Appendix 5. Medium-term climatic variability and its effects on pasture and livestock production

Introduction

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

Modelling pasture and livestock production under climate variability can give insights into the probable effects of rainfall variation and uncertainty. Previous modelling studies that have examined these issues across large areas have used ecohydrology models (Eagleson 2002; Kochendorfer et al. 2010) and have focussed on vegetation cover and runoff production. The consequences of medium-term rainfall changes on pasture livestock production have been examined at small numbers of sites in south-eastern Australia (Salmon et al. 2007; Cullen et al. 2011), but a large-scale examination of the effects of medium-term rainfall variability on livestock production has not yet been attempted.

In this analysis, a simulation experiment based on the GRAZPLAN biophysical models is used to explore the effects of medium-term climatic variations in the historical record on pasture and livestock production, while holding the management of grazing systems (plant and animal genetics, soil fertility etc) and their financial environment constant. Our aims are to clarify the uncertainty of pasture and livestock production under the spatially and temporally varying climates of southern Australia, and in particular to place recent climatic conditions in their longer-term context.

Methods

The GRAZPLAN grassland simulation models (Moore et al. 1997, Freer et al.1997; www.csiro.au/grazplan), as implemented in the GrassGro decision support tool (Moore et al. 1997), were applied in order to simulate the potential effects of medium-term climate variation between 1899 and 2010 on pasture and livestock production. The historical period was divided up into 8 periods, each 14 years in length. Each period is denoted by its midpoint, i.e. 1906, 1920, 1934, 1948, 1962, 1976, 1990 and 2004.

The models simulated pasture and livestock dynamics under historical climate data at a set of 25 locations chosen to be representative of southern Australia. At each location, five grazing enterprises (self-replacing Merino ewes, crossbred ewes, self-replacing Angus beef cattle, Angus steers and Merino wethers) were modelled. More detail on the development of the set of modelled grazing systems can be found in Appendices 7 and 11.

The set of simulations was designed to keep as many factors as possible constant, so that modelling results could be used to compare the effects of climatic variation over time and space. Atmospheric CO_2 concentrations of 350 ppm and present-day pastures and livestock were modelled at all time periods. Management policies (livestock replacement, the timing of the reproductive cycle, the sale of young stock and thresholds for supplementary feeding) were not changed from 1899 to 2010, with the exception of stocking rates. For each time period x location x enterprise combination, an “optimal sustainable” stocking rate was selected that maximized profit within a constraint that the frequency of low ground cover should not exceed a

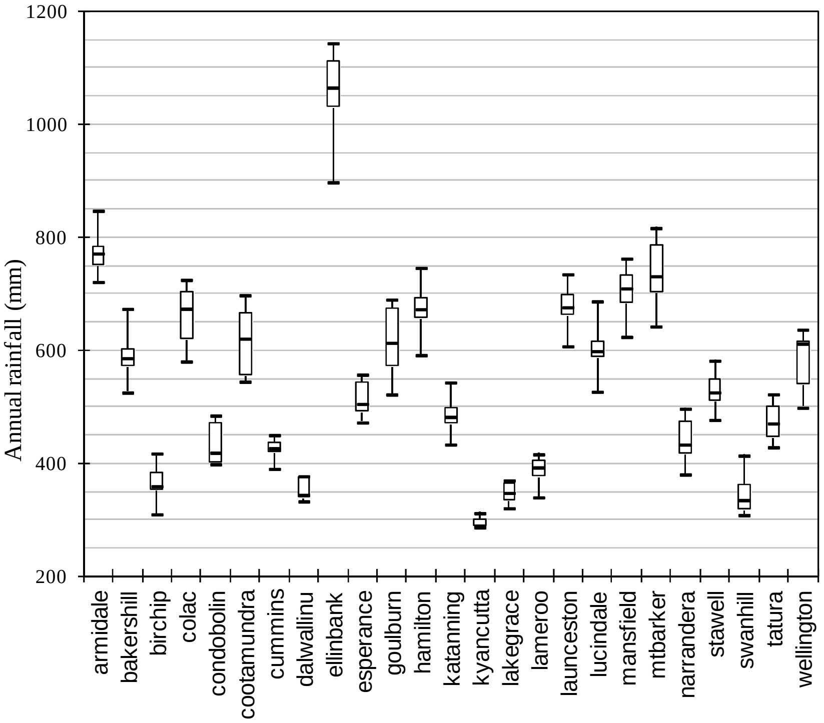


Figure A5.1. Variation of 14-year average rainfall across 25 representative locations in southern Australia. Boxplots illustrate the median (thick line), 10th, 25th, 75th and 90th percentiles. Each boxplot shows the distribution of average annual rainfall over a set of eight 14-year periods, starting with 1899-1912.

location-specific threshold. Within each enterprise, the same livestock genotypes, recent prices for livestock and wool and recent variable costs of production were assumed.

