was observed, however, with near-optimal values obtained over a range of stocking rates and also for a 15 February joining. Spring (15 November) joining was clearly sub-optimal. Average rates of profit declined sharply over the historical period (Figure A4.6), as a result of declining real prices for wool.

Figure A4.6. Time course of average annual profit for the Lucindale dual-purpose ewe production system at a fixed stocking rate of 7.5 ewes/ha and a joining date of 15 January. Curves have been fitted to the individual profit values computed from model results (all GCM realizations combined, see Figures 7 and 8) using natural cubic splines with fixed knots at 1990, 2010, 2040 and 2070.



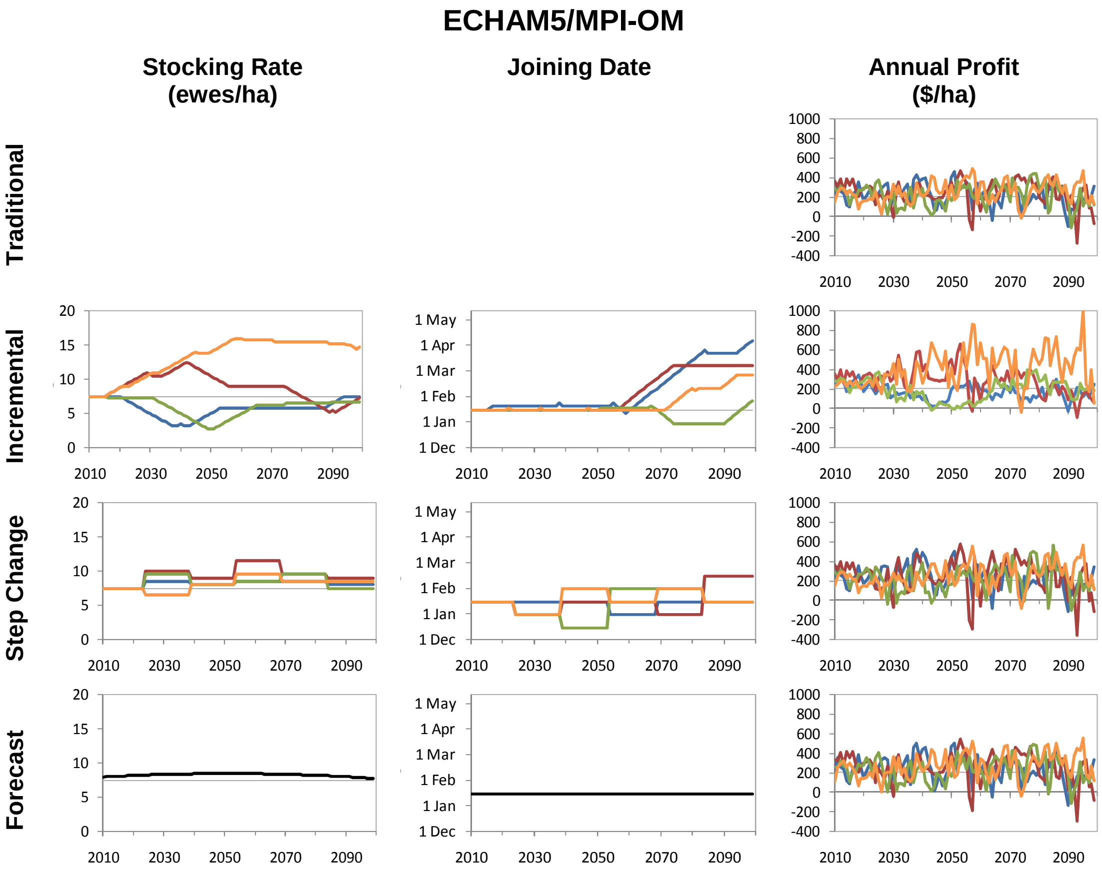
“Traditional” adaptation policy. Annual profit values for the traditional management policy under each of the eight realizations of projected climate are shown in Figures A4.7 and A4.8, and smoothed time courses of average profit are given in Figure A4.6. Despite the projected decreases in rainfall, average profitability of the grazing system rises slowly through to mid-century for both GCMs and then decreases again. The temporary rise in system profitability is greater for the CCSM3 projection than the ECHAM5/MPI-OM projection, which is consistent with its higher average pasture productivity and earlier shift to legume-dominance. For both GCMs, the traditional adaptation policy resulted in a higher risk-adjusted average profit than did the historical simulation over 1990-2010. Overall, however, it seems likely that climate change adaptation for this grazing system at this location will be more a matter of capturing opportunities than of responding to deteriorating conditions.

