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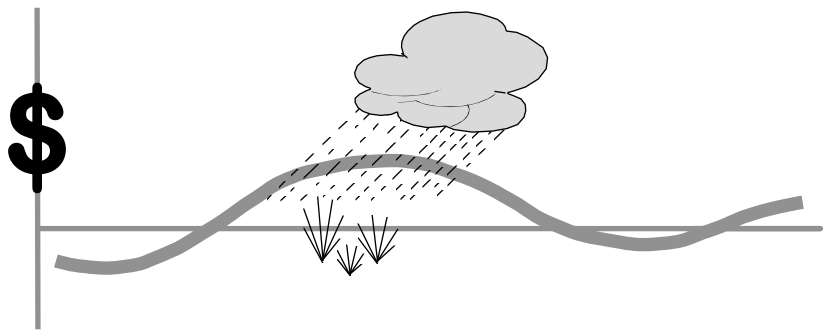

Validation of reproduction and mortality rates for northern Australian beef and sheep breeders

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SUMMARY

Climatic variability and stocking rates in the grazing lands of Australia have a major influence on animal mortality and reproduction. This study aimed to quantify those effects so that the key “biological rates” of mortality and reproduction could be predicted, and then tested against data from producers’ properties.

For sheep, a reparameterised GRAZPLAN process model with an empirical equation to predict the probabilty of ewes mating, predicted the probability of pregnancy well (86% variation explained) but the GRAZPLAN model to predict mortality did not apply. Empirical models explained 88% and 78% of the variation in pregnancy and mortality rates respectively. However, a crucial predictor in these models was liveweight which is not often recorded on producer properties.

Hence the pasture production model GRASP was used to estimate climatic and pasture measures for Mitchell grass (*Astrebla sp.*) pastures, from which marking and mortality rates could be predicted. Age of the ewe, measures of favourable conditions for pasture growth, and the availability of dry matter at joining proved to be major predictors. Predictions were improved with the inclusion of a measure of frost on the pasture during the crucial joining to marking period together with other grass quality measures. These prediction equations were then tested against independent data from producer properties and the model successfully validated for Mitchell grass communities. Further testing on properties with other vegetation such as mulga and chenopod shrubland which have a browse component, was undertaken to examine the potential of this approach. Further work is needed to produce a better model for non Mitchell grass pasture communities and to explain the variation experienced under extreme and infrequent conditions on all pasture communities. The inclusion of climatic variables in addition to pasture measures could indicate the need to evaluate further the responses to the growth of forbs.

For beef cattle, the key predictors of biological rates in the research stations data were liveweights, age, breed, lactation status and weight changes of the animals. From beef producers’ properties, an adequate number of validation data sets were collated, which included these key variables. The observed patterns in the producers’ data differed significantly from those found in the research stations data, upon which the predictive models were formed. Mortalities on the producers’ properties were about twice those predicted, and conception rates (per oestrus cycle) were only around 0.64 of the estimates. Acquisition of beef producers’ data is ongoing, particularly from the Northern Territory, with a view to fitting separate models for these. In the interim, the above calibration rates applied with the research stations model can be used to predict the likely range of biological rates on producers’ properties.

INTRODUCTION

The DroughtPlan project is seeking to develop profitable and sustainable strategies for managing climatic variability in the grazing lands of Australia. One of the key linkages between variability in rainfall and variability in economic production lies in differences between seasons in the "biological rates" of flocks and herds, i.e. the rates of animal mortality and reproduction (e.g. Foran *et al.* 1990). Our lack of understanding of this link is a significant bottleneck in our ability to analyse the effects of climatic variability on pastoral systems, especially in the rangelands.

In Working Paper No. 5 “Modelling of research data on reproduction and mortality of cattle and sheep” Moore *et al.* (1995) established models to predict the probability of pregnancy and mortality. Based on data from Toorak Sheep Field Research Station and producer properties in the Augathella and Charleville area, these biological rates explained 86-8% and 78% variation for pregnancy and mortality respectively. To predict pregnancy rate, age class (maiden or mature) and the liveweight at post-joining were needed. While to predict mortality, minimum body condition at pre-joining, post-joining, pre-lambing and marking were required together with pregnancy rate and age. Hence, liveweight is a crucial index. Given the paucity of liveweight data on producer properties, the validation was planned as a two stage process. The grass production (GRASP) model would predict liveweight from climatic measures and pasture estimates and these predictions in turn would be used to estimate the probability of pregnancy and mortality from the biological rate equations. A detailed analysis of liveweight data from grazing trials (W. Hall and G. McKeon, *per. comm.*) showed that it was not possible to simulate liveweight change with the required accuracy to use in vital statistics models. (Percent variation explained was usually less than 50%.) Hence this approach was abandoned in favour of predicting marking rate and mortality directly from climatic measures and pasture estimates, and validating these predictions against independent producer data.

For beef cattle, liveweight or condition scores were generally available in the producer data sets. Hence the estimated relationship from Moore *et al.* (1995) could be directly compared against observed mortality and conception rates.

DATA SOURCES

Northern Australia – sheep

Prediction data

Sheep data were drawn from those studies which recorded liveweight and were previously used to establish the biological rates for northern Australian sheep (Moore *et al.,* 1995) together with another reproduction study involving commercial properties in south west Queensland (O'Dempsey, 1990). Details of these flocks with data on joining dates, age of ewe, number of ewes at joining and marking and marking percentages, which were used in the prediction of reproduction and mortality are given in Table 1.