A three-way factorial simulation experiment was conducted in which the factors were time period within the historical record (8), location (25) and livestock enterprise (5). For each combination, a range of 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 was calculated as the gross margin less overhead costs, an operator allowance and a further adjustment for the capital cost of the livestock required. An optimal sustainable stocking rate was selected as that which gave highest profit while keeping the frequency of low ground cover of at least 70% below a location specific threshold; all results are reported at this stocking rate.

Results

Rainfall

Long-term (1899-2010) annual average rainfall ranged from a minimum of 297 mm at Kyancutta to a maximum value of 1058 mm at Ellinbank. As shown in Figure A5.1, Ellinbank had the largest variation among locations (S.D. = 76 mm) while Lake Grace had the lowest variation (S.D. = 18 mm). The expected relationship of increasing rainfall variability with increasing average rainfall across locations was clearly evident (Figure A5.2).

Averaged over the locations, 1997-2010 was the driest of the eight 14-year time intervals across southern Australia with an (area-weighted) average annual rainfall of 479 mm; the wettest period was 1955-68, where the corresponding average rainfall was 560 mm. Average rainfall was least variable across locations in 1997-2010

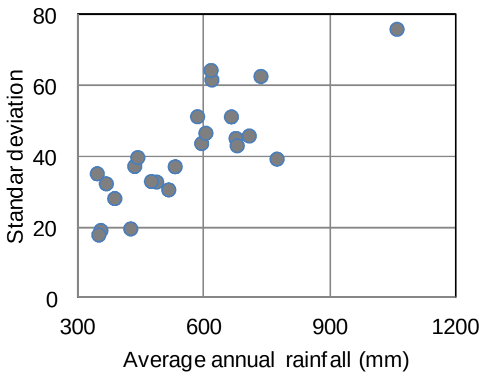


Figure A5.2. Relationship between standard deviation and average of annual rainfall of the eight focus periods. Each point denotes a location.

(area-weighted S.D. = 134 mm), showing that this dry period affected entire southern part of Australia. The largest variability across locations was observed during 1941-54 (S.D = 175 mm), which was the second-wettest of the 8 time periods.

Temperature

Annual average temperatures are less variable over time than annual rainfall. As shown in Figure 3, average temperature was least variable at Stawell (S.D = 0.15ºC) and the most variable at Colac (S.D = 0.55 ºC). Over the examined locations, there was no correlation between the standard deviation and annual mean values of temperature.

Above-ground net primary productivity (ANPP)