Figure A4.7. Changes in stocking rate and joining date and the resulting annual grazing system profits of a dual-purpose ewe production system at Lucindale under changing climate projected by the CCSM3 global circulation model from 2010 to 2099. Each row of the figure shows results for one of four policies for adapting stocking rate and joining date, as described in the text. Each coloured line denotes outcomes for a weather sequence downscaled from a realization of the CCSM3 global circulation model under the SRES A1B emissions scenario. 1990-2010 average values for the historical optimum grazing system are shown as grey lines.



CCSM3

Figure A4.8. Changes in stocking rate and joining date and the resulting annual grazing system profits of a dual-purpose ewe production system at Lucindale under changing climate projected by the ECHAM5/MPI-OM global circulation model from 2010 to 2099. Presentation is as for Figure A4.7.



"Incremental" adaptation policy. Management policies (i.e. combinations of stocking rate and joining date) resulting from the incremental adaptation policy proved to be very different both between projected climates (CCSM3 vs ECHAM5/MPI-OM) and between realizations of the same climate. For the CCSM3 projection, stocking rates remained close to the historical-optimum level until about 2040, rose in two of the four realizations and then fell in all four realizations between about 2060 and 2080. By 2099 the selected stocking rate was in the range 5.0-5.5 ewes/ha for three of the four realizations. Meanwhile the joining dates selected in this realization moved later than the 15 January starting point; in one realization the joining date moved as far as early April (i.e. an early September lambing).

Under the ECHAM5/MPI-OM projected climate, joining dates shifted very little until about 2055; the different realizations then followed individual (but generally later) trajectories. The selected stocking rate trajectories were very different between realizations. In one realization, stocking rate built up to 16 ewes/ha in 2060 before declining slightly. At these stocking rates, significant supplementary feeding (20-80 kg wheat/ewe/year) is required every year to maintain the sheep flock over summer.

As can be seen in Figure A4.8, the end-points of the grazing systems under the four realizations of ECHAM5/MPI-OM were each quite different. One system had a high stocking rate, a high average profit and high year-to-year profit variability, and there were joining dates in January, February, March and April. Over the 90-year period, the incremental adaptation policy resulted in a higher risk-adjusted average profit than the 1990-2010 base period for two of the ECHAM5/MPI-OM realizations and a lower risk-adjusted profit for the other two.

"Step-change" adaptation policy. Basing infrequent management changes on the last 15 years' outcomes resulted in smaller, and more consistent, changes than the incremental adaptation policy (Figures A4.7 and A4.8). Late-lambing systems were not selected by the step-change policy – the latest lambing date chosen was 15 February – and stocking rates only moved within the range 6.5-11.5 ewes/ha (cf 2.8-16.0 ewes/ha for the incremental policy). There was something of a tendency for stocking rates to increase and then decrease over 2010-2099 for both GCMs.

"Forecast" adaptation policy. The forecasts for aboveground net primary productivity (*ANPP*, kg/ha) were estimated as:

$ANPP = 7674 + 48.7 \times (year - 2009) - 0.329 \times (year - 2009)^2$ CCSM3
$ANPP = 8346 + 32.6 \times (year - 2009) - 0.401 \times (year - 2009)^2$ ECHAM5/MPI-OM

No relationship between *ANPP* and optimal joining date could be detected, so for this policy all joining dates were left at 15 January. The relationship between stocking rate (SR, ewes/ha) and *ANPP* was estimated over both GCMs to be:

$SR = 1.71 + 0.00075 \times ANPP$

The resulting management policies for the two GCM-projected climates were not very different from the "historical optimum" policy. For CCSM3, stocking rate started at 7.5 ewes/ha, increased to 8.8 ewes/ha in 2083 and then declined very slightly. The selected stocking rate for ECHAM5/MPI-OM started at 8.0 ewes/ha, increased to 8.5 ewes/ha by 2050 and then declined to 7.8 ewes/ha by 2099. Profit levels over 2010-2099 showed a similar trajectory but overall were slightly higher than for the traditional adaptation policy.