Table 1. Summary of data sets used for prediction

Source	District	Cohorts	No. ewes years	Joining times	Stocking rate (sheep/ha)	Pasture
Rose (1972, 1974, 1976, 1978, 1982)	Julia Creek	80	4209	November	.63	Mitchell (*Astrebla sp.*)
Jordan *et al.* (1989)	Augathella	6	991	April, May, June	.76	Mitchell
Jordan *et al.* (1989)	Charleville	5	2317	April, May	.76	Mitchell
O'Dempsey (1990)	Blackall	4	1642	July, October, December	.62, .71	Mitchell

Meteorological data (daily rainfall and maximum and minimum air temperatures) at the above sites were made available per courtesy of the Drought Research Group, Department of Primary Industries. For properties in the Blackall district, meteorological data from Blackall town were used.

Validation data

The validation data can be grouped into three categories:

1. Flocks from similar areas to those of the prediction data, and for which the number of ewes at joining are known in addition to age, time of joining, number of ewes and lambs at marking (Table 2).

Table 2. Summary of data sets used for validation of marking and mortality predictions

Source	District	Cohorts	No. ewe years	Joining times	Stocking rate (sheep/ha)	Pasture
Jordan *et al.* (1989)	Charleville	3	532	April, May	.76	Mitchell
Jordan *et al.* (1989)	Roma	1	251	April	1.1	Mitchell
Jordan *et al.* (1989)	Muckadilla	9	3342	March, April	1.1	Mitchell
Armstrong *et al.* (1976)	Roma	3	774	July, March, May	1.1	Mitchell
O'Dempsey (1990)	Blackall	4	1826	February, April & September	.49, .62, .71	Mitchell

2. Flocks from similar areas to those of the prediction data, for which only the number of ewes and lambs at marking, age and time of joining are known (Table 3).

Table 3. Summary of data sets for validation of marking rate (lambs/no. ewes at marking)

Source	District	Cohorts	No. ewe years	Joining times	Stocking rate (sheep/ha)	Pasture
O'Dempsey (1990)	Blackall	19	18538	February, September, March, April	.62, 71	Mitchell
O'Dempsey (1990)	Augathella	4	2704	September, October	.71	Mitchell
O'Dempsey (1990)	Charleville	3	2396	November, February	.25, .62	Mulga Frontage

3. Flocks with reproduction and mortality records of similar detail to category (2) but from other geographical areas with different pasture communities.

   Details of marking and mortalities data recorded for different age groups over several years for merino sheep on five properties in New South Wales and South Australia are given in Table 4.

Table 4. Data sets from other geographical areas

Source	District	No. of Cohorts	Joining times	Stocking rate (sheep/ha)	Pasture	Sheep
R Buxton (1995 *per. comm.)*	Darnick	57	February/ March	.25	chenopod shrublands with lakebed country	medium framed Merino
R Buxton (1995 *per. comm.)*	Weilmoringle	23	February/ March	.46	floodplains with coolibah and blackbox trees and neverfail and coolah grasses	small framed Merino
R Buxton (1995 *per. comm.)*	Tarcoola	28	December/ January	.077	Mulga country with bluebush and saltbush understorey	large framed Merino, SA strain
		61	February/ March	.026		
R Buxton (1995 *per. comm.)*	Port Augusta	23	December/ January	.054	Saltbush/bluebush with overstorey of Western Myall; predominantly annuals	medium framed Merinos - rams SA strain

Although these five properties lie outside the area for which the Mitchell grass prediction model could reasonably be extrapolated, they are included to investigate the potential of the approach.

In a few cases in each of these categories, age was not defined accurately eg 2 and 3 yr olds; 4, 5 and 6 yr olds. In these cases, estimates were made over the range of ages. As with the meteorological data for the sources of the prediction data, daily rainfall, maximum and minimum temperature were obtained for the latitude and longitude of the properties from which validation data was drawn. For properties in the Blackall district, the meteorological data at Blackall was used.

Northern Australia – cattle

An extensive literature and data search was conducted, with usable sets limited to

- Northern Australia (Queensland, Northern Territory and northern Western Australia)
- data from commercial producers' properties (ie, not research stations)
- listed reproduction or mortality rates for cohorts of breeders
- listed weights or body condition scores

The last condition was included because the prediction equations require estimates of the key 'body condition' variable ($BC_{0.01}$). As expected, data sets were initially hard to find, but persistence indentified a good number, from a range of sources. An overview of these is listed in Table 5. In all, the mortality data covers 1,925 cow-years, and 17,796 cow-years are reported in the conception rate data.

Table 5. Summary of data sets containing biological rates for northern Australian beef breeders, from properties other than research stations.