Long-term average area-weighted ANPP across Southern Australia was modelled to

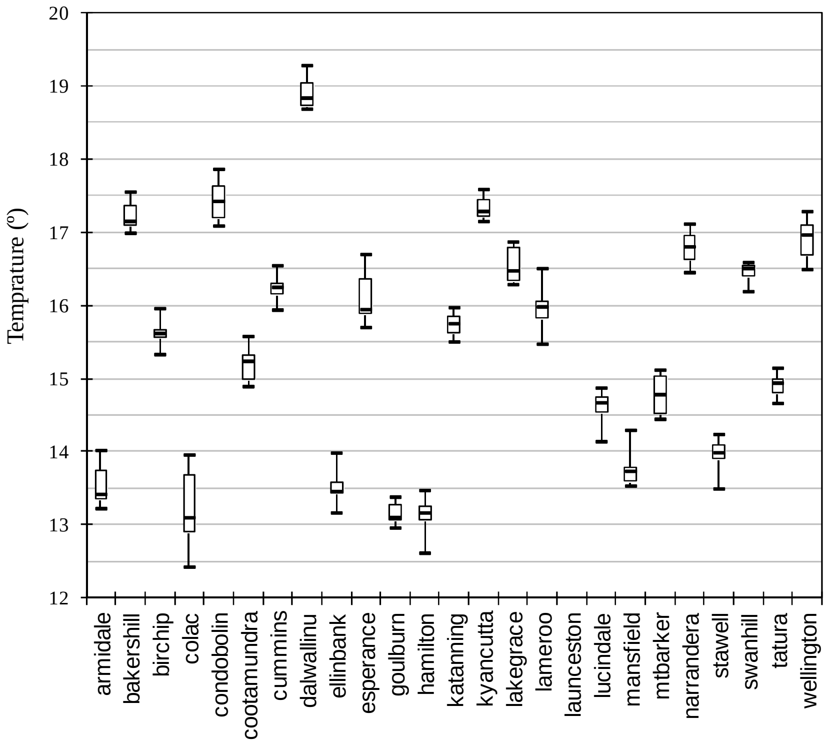


Figure A5.3. Boxplots showing the variation of 14-year average temperatures across 25 representative locations in southern Australia. Each boxplot shows the distribution of average mean temperature over a set of eight 14-year periods starting with 1899-1912.

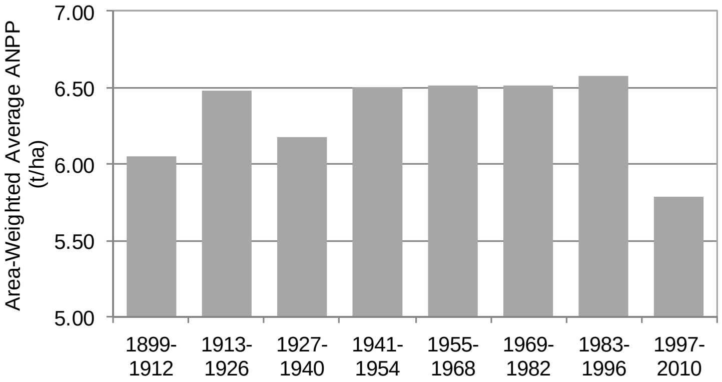


Figure A5.4. Area-averaged annual aboveground net primary productivity across 25 regions of southern Australia in each of eight 14-year periods when modelled with present-day grazing systems.

be 6.2 t/ha. Over the 1899-2010 period, the average ANPP estimated for the single Tasmanian location (Launceston) was 8.5 t/ha. South Australia had the lowest state average ANPP of 5.2 kg/ha, with locations ranging from 3.1 t/ha to 8.4 t/ha. For Victoria, pasture production was estimated to range from 3.5 t/ha to 14.0 t/ha with an average 7.6 t/ha. New South Wales had average value of 5.6 t/ha (3.4 to 8.1 t/ha across locations), and for Western Australia the average was 5.7 t/ha (2.9 to 11.3 t/ha across locations).

Over the eight 14-year time periods, there were five periods with very similar area-weighted average ANPP and three periods (1899-1912, 1927-1940 and 1997-2010) where it was much lower (Figure A5.4). Pasture production across South Australia over the 1997-2010 period was estimated to be 22% lower than the 1899-1996 average; the corresponding decline in Tasmania was estimated to be only 3%.

The modelled variability of annual ANPP also differed between locations (Figure A5.5). Bakers Hill had the lowest ANPP variability with a standard variation of 0.22

