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Modelling Mortality and Reproduction Rates for Management of Sheep Flocks in Northern Australia.

P. M. Pepper[1], D. G. Mayer[1], G. M. McKeon[2] and A. D. Moore[3]

[1]*Biometry, Queensland Department of Primary Industries, LMB 4, Moorooka QLD 4105, Australia; pepperp@dpi.qld.gov.au*
[2]*Climate Impacts and Grazing Systems, Queensland Department of Natural Resources, Indooroopilly QLD 4068, Australia.*
[3]*CSIRO Division of Plant Industry, P. O. Box 1600, Canberra ACT 2601, Australia.*

Abstract

By quantifying the effects of climatic variability in the sheep grazing lands of north western and western Queensland, the key biological rates of mortality and reproduction can be predicted for sheep. These rates are essential components of a decision support package which can prove a useful management tool for producers, especially if they can easily obtain the necessary predictors.

When the sub-models of the GRAZPLAN ruminant biology process model were re-parameterised from Queensland data along with an empirical equation predicting the probability of ewes mating added, the process model predicted the probability of pregnancy well (86% variation explained). Predicting mortality from GRAZPLAN was less successful but an empirical equation based on relative condition of the animal (a measure based on liveweight), pregnancy status and age explained 78% of the variation in mortalities.

A crucial predictor in these models was liveweight which is not often recorded on producer properties. Empirical models based on climatic and pasture conditions estimated from the pasture production model GRASP, predicted marking and mortality rates for Mitchell grass (*Astrebla sp*.) pastures (81% and 63% of the variation explained). These prediction equations were tested against independent data from producer properties and the model successfully validated for Mitchell grass communities.

Key Words: model, sheep, reproduction, mortality.

Introduction

Climatic variability and stocking rate in the grazing lands of Australia have a major influence on animal mortality and reproduction. The average annual rainfall for Mitchell grass pastures, which are a major production area for sheep in Queensland, fluctuates between 250mm and 550mm [1]. Low reproductive rates and high mortalities in poor seasons can strain the economic viability of sheep enterprises. This study aimed to quantify the effects of climatic variability and animal characteristics so that the key biological rates of mortality and reproduction could be predicted for sheep. Previously collected data from grazing trials and monitoring studies were used to explore the spatial and temporal variation in these key biological rates.

Two major approaches were investigated. Firstly, the sub-models of the GRAZPLAN ruminant biology process model [2], developed for sheep grazing temperate grasslands, were tested to determine if mortality and conception rate could be satisfactorily predicted. The process model was refined by re-parameterising the equations with Queensland data and adding an empirical equation to predict the probability of ewes mating. The second approach involved developing empirical models based on climatic and pasture conditions for prediction. The prediction equations from the second approach were then tested against independent data from further producer properties to validate the model for Mitchell grass communities. Further testing on properties with other vegetation, such as mulga (*acacia aneura*) shrubland which have a browse component, was undertaken to examine the potential of this approach.

Data Sources

Data for model development (prediction data) were drawn from three studies, the first from Toorak Sheep Field Research Station at Julia Creek in north-west Queensland, and the other two involving commercial properties in the south-west and central west of Queensland respectively. At Toorak, comprehensive records were available on reproduction and mortality, bodyweight at pre-joining, post-joining, pre lambing and marking, together with greasy fleece measurements at shearing in June [3,4]. Ewes were joined in spring, following normal practice in north-west and central west Queensland. As part of a study on reproductive wastage up to lamb marking, reproduction, bodyweight and age records were kept on eight commercial flocks [5]. These flocks in south-west Queensland were joined in autumn. During the research part of a comprehensive examination of sheep reproduction in the Blackall Shire, statistics on marking percentages and ewe numbers were collected on several co-operator properties [6]. Four flocks with data on joining dates, age of ewe, number of ewes at joining and marking, and marking percentages were used in the prediction of reproduction and mortality. Sheep were joined either in July, October or December.

Ewe liveweights were corrected for mean greasy fleece weight on a *pro rata* time basis. Similarly, pre-lambing liveweights were adjusted for the foetal system using published equations [7]. These equations were scaled using the ratio of birth weight to the prediction of foetal weight of foetus at birth, resulting in the following equation:

$$W_C = \frac{W_{birth}\,(0.0358(t-4)^{2.43})}{9.11g-0.349g^2+0.00343g^3}$$

where t = time from mating (days),
g = gestation length (days).