Reference	Location	Years	Breeds+	No. cow-years for -	
				Mort.	Concept.
With weights -					
Barr & Burns (1972)	Brisbane Valley (SQ)	1970	Br	80	80
Donaldson (1971)	Townsville (NQ)	1967	*Zx*	-	50
Donaldson *et al.* (1967)	Townsville (NQ)	1961	Br	-	107
Hart & Michell (1965)	Barkly Tableland (NT)	1961-'62	*Zx*	-	166
Rudder *et al.* (1985)	Mt Eugene (CQ)	1972-'83	Mixed	-	3868
Schlink *et al.* (1988)	NT herds	?	*Zx*	-	167
Schlink *et al.* (1994a)	Gulf Region (NT)	1985-'90	*Zx*	570	2280
Schlink *et al.* (1994b)	Townsville (NQ)	1992	*Zx*	-	55
Stone & Burnside (1987)	Yarraloola (WA)	1971-'75	*Zx*	-	261
Taylor *et al.* (1982)	Mingela (NQ)	1971-'73	*Zx*	93	364
unpublished (QDPI)	Mt Tom (SQ)	1989	*Zx*	-	366
unpublished (QDPI)	Mundubbera (SQ)	1989	*Zx*	42	-
unpublished (QDPI)	Monto (SQ)	1989	*Zx*	103	-
With Condition Scores -					
Donaldson *et al.* (1967)	Properties across Qld	1960-'61	Br & *Zx*	-	1680
Fordyce *et al.* (1990)	Charters Towers (NQ)	1982-'83	*Zx*	1037	814
Holroyd 1977	NQ herds	1970-'76	Br & *Zx*	-	3480
unpublished (QDPI)	Mingela (NQ)	1990-'94	*Zx*	-	4058

+*Zx* = Zebu crosses ; Br = British

METHODS OF ANALYSIS

Sheep - Calculation of climatic measures

From the meteorological data, a number of climatic measures were calculated, as possible explanatory variables to predict mortality or marking percentages.

Table 6. Climatic measures investigated as potential predictors.

Measure	Descripton
rd_i	rainfall in the growing season prior to joining. The beginning of the growing season was defined as the date after 1 July when the sum of the rain over up to three days was greater than 10 mm and the average temperature greater than 14^0C for Mitchell grass and 9^0C for mulga. The end of season was specified by the date of the last similar event before 30 June of the next year
rd_{i-1}	rainfall in the previous growing season
$days_i$	days from end of growing season to mid joining (as a crude estimate of quality)
day_{i-1}	days from end of previous growing season to mid joining
rddays	number of rain days in the growing period
drydays	days from the end of previous growing period to beginning of next
rdbreak	rainfall if current season breaks, from that time to mid joining eg if joining is in November and there are early storms, the growing season is still defined as the previous spring summer and the rainfall since the first significant event (defined above) to mid joining recorded as a separate variable

Sheep - Calculation of GRASP soil moisture and pasture measures

Parameters for GRASP describing the soil; water balance; growth, death, detachment and utilisation of pasture by animals had been calibrated for Mitchell grass on clay at Toorak and mulga on sandy soils (McKeon *et al.* 1988) and Mitchell grass on clay at Airlie (P. Johnston, 1995, *per. comm.*).

The Toorak parameter file was used for all sites of the prediction data, validation data categories 1 and 2 with the exception of the Mulga sites, and the second property of category 3. For all the other properties in category 3, GRASP parameters were derived from calibration with pasture data from Kinchega, NSW (data from G. Robertson) and Alice Springs, NT (data from T. Hobbs). Tree/scrub basal area (m^2/ha) was varied.

For the purpose of determining utilisation the small, medium and large bodied Merinos were assumed to weigh 40, 50 and 60 kg. The only other parameter in the management file to vary was stocking rate.

With the meteorological data as input variables, the GRASP model was run to obtain estimates of soil moisture and pasture growth (Table 7).

Table 7. Soil moisture and pasture measures investigated as potential predictors.

Measure	Descripton
dm	dry matter (kgs) at mid joining
Δdm	change in dry matter between mid joining and marking
N	proportion of nitrogen at mid joining
ΔN	change in proportion nitrogen from mid joining to marking
U	proportion of growth utilised by stock in year prior to mid joining
ΔU	proportion utilised by stock between mid joining and marking
d_j, d_m	number of drought days at joining and marking since soil moisture went below a threshold of soil water in 10-100cm layers
g	proportion of green leaf at mid joining

Measure	Descripton
Δg	change in proportion green leaf joining to marking
swi_{j-1}, swi_{m-1}	number of days the soil water index was higher than 0.4 in the two years period to mid joining or marking
$tswi_{j-1}$, $tswi_{m-1}$	as above except average temperature must also be greater than 14^0C for Mitchell grass and 9^0C for Mulga (conditions for growth
swi_j	number of days the soil water index was higher than 0.4 in the year prior to mid joining
$tswi_j$	as above except average temperatures must also be greater than 14^0C for Mitchell grass and 9^0C for mulga
Δswi	number of days the soil water index was higher than 0.4 from mid joining to marking
$\Delta tswi$	as above except average temperature must also be greater than 14^0C for Mitchell grass and 9^0C for mulga
dr_j	number of drought days in year prior to mid joining
dr_{j-1},dr_{m-1}	number of drought days in two years prior to mid joining and marking
Δdr	number of drought days from mid joining to marking
f	measure of frost and its severity on pasture as defined by $\sum$(2- minimum temperature) if minimum temperature 2^0C or less in the period from end of growing period to mid joining
Δf	as above except for period mid joining to marking

Sheep - Statistical Analysis of Prediction Data

Screening analyses were undertaken to determine prospective predictors from the climatic, soil moisture and pasture measures defined above. General linear models (of both discrete factors and continuous variates) were fitted to the dependent variates.

For marking percentages, the general linear models were fitted by analyses of variance using a normal error model. However, as a considerable portion of the mortality data was in the 0 to 5% range, it was inappropriate to assume a normal distribution of sampling errors. General linear models were therefore fitted via analysis of deviance, using a binomial error distribution and logit link function.

Models were determined by using the step-forward method of successively including the next best predictor. In all analyses, the number of observations in each cohort or cell was used as a weighting factor.