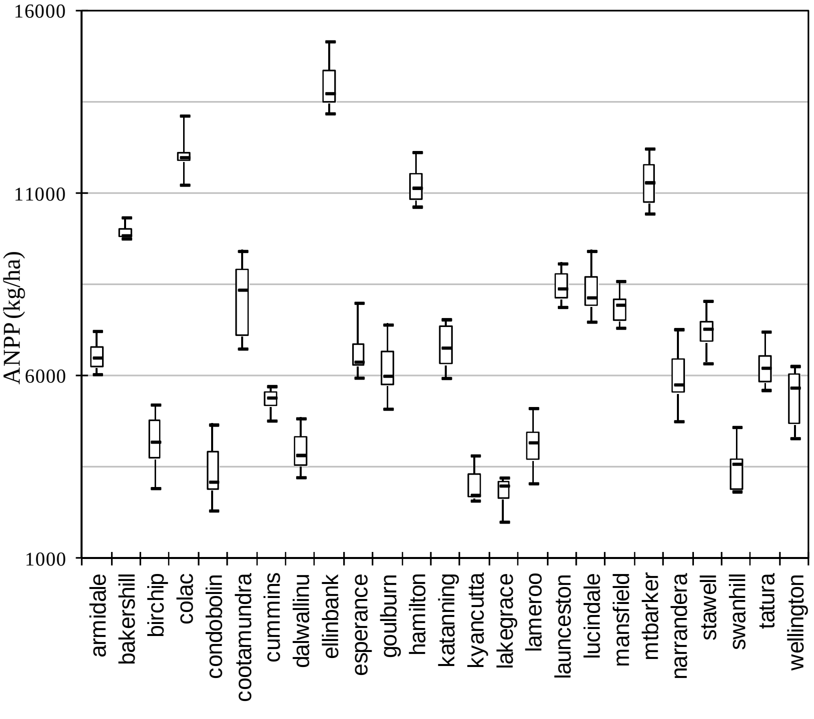


Figure A5.5. Boxplots showing the variation of 14-year average aboveground net primary productivity across 25 representative locations in southern Australia. Each boxplot shows the distribution of average annual ANPP over a set of eight 14-year periods starting with 1899-1912.

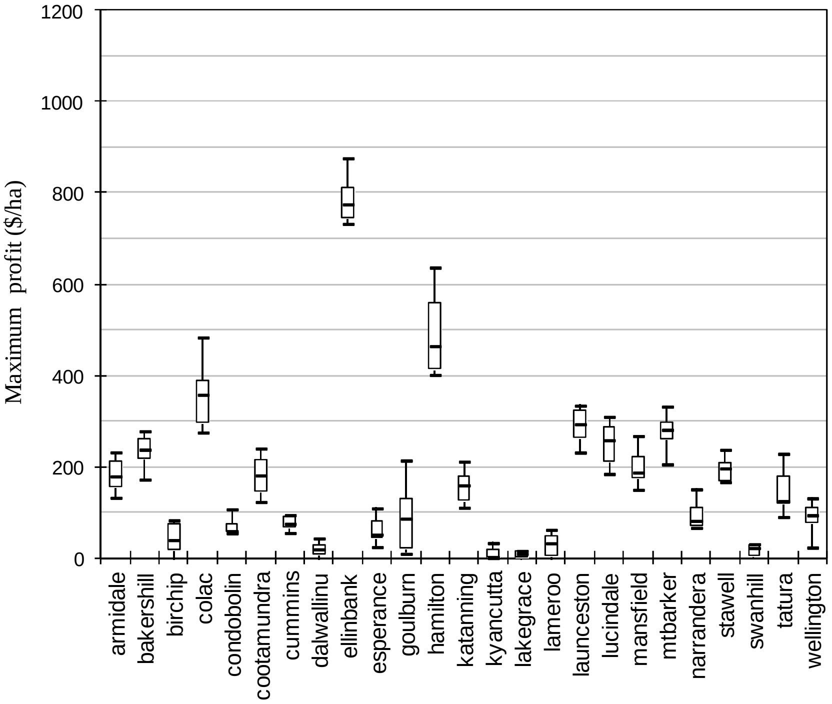


Figure A5.6. Boxplots showing the variation of 14-year average operating profit across 25 representative locations in southern Australia. Each boxplot shows the distribution of average annual operating profit (at the period's optimal sustainable stocking rate) over a set of eight 14-year periods starting with 1899-1912.

t/ha; Cootamundra and Narrandera had most variable of pasture production, with standard deviations of 1.03 and 0.83 t/ha, respectively. As expected, mean ANPP was lower at locations with lower rainfall. No relationship was observed between modelled ANPP and its standard deviation across either locations or focus periods.

Operating profit

The highest modelled long-term average operating profit (at the optimal sustainable stocking rate) was found at Ellinbank (Victoria) with $910 /ha/year, and the lowest estimated operating profit was at Lake Grace ($1/ha/year). The highest variation and consequently uncertainty of maximum profit among the locations were at Colac, Goulburn and Hamilton; however the lowest profit values at Colac and Hamilton were still larger than the maximum at most of the other locations (Figure A5.5).

When comparing States, South Australia had the lowest average profit at optimal sustainable stocking rates ($93/ha, with locations ranging from $13/ha to $253/ha. The mean operating profit of Victorian locations was $279/ha (range $18/ha to $785). For New South Wales the corresponding figure was $124/ha (range $69 to $183/ha); in Western Australia it was $126/ha ($9 to $275/ha); and for the single Tasmanian location, operating profit was 291 $/ha.