Table A4.5 compares the profitability outcomes of the four adaptation policies (measured as risk-adjusted profit over 2010-99) with a 1990-2010 baseline and with one another. On average, all four adaptation policies – including no change – produce risk-adjusted profit levels that are higher than 1990-2010 under changing climate and stationary, but varying, prices. One likely reason for this was the use of a confinement feeding policy in poor summers in the modelled grazing system; this tactic appears to have been cost-effective as a means of maintaining stocking rates (and hence average profitability) at or above historically optimum levels.

Discussion and conclusions

In this case study, Pannell's (2010) contention that on-farm practice change can keep pace with a changing climate is clearly borne out. If it comes to pass, the shift to legume dominance predicted by the GRAZPLAN models will be clearly apparent to graziers, but the long-term shifts in profitability over time shown in Figure A4.6 are quite small relative to the year-to-year variability that is apparent in Figures A4.7 and A4.8 and his argument that changes in profitability will be hard to discern amongst year-to-year "noise" is also supported.

For the incremental policy and the ECHAM5/MPI-OM projected climate, major differences between climate realizations appeared. In two realizations this adaptation policy was much more profitable than the historical baseline, while for the other two – where short-term conditions led to transient drops in stocking rate – it was much less profitable. It appears that intra-decadal variation around the same mean climate and prices can entrain very different trajectories from incremental management. Indeed,

Table A4.5. Differences in risk-adjusted average annual profit ($/ha) between each realization of two projected climates and the historical optimum policy for over 1990-2010, the frequency with which each adaptation policy had the highest risk-adjusted profit for a given climate realization (“best policy”) and the frequency with which the incremental, step change and forecast policies had higher risk-adjusted profit over 2010-2099 than the traditional adaptation policy (“better than traditional”).

	Traditional	Incremental	Step Change	Forecast
CCSM3	+50	+32	+79	+64
	+78	+5	+3	+18
	+34	+55	+3	+35
	+78	+120	+106	+127
Average	+60	+53	+48	+61
S.D. Over Realizations	21	48	53	48
ECHAM5/MPI-OM	+12	-43	+27	+20
	+25	+92	+5	+25
	0	-44	-16	+6
	+62	+254	+56	+77
Average	+25	+65	+18	+32
S.D. Over Realizations	27	141	31	31
Best Policy?	1/8	3/8	2/8	2/8
Better than Traditional?		4/8	3/8	7/8

the high-stocking-rate system arising in one of the realizations can be regarded as a transformational change in management that has emerged from incremental adaptation.

None of the four adaptation policies consistently outranked all others in terms of risk-adjusted profit (Table A4.5). The forecast policy did better than the traditional policy in 7 of the 8 climate+price realizations, and so can be regarded as a robust alternative to no change, but it usually only improved economic performance by a modest amount (Table A4.5). The incremental policy did better – often much better – than traditional management in 4 of the 8 realizations but was not resilient to uncertainty in future climate. The step-change policy did not appear to offer any advantages over unchanged, stable management. One possibility worth exploring further is that a combination the forecast and incremental policies may retain the attractive features of both.

A final point is that the profitability results obtained under different realizations of the same GCM were fairly variable even under constant management. This suggests that multiple simulations, based on ensembles of GCM results, should be carried out routinely when using biophysical simulation models to examine climate change impacts and adaptation, especially under changing climates as in this study. Ensembles of GCM realizations are available for relatively few GCMs at present, however, and so this will probably have to wait until the results of the fifth Climate Model Intercomparison Project (CMIP5) are generally available.

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