Sheep -Validation

The statistical models determined from the analysis of the prediction data were used to predict reproduction and mortality from raw climatic and GRASP climatic and pasture measures for the sites of the validation flocks at the relevant times.

These estimates were compared with the observed reproduction and mortality data. Where only the age range of the ewes was known, values were predicted for the range. However to calculate the correlation between predicted and observed values the mean age was used.

For the validation set from other geographical areas with differing pasture communities preliminary analyses were undertaken to investigate the potential of explaining reproduction and mortality from climatic and pasture measures.

Cattle - Statistical Methods and Validation

The empirical models derived in Moore *et al.* (1995) were used to predict conception rate and mortality.

$$CR = -1.35 + 2.57BC_{0.01} - 0.99BC_{0.01}^{2} + AL + B + 0.0428\ell n(\Delta W + 8.0)$$

where *CR* is conception rate per cycle, $BC_{0.01}$ is relative condition (ratio of current to normal weight N), ΔW is weight change during the mating period (in kg per month) and the age/lactation (*AL*) and breed (*B*) factors are given in Table 8.

Table 8 Age/lactation and breed parameters.

Age & lactation status	AL
Heifers	0.0
Cows (three years old, lactating)	-0.103
Cows (>three years old, lactating)	-0.046
Cows (non-lactating)	0.030

Breed	B
British (F_n)	0.0
European crosses (F_1,F_n)	-0.006
Africander crosses (F_n)	0.120
Zebu crosses (F_1)	0.061
Zebu crosses (F_n)	0.025

The normal weight, *N*, of a mature animal is defined as

$$N = SRW - (SRW - W_{birth})\exp\left(\frac{-0.010_1 A}{SRW^{0.27}}\right)$$

where *A* is the age of the animal (in days), W_{birth} is weight at birth and the standard reference weight, *SRW*, is defined in SCA (1990) as the liveweight excluding fleece and conceptus, *W*, of an animal when skeletal development is complete and condition score is in the middle of the range.

$$AMR = \frac{1}{1 + e^{-y}}$$

$$y = -21.3 + 40.7BC_{0.01}^{*} - 24.2BC_{0.01}^{*2} + 1.05A - 0.893A \cdot BC_{0.01}^{*} - 0.0225\Delta W$$

where *AMR* is annual mortality rate, *A* is age in years and ΔW is weight change over the dry period in kg per month.

To test these equations against the validation data, cohorts of animals were processed at the maximum degree of resolution reported. Frequently, these were whole or sub-herd totals, pooling across years, age or lactation classes, or applied paddock or animal treatments. Fortunately, breeds were usually reported separately. Due to the scarcity of data, condition scores (CS) were provisionally included in the analyses with equal weighting to data with liveweights. Across these and the initial data sets, three different CS scales were found, with varying levels and animal descriptions. The conversion of these scales to $BC_{0.01}$, the necessary variable for the prediction equations, is as listed in Table 9. The mid-point of each range was assigned to each score, and intermediate values interpolated. These values appear reasonable, as in the original data, $BC_{0.01}$ ranged between 0.59 and 1.36 for groups of animals.

Table 9. Conversion of condition score (CS) scale to $BC_{0.01}$

Description of animal	CS Value (0-9 scale)	Nominal $BC_{0.01}$ Range
Emaciated	0	0.5 - 0.6
Very poor	1	0.6 - 0.7
Poor	2	0.7 - 0.8
Backward store	3	0.8 - 0.9
Store	4	0.9 - 1.0
Forward store	5	1.0 - 1.1
Prime	6	1.1 - 1.2
Fat Prime	7	1.2 - 1.3
Fat	8	1.3 - 1.4
Over-fat	9	1.4 - 1.5

For each cohort of animals, conception and mortality rates were calculated, along with the key predictor variables identified from previous analyses. Data summaries of these are listed in Tables 10 and 11. These data were extracted both to test the degree of relationship across the range of observed values, and to facilitate any re-parameterisation or fitting of alternate models which may prove necessary. Some of the data sets were identified as 'having problems', for example Donaldson (1971) reported that vibriosis was present, but the extent or impact of this problem was not discussed. Also, a number of data sets were somewhat dated, and the genetic makeup of these animals may be different from those in the industry in more recent times.

Table 10. Data summaries for mortality (% per annum) data

Variable :	Observed Mortality	Predicted Mortality	$BC_{0.01}$	Age (years)	Dry Season Weight Change (kg/month)
Mean	13.7	6.0	0.83	4.1	-16.9
Std. Deviation	14.5	3.4	0.10	0.9	8.1
Minimum	0.0	0.4	0.70	2.8	-24.4
Maximum	51.0	11.5	1.05	5.3	-5.0

Table 11. Data summaries for conception rates (CR, % per cycle) data

Variable :	Observed CR	Predicted CR	$BC_{0.01}$	Age (years)
Mean	17.3	28.9	0.94	4.1
Std. Deviation	9.5	10.8	0.13	1.4
Minimum	4.5	6.3	0.68	2.0
Maximum	52.8	42.3	1.16	6.0

Regression analysis, weighted by the number of cow-years for each point, was used to compare predicted mortality and conception rates with observed values. The latter were taken as the independent (Y) variable, to conform with statistical assumptions (Mayer & Butler 1993). The relationship was tested for curvature, for the significance of an intercept different to zero and a slope different to one, and for poolability across the discrete factors (breed, lactation status) and the observed ranges of the continuous predictor variables (age, $BC_{0.01}$, weight changes).