Variability and uncertainty of production at national, state and regional scales under variable climate

Taken across southern Australia, operating profit over the 8 time periods was non-linearly related to the both annual rainfall and the standard deviation of annual rainfall for the period, with declining returns to increasing annual rainfall (Figure A5.7). As shown in Figure A5.7, period-average operating profit was more closely related to the standard deviation of rainfall than to average rainfall. Variability of operating profit variation was not related either to rainfall or to its spatial variability.

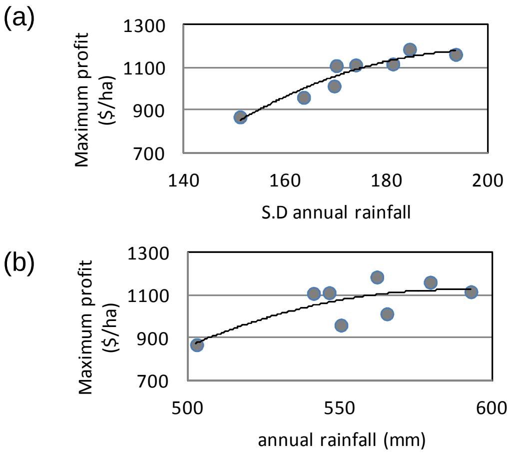


Figure A5.7. (a) Relationship between standard deviation of maximum profit over classified time periods and annual rainfall depth and (b) standard deviation of rainfall.

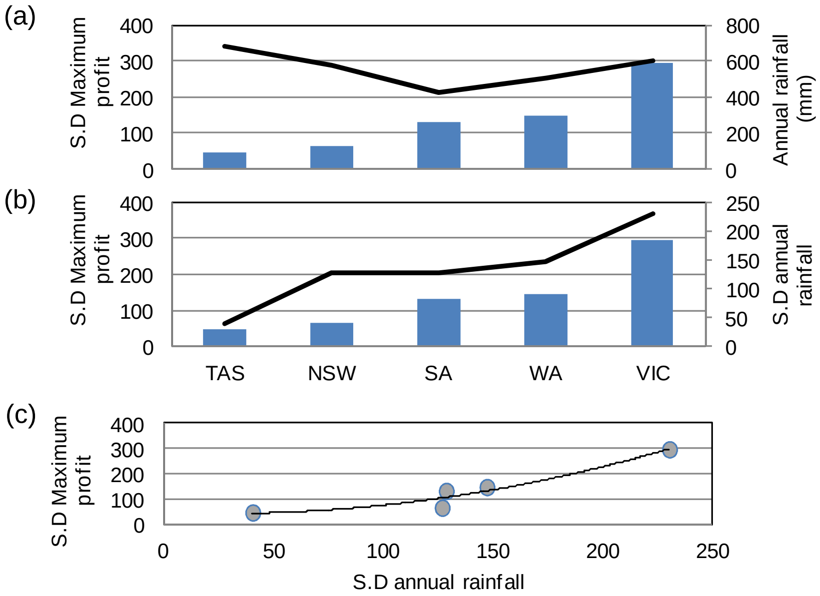


Figure A5.8. Trend of change in standard deviation of maximum profit at states (column) with (a) annual rainfall shown with solid line and (b) standard deviation of annual rainfall. (c) Relationship between standard deviations of maximum profit and annual rainfall as index of variability

As shown in Figure A5.8(a), the standard deviation of operating profit and annual rainfall didn’t have similar trend, but had similar trend with standard deviation of rainfall (Figure A5.8(b)), and there was a slightly non-linear relationship between standard deviations of maximum profit and standard deviation of annual rainfall depth (figure A5.8(c)). However individual examination of locations didn’t demonstrate similar trend of maximum profit was observed in association to either annual rainfall or standard deviation of rainfall (Figure A5.9).