RESULTS

Northern Australia - sheep

Statistical Analysis of Prediction Data Set

Many of the raw climatic and GRASP climatic and pasture measures listed as potential predictors are indirect measures of the same parameter (availability and quality of diet and the animals' condition) and are correlated. The amounts of variation explained by individual predictors are given in Table 12. Marking rate (MR_j) is defined as the number of lambs as a proportion of the number of ewes at joining. As shown in Tables 13 and 14, and Figures 1 and 2, 81% and 63% of the variation in mating and mortality rates (DR) respectively could be explained by age, climatic and pastures measures, condition of the animal being indirectly described by climatic and pastures measures of the previous season.

$$MR_j = -0{\cdot}018 + 0{\cdot}000911\, swi_{j-1} + 0{\cdot}1396\, age - 0{\cdot}01341\, age^2 + 0{\cdot}000417 dm$$
$$-0{\cdot}00000015\, dm^2 + 0{\cdot}0858\, \Delta N + 0{\cdot}00501\, rddays - 0{\cdot}0031 \Delta f - 0{\cdot}000658\, day_{i-1} \cdots (1)$$

or

$$MR_j = 0{\cdot}360 + 0{\cdot}000862\, swi_{j-1} + 0{\cdot}1391\, age - 0{\cdot}01336\, age^2 - 0{\cdot}363 e^{-0.00262 dm}$$
$$+ 0{\cdot}0734\, \Delta N + 0{\cdot}00476\, rddays - 0{\cdot}00321 \Delta f - 0{\cdot}000801\, day_{i-1} \cdots (1a)$$

$$DR = \frac{1}{1 + e^{-y}}$$

where $y = -3{\cdot}218 + 0{\cdot}2383\, age - 0{\cdot}00226\, tswi_{j-1} - 0{\cdot}000619\, dm + 0{\cdot}01586 \Delta f$

$$-0{\cdot}01026\, rdbreak + 0{\cdot}002513\, day_{i-1} - 0{\cdot}001345\, rd_{i-1} \cdots (2)$$

Table 12. Sheep prediction data set: statistical predictors of marking and mortality rate. Figures are R^2 given as a percent.

	Marking	Mortality
Age	12.4	35.7
Age + Age^2	24.6	
Raw Climatic Measures		
rd_i	6.3	7.9
rd_{i-1}	21.4	21.2
rdbreak	11.6	17.1
rddays	55.5	24.5
$days_i$	33.0	3.2
$days_{i-1}$	44.7	5.5
drydays	50.8	18.0
Climatic Measures from GRASP		
swi_j	53.4	11.7
swi_{j-1}	61.1	17.3
$tswi_j$	38.7	12.7
tsw_{j-1}	51.0	23.0
dr_j	45.8	7.8
dr_{j-1}	54.7	15.0
swi_{m-1}	57.9	9.9
Δswi	4.8	0
$tswi_{m-1}$	53.4	10.5
dr_{m-1}	46.8	5.8
d_j	32.6	9.3
Pasture Measures from GRASP		
dm	35.0	14.6
$dm + dm^2$	46.6	
N		
U	8.1	2.5
g	29.4	7.2

Marking rate (MR_m) as defined by the number of lambs as a proportion of the number of ewes at marking (Figure 3) was calculated as $MR_m = \frac{MR_j}{(1-DR)}$. Figure 3 illustrates the relationship between the observed and predicted MR_m.

Table 13. Step-forward multiple models predicting marking rate. Bold entries indicate statistical significance ($P<0.01$)

Terms	F-Value (Improvement)	R^2	Standard Error Of Estimate (Ewes/Year)
swi_{j-1}, age, age^2	**10.74**	69.3	0.15
swi_{j-1}, age, age^2, dm, dm^2	**9.25**	75.2	0.13
swi_{j-1}, age, age^2, dm, dm^2, ΔN	**7.10**	77.3	0.13
swi_{j-1}, age, age^2, dm, dm^2, ΔN, $rddays$	5.75	78.9	0.12
swi_{j-1}, age, age^2, dm, dm^2, ΔN, $rddays$, Δf	3.10	79.7	0.12
swi_{j-1}, age, age^2, dm, dm^2, ΔN, $rddays$, Δf, $days_{j-1}$	5.82	81.2	0.11

Table 14. Step-forward multiple models predicting the logit of mortality rate. Bold entries indicate statistical significance ($P<0.01$)

Terms	F-Value (Improvement)	R^2	Standard Error Of Estimate Logit (Ewes/Year)
age, $twsi_{j-1}$	**69.84**	43.8	.25
age, $twsi_{j-1}$, Δf	**103.29**	55.8	.22
age, $tswi_{j-1}$, Δf, dm	**22.71**	58.4	.21
age, $tswi_{j-1}$, Δf, dm, $rdbreak$	**15.86**	60.2	.21
age, $tswi_{j-1}$, Δf, dm, $rdbreak$, $days_{j-1}$	**17.56**	62.2	.20
age, $tswi_{j-1}$, Δf, dm, $rdbreak$, $days_{j-1}$, $pregrow$	**9.10**	63.3	.20

In Figure 2, it is apparent that the predicted values for very high mortalities are lower than the observed. These points are for aged ewes over eight years of age and as there were very few animals in the cohorts they made very little contribution to the estimation of the parameters of the prediction equations.

The ranges of the predictors for the data available to predict Mr_j are as listed in Table 15. The ranges for DR were similar.

Table 15. Ranges of Predictors (Prediction Data Set)

Predictor	Mean	Minimum	Maximum
swi_{j-1}	181	89	537
$tswi_{j-1}$	164	89	364
age	6	1.5	12
dm	980	208	1964
ΔN	0.33	-.75	1.1
rddays	22	8	56
Δf	5	0	71
day_{j-1}	563	313	664
rdbreak	10	0	196
rd_{j-1}	312	118	568

Comparison of observed and estimated marking and mortality rates for validation flocks

The dry matter available at joining (*dm*) was higher for some flocks in the validation data set than for those in the prediction data set. Hence rather than use a quadratic term which would lower the marking rate at high dry matter yields outside the range of the prediction data, equation 1a with the exponential term was used to give a plateauing effect. The predictors can be validly interpolated in most other cases.

Table 16. Range of Predictors (Validation Data Sets 1 and 2)

Predictor	Set 1			Set 2		
	Mean	Min.	Max.	Mean	Min.	Max
swi_{j-1}	448	209	600	329	230	460
$tswi_{j-1}$	339	172	455	281	211	354
age	4	1.5	7.5	3	2	6
dm	1797	686	2384	1360	544	2697
ΔN	0.1	-0.5	0.43	0	-0.3	0.6
rddays	37	8	53	39	15	54
Δf	40	0	128	9	0	54
day_{j-1}	328	282	537	388	299	632
rdbreak	1.0	0	18	47	0	247
rd_{j-1}	546	223	722	490	323	668

Table 17. Range of Predictors for Validation of Set 3.

Predictor	Property 1			Property 2			Property 3			Property 4			Property 5		
	Mean	**Min**	**Max**	**Mean**	**Min**	**Max**	**Mean**	**Min**	**Max**	**Mean**	**Min**	**Max**	**Mean**	**Min**	**Max**
swi_{j-1}	362	256	458	367	162	543	160	54	263	125	36	228	224	157	288
$tswi_{j-1}$	325	242	415	267	134	375	156	54	248	120	36	221	218	157	269
age	4	2	7	4	2	6	3.5	2	5	4	2	7	3	2	5
dm	629	209	1176	1214	668	2000	423	166	1058	255	35	706	500	143	1189
ΔN	0	-0.5	1.1	-0.3	-0.5	-0.1	-0.1	-0.8	1.0	0.2	-0.7	1.3	0.2	-0.2	0.7
rddays	26	1	47	24	11	42	17	7	34	19	2	41	39	24	49
Δf	29	0	82	5	0	10	2	0	12	11	0	31	0.3	0	1.5
day_{j-1}	280	260	325	314	284	393	604	555	679	319	259	516	609	557	709
rdbreak	0	0	0	0	0	0	66	0	188	0	0	0	108	16	309
rd_{j-1}	274	14	557	359	132	622	147	74	359	152	69	272	249	153	351

A. Validation set 1

Figures 4, 5 and 6 give the comparison for marking rate (lambs per ewes joined), mortality, and marking rate (lambs per ewe present at marking) respectively. Points joined by lines indicate the range of possible predictions, given that ages were only specified as ranges. Correlation coefficients were .77, .62 and .70 respectively. Hence, there was a good relationship between the predicted and observed values for both mortality and marking rates. An exception is one flock for which the observed marking percentage was 5% (Figure 4). The GRASP model suggested there was ample dry matter at joining although there was a strong indication of decay from frosting by a large Δf measure. However this only translated into a predicted marking percentage, *MRj*, of 60%.

B. Validation set 2

Figure 7 gives the comparison for marking rate (lambs per ewes present at marking). The correlation coefficient was .30.

For the Mulga properties with observed marking rates (Mr_m) from .79 to 91, the predictions (.42 to .56) were far too low. The frosting measure, Δf, and days since the previous growing period had a dampening effect on the predictions.

In addition there was a property in the Blackall district with high marking rates (1.21-1.39). The predicted values ranged from .83 to .92.

At the other end, a maiden flock in the Blackall district was observed to have a MR_m of .32 but .75 was predicted from satisfactory climatic and pasture measures.

C. Validation set 3

Figures 8, 9, and 10, 11 give the comparison for marking rate (lambs per ewes present at marking) and mortalities for the properties in New South Wales (Properties 1 & 2) and South Australia (Properties 3, 4 & 5) respectively. Mortality has been predicted for joining to marking while the observed mortality, where available, is usually from shearing to shearing. However, most mortalities would be expected to occur from joining to marking.

Preliminary screening analyses show that 34% variation in the marking rates (lambs per ewes present at marking) on the NSW properties could be explained by age and number of drought days from mid joining to marking. If the dry matter available at marking is added as a predictor this could be increased to 38% (Figure 12). This could be further improved to 52% with additional predictors, number of rain days in growing period, frost since end of growing period. However, the properties are different.

For the South Australian properties, 50% variation in marking percentages can be explained by age, age^2 and number of drought days from mid joining to marking (Figure 13). This can be further improved to 60% with additional predictors such as drought days in the year prior to joining, nitrogen at joining and days since growing season ended. However, the property labelled "bluebush, saltbush, annuals" was different from the other two.

Superior relationships (up to 85% variation explained) can be obtained by fitting general linear models on an individual property basis.