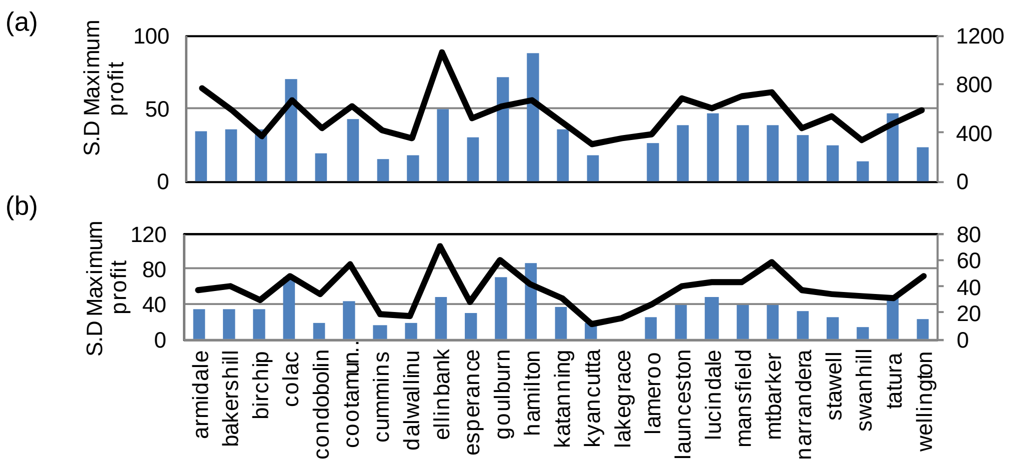


Figure A5.9. Standard deviation of operating profit over 1899-2010 at each of 25 locations (columns, left axis) compared with (a) mean annual rainfall (solid line, right axis) and (b) standard deviation of annual rainfall.

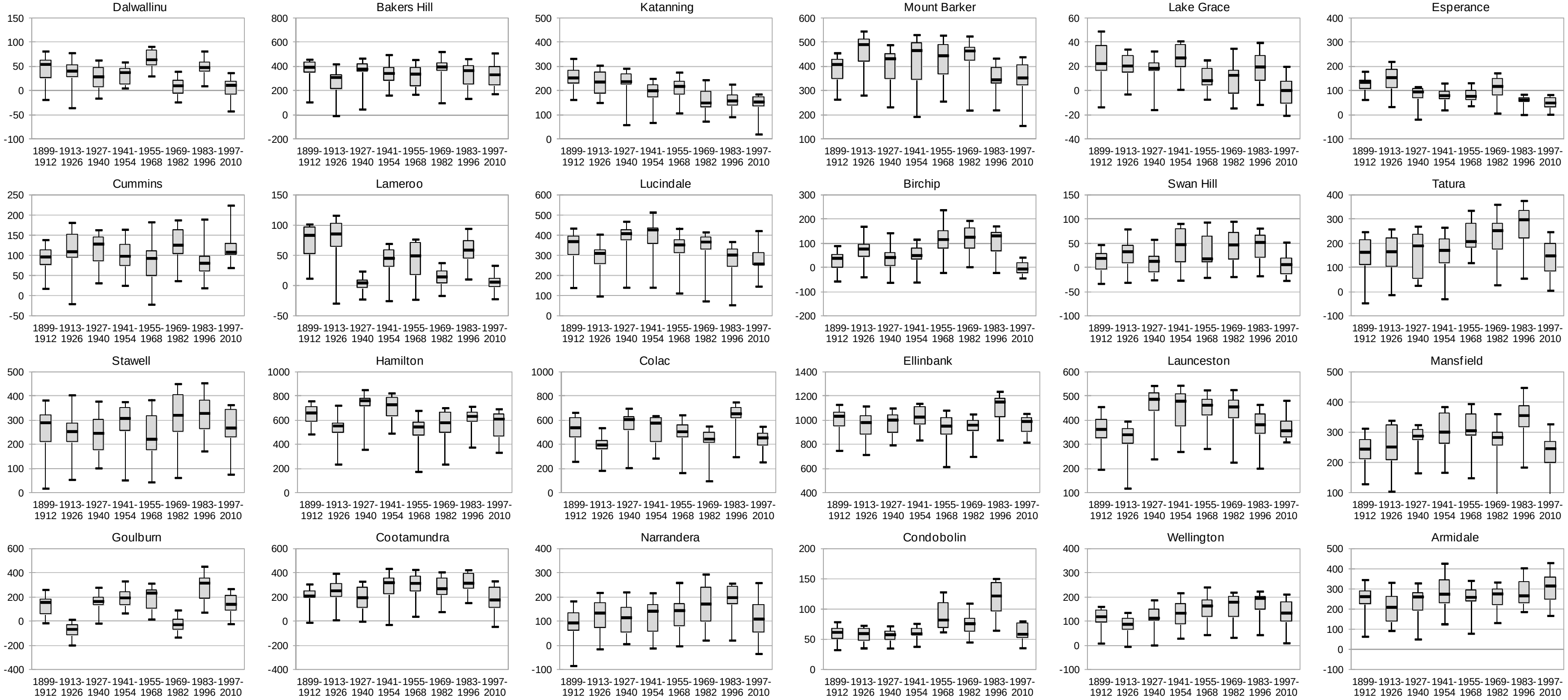
The null hypothesis that the rainfall, temperature, ANPP, and maximum profits at focus dates of 1906, 1920, 1934, 1948, 1962, 1976, 1990 and 2004 followed a normal distribution was rejected by a t-test at all locations. The only exception was normality of operating profit distribution at Birchip.