Northern Australia - cattle

Conception Rates

As evident in Figure 14, these data display considerable variability, on both sides of the expected line. A significant ($P<0.01$) relationship was found, with an intercept not different ($P>0.05$) from zero, a slope of 0.64 (s.e. 0.04) and R^2 of 24 %. The degree of fit is not high, but no alternate statistical model could be found which fit these data as well. There was insufficient data distribution to test the full range of models previously investigated, but a simple model including breed and $BC_{0.01}$ (linear) gave an R^2 of only 11 %. This indicates that the data contain considerable random variability, and that the existing nonlinear model, including breed, lactation status and $BC_{0.01}$ terms, is probably as good as can be achieved, given these variables.

The fitted slope (0.64) is significantly (P<0.01) different from one, indicating overprediction of conception rates. This slope was not different (P>0.05) between ages, lactation classes, or the 'problem data sets' vs. the remainder. There was evidence (P<0.05) of differences in slope between breeds and between $BC_{0.01}$ ranges, and these appear to be indicating the same effect. The slope for British breeds was 0.72, and for Zebu crosses was 0.55. For 'high' $BC_{0.01}$ (greater than 0.95) the slope was 0.70, and for those in the lower ranges was 0.52. Given that the British breeds tend to be found in the more endowed areas, and consequently tend to have higher body condition scores, it is proposed that producers in these areas achieve around 70 % of the conception rates predicted by the 'research stations data' model. In the less productive areas, this factor appears closer to 50 %. Note that this refers to the probability of conception *per oestrus cycle*. Given the multiple cycles experienced under extended mating periods (3 months or longer), the multiplicative nature of these rates means that the actual pregnancy rates achieved under research *vs* commercial producer conditions will tend to be closer than quoted above. The actual pregnancy rates are dependent on a number of factors, which can now be accounted for with the calibrated model.

Mortality Rates

As shown in Figure 15, a good degree of relationship was obtained (R^2 of 55 %), but the fitted line differed significantly (P<0.01) from the expected (y=x) line. The relationship was not curved, and the fitted intercept did not significantly differ from zero, so a linear model with no intercept was adopted. The fitted slope, 2.33 (s.e. 0.30) was consistent across the observed ranges of $BC_{0.01}$, weight change and ages. There was insufficient distribution of data across breeds to statistically test for differences, but the relationship appeared similar for British and Zebu animals.

It is apparent from Figure 15, especially given the different scaling (the highest predicted value was 11.5 %, whereas the highest observed mortailties were 30 and 51 %), that the model seriously underpredicts. The 'extreme' observation of 51 % appears an outlier, despite having the lowest observed $BC_{0.01}$ value. These animals were in 'very poor - poor' condition and going into a drought in a dry tropical environment (Fordyce *et al.* 1990). In a commercial situation under these circumstances, managerial intervention (supplementation, agistment, sales) seems more likely than 'letting them die', so mortality levels this high are unlikely to occur. Even when this figure is excluded, however, the fitted slope is still 2.03 (s.e. 0.02), which is considerably higher than one. It is thus obvious that *for these data* the model from research stations data underpredicts on-property mortalities, by a factor of around two.

Care must be taken in generally extrapolating these findings, however, due to the possibility of reporting bias. It was noted from the literature that, under 'normal' conditions and years, mortality was generally not a problem, and as such was not specifically tabulated. The majority of reported mortalities occurred in the more 'extreme' situations. Here, low $BC_{0.01}$s and highly negative weight gains dominate (see Table 7), so 'normal' conditions are under-represented. It is likely that under these circumstances, with relatively low mortalities, the research stations model would perform better.

DISCUSSION

Sheep

The analysis of the prediction data set showed that reproduction and mortality models of reasonable accuracy (R^2 81% and 63%) could be developed for Mitchell grasslands from age of ewes together with climate inputs and simulation of soil moisture and pasture growth. While the predictive ability of the models with ewe measures, liveweight and age, (Moore *et al.* 1995) is superior, the equations derived here provide an alternative method if liveweight measurements at crucial times are not available. Unfortunately, the models based on liveweight are unvalidated.

The results of the first validation set confirm that predictions from age and climatic and pasture measures can be achieved satisfactorily in most cases for Mitchell grasslands. The outlier in the adverse seasonal conditions of 1970 in the Roma district has not been satisfactorily modelled and requires further investigation.

The discrepancy between predicted and observed on the property with high marking percentage in the second validation set could be due to management practices (O'Dempsey 1990). This would need to be investigated more fully in order to capture them in the model.

Stocking rates were an estimate of the overall stocking rates on a property. However, ewes in late pregnancy and with lambs would utilise the pasture at a higher rate than "dry sheep equivalent". However, breeding ewes could have been given preferential treatment. In the absence of this knowledge on historical data, the stocking rate was not varied in GRASP. Assuming a constant stocking rate would affect simulation of dry matter.

The inclusion in the prediction equations of climatic measures in addition to pasture measures simulated from GRASP possibly means that forbs growth has not been adequately simulated in GRASP. Steps to address this are planned in future work.

The application of the Mitchell grass model to properties in mulga communities in Queensland and to NSW and SA was not successful. In these cases the major problems are likely to be:

1) a highly variable landscape with different pasture communities and significant contribution to soil moisture from run-on (eg. lake beds and floodplains);

2) significant contribution of browse (mulga or chenopod shrubs) to the diet.

GRASP simulated the annual biomass component but did not simulate the availability of browse. Given the importance of chenopods for animal nutrition, it is not surprising that the Mitchell grass reproduction model underestimates reproduction in the shrub lands. The picture could be further confused by the different strain of Merinos in South Australia.

However, the preliminary analyses of this data set show the potential for predicting reproduction from climatic and pasture measures.

The approach required to produce a better model for chenopod would involve:

1) calibration and validation of a multi-species and multiple landscape model of hydrology and plant growth;

2) analysis of diet selection to determine important plant classes dry matter, eg. browse, annual pasture, seeds;

3) construction of empirical models using the outputs and observed reproduction and mortality statistics.

Analyses for each southern Australian property showed that the major effects of animal age and rainfall variability or derived variables such as number of drought days, account for a large proportion of variation in marking and mortality rates. However, there were large differences between properties and hence better resource description and models will be needed.

In summary, the approach adopted in this study accounted for the major effects of age, rainfall, soil moisture, and pasture yield, allowing some of the likely variation between properties to be accounted for. The remaining differences may be due to unaccounted climatic/pasture effects such as the overriding effect of short severe drought at critical times in embryo and lamb development (e.g. Autumn 1985 at Blackall) or due to managerial differences in pasture management and/or stock rotation. The success of some properties in increasing reproduction rates above that simulated by the general multiple regression suggests that management opportunities for increasing production do exist even in these relatively arid environments (O'Dempsey 1990). In consultation with graziers and extension officers, the cattle and sheep models provide tools to examine further the causes of property differences and identification of opportunities for increasing reproduction and hence bridge the gap between extensive grazier information and limited research data.

Beef Cattle

Despite the good number of cow-years contributing to these producer data sets, there is currently insufficient data coverage across the key factors (breeds, lactation classes, ages, $BC_{0.01}$s) to re-estimate parameters of the current model, or investigate alternate models. Data acquisition is on-going, both from commercial properties within Qld., and in co-operation with the Northern Territory DPI&F. Here, extensive producer data sets (including liveweights) have been recorded, with animal cohorts by breed, age, lactation status and years. These data are currently being sorted and prepared for analyses, which should take place during 1996. If these data become available, 'producer data' models could be fitted with confidence.

For now, a recalibration of the existing 'research stations data' models seems most useful. The variables in these models have previously been screened both biologically and statistically, and the predictions from it are related to the biological rates observed on producers' properties. The appropriate callibration factors appear to be 2 for mortality (ie, producers' mortalities are twice those predicted from the previous model), and between around 0.55 to 0.70 (overall average 0.64) for conception rates.

One further potential source of bias must also be noted. The above rates, whilst significantly 'poorer' than those observed on research stations, may typify only the 'better' end of producers as a whole. Herd records tend to be collected by only the 'better' managers (and proved very hard to find), and producers who allow researchers to observe and measure their herd dynamics are more likely to be 'more careful' managers. The calibration rates applicable to the 'bottom end' of producers can only be speculated upon. Despite these reservations, the above calibration factors may in fact be generally applicable, as the overall average rates appear 'typical' of the industry as a whole, and have been evaluated and accepted in herd dynamics models (P. Smith, *per. comm*.).

Future opportunities

An important tactical option in drought management is the reduction of stock numbers by selling, agistment or death. Evaluation of stocking options requires accurate calculation of stocking rate effects on reproduction and mortality. However, there are very few experimental trials carried out on the effect of stocking rate because of the large number of animals and area required for formal experiments.

This study shows that property data are the most likely sources of information. However the effects of different pasture growth rates occurring in breeder paddocks have to be accounted for before properties can be compared. Pasture growth is used to calculate the term *pasture utilisation* (% eaten/growth) which is a better variable than stocking rate for inter-property comparisons (K.A. Day and W.J. Scattini *per. comm.*). The methodology to assess paddocks, especially highly variable breeder paddocks, has been demonstrated elsewhere in the DroughtPlan project and hence future research will allow some stocking rate effects to be determined from property data. This approach, however will have some limitations because of other possible sources of variation such as management as indicated above.

The general models developed in stream 3 provide an alternative approach to modelling stocking rate effects. For both cattle and sheep, models were derived which included the effect of liveweight and liveweight gain on reproduction and mortality.

The generality of these models for a wide range of 'well-managed' situations suggests that they can be used to predict stocking rate effects provided the stocking rate effect on input variables (e.g. liveweight, dry season, liveweight gain) can be calculated.

The empirical equations developed in GRASP to simulate the liveweight of steers and wethers, as reported in DroughtPlan Working Paper No. 8, provide the link for simulating both climatic and stocking rate effects on reproduction and mortality, and hence the simulation of the whole herd or flock enterprise (stream 5).

For sheep the liveweight gain model for the Mitchell grass pasture community requires improvement to account for the effects of pasture composition (such as forbs, annual grasses) on diet quality. The issue of modelling pasture composition will be addressed in future projects. Similarly, modelling the effect of browse on diet quality in the chenopod shrublands and mulga lands is also a priority for further work.

This study shows that, for cattle and sheep in the tropics, general models of reproduction and mortality can be developed from both research station and real property data. These models provide a sound basis to assess management opportunities by analysing the likely cause of departure between these general models and property data.

The general models are of a form that can be linked to other models (such as GRASP) which simulate the effects of climate and management (i.e. stocking rate) on live weight of sheep and cattle and hence can be used in the simulation of a range of tropical issues for grazing enterprises. These include determination of sustainable stocking rates, drought management and recovery, tree clearing, the effects of improving pastures or breeds, enterprise mix, adapting to changing markets, etc.

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