Operating profit and its variability at local scales

Figure A5.10 shows modelled average operating profit and its variability (at individual optimal sustainable stocking rates) at each location over each of eight 14-year periods going back to 1899. Examination of these figures shows that the locations fell into a relatively small number of groups:

- At most of the Western Australian locations, profitability during 1997-2010 was lower than in the other 7 periods but this reflected a steady decline in the climatically-driven level of profitability, rather than a sudden shift. (Bakers Hill was an exception, showing no clear trend over time.) Lameroo (SA) exhibited a similar, but less pronounced, pattern.
- At Cummins (SA), no trends in profitability over time could be discerned; profitability in the 1997-2010 period fell within the range found in other periods.
- The six Victorian sites, Launceston (Tas), Lucindale (SA) and Cootamundra (NSW) showed increasing profitability early in the long-term record followed by later decreases. At Hamilton, Colac, Stawell and Launceston the 1997-2010 period, while less profitable than the immediately preceding period, fell within the overall range of climatic conditions as a driver of livestock systems; at the other 5 locations the 1997-2010 period showed a lower average operating profit than all of the 7 preceding periods.
- At Armidale, there was a generally increasing trend in profitability that continued into the 1997-2010 period.
- The other 3 New South Wales sites (Narrandera, Condobolin and Wellington) also exhibited a long-term trend of increasing profitability. At these locations the 1997-2010 period was much less profitable than the immediately preceding period, but there were earlier periods that were less profitable.

Figure A5.10. Boxplots showing modelled annual operating profit of a Merino ewe enterprise over 8 periods from 1899 to 2010 at each of 25 locations across southern Australia. Locations are arranged geographically, and the scales for each location are different so as to show the differences between periods more clearly.



There was no evidence to suggest an increase in the variability of profitability (measured in absolute terms) at any of the locations, either comparing the 1997-2010 period with the rest of the historical record or as a trend over time.

Discussion and Conclusions

As expected, there was a strong relationship between the variability of rainfall over the medium term (14-year periods) and average rainfall at a location (Figure A5.2); locations with high rainfall and larger variability still had higher minimum rainfalls than locations with low rainfall. Annual rainfall variability differed among locations across Southern Australia in ways that that may lead to different risk profiles among locations as climate changes.

Modelled ANPP showed much lower variation than did operating profit, demonstrating higher degree of uncertainty in profit modelling. This increased uncertainty can be result of uncertainties in model input, model structure, current animal modelling formulations, and also averaging five probable livestock systems without selecting the most suitable one.

The modelled variability of operating profit between periods looked quite different at different spatial scales. Over southern Australia as a whole or across States, operating profit or its medium-term variability could be related to the medium-term variability of rainfall (Figures A5.7 and A5.8), but within individual regions, variation was not related to the rainfall or ANPP; uncertainty increases with movement toward smaller spatial scales. This would suggest the advisability of designing and evaluating adaptation strategies at more local scales.

Whether the recent drought (included in the 1997-2010 period) was the worst in the 112 years modelled here depended on the location. Across most of Western Australia and at Lameroo, the 1997-2010 period could reasonably be seen as part of a larger drying trend. In much of south-eastern Australia, on the other hand, the impact of the “millenium drought” may have been due as much to the sudden change from the relatively favourable conditions experienced in the late 1980s and 1990s as to departure from the long-term average climate. In central New South Wales, and especially at Armidale, there were other time periods when the profitability of present-day grazing systems would have been lower than during 1997-2010

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