Average birth weights and gestation lengths were available for the Toorak data set; a birth weight of 3.5 kg and a gestation length of 149 days were assumed for south-west Queensland.

Validation data were obtained from two sources:

(1) Flocks from similar areas to those of the prediction data, and for which the number of ewes at joining were known in addition to age, time of joining and number of ewes and lambs at marking. Fourteen flocks from the south-west were joined in autumn and grazed at 0.76 or 1.1 sheep/ha [5,8] together with further four flocks from the Blackall area [6], grazing at 0.49 to 0.71 sheep/ha, and joined in February, April and September.

(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 were known, and not the number of ewes at joining. Data from twenty-three flocks grazing Mitchell grass in the Blackall and Augathella area together with three from properties with Mulga frontage in the Charleville area were used as validation data [6]. Stocking rates were 0.62 to 0.71 sheep/ha with the exception of one mulga property with 0.25 sheep/ha.

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.

Meteorological data (daily rainfall and maximum and minimum air temperatures) were obtained for the latitude and longitude of the properties at the above sites. For properties in the Blackall district, meteorological data from Blackall town were used.

Methods

GRAZPLAN Conception Submodel. The GRAZPLAN conception equations predict conception rate as conceptions per head per oestrus. Conception rates are modelled as a function of time of year and of the relative size and body condition of the sheep. The following equation gives the probability of a sheep conceiving n young:-

$CR_{\geq 0}=1$

$CR_{\geq n}=(1-CF1(1-\sin(2\pi\,(d+10)/365)))SF$

$CR_n=CR_{\geq n}-CR_{\geq n+1}$

where CF1=0.3 for merino sheep,
d = time of mating, and SF =

$$\frac{1}{1+\exp-\left(\frac{W}{SRW}-\frac{C_{F2,n}+C_{F3,n}}{2}\right)\left(\frac{5.88}{C_{F3,n}-C_{F2,n}}\right)}$$

where, for n=1 $C_{F2,1}=0.2$; $C_{F3,1}=1.1$;
for n=2 $C_{F2,2}=0.7$; $C_{F3,2}=1.5$;
W= weight of ewe at mating;
SRW= standard reference weight, assumed to be 40kg. This is the mature weight in North-West Queensland [4] and South-West Queensland [9].

Pregnancy rate was then determined:

$PR=1-(1-CR)^{cy}$,
where cy = no of cycles during mating period.

GRAZPLAN Mortality Submodel

$$MR=\begin{cases}0.00003+0.3(1-\frac{BC}{BC_{crit}}) & \text{if } BC<BC_{crit} \text{ and dailygain}<0.2\delta N\\ 0.00003 & \text{otherwise}\end{cases}$$

where BC_{crit} = 1 - 0.2(1+Z)

$$Z=\text{minimum}\left(\frac{N}{SRW},1\right)$$ …relative size of ewe

$$N=SRW-\left(SRW-W_{birth}\right)\exp\left(-\frac{0.0157age}{SRW^{0.27}}\right)$$

... normal body weight

$$BC=\frac{W}{N}$$ …relative condition

Empirical Equations when liveweight of animals known: This approach involved fitting generalised linear models to predict conception rate per oestrus (given that mating occurred) from potential predictor variates such as weight, weight change, pregnancy and relative condition. The probability of mating and the pregnancy rate was estimated as in the previous approach**.**

To investigate the effect of potential explanatory variables (age, proportion pregnant, minimum relative condition (bc) or minimum weight, weight change) on the proportion dying, general linear models were fitted via analysis of deviance, using a binomial error distribution and logit link function. 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.

Models were determined using the step forward method of successively including the next best predictor. This was also done without the site factor in an endeavour to determine a satisfactory model across sites. In all analyses, the number of observations in each cohort or cell was used as a weighting factor.

Empirical Equations when liveweight of animals unknown: As liveweight is not often recorded on producer properties, empirical models based on climatic and pasture conditions were also investigated.

From the meteorological data, a number of climatic measures such as rain days in the growing season were calculated. With the meteorological data as input variables, the dynamic pasture production model GRASP [10], was run to obtain the numerous estimates of soil moisture and pasture growth for Mitchell grass pastures. 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 [10]. The only parameter in the management file to vary was stocking rate.

Many of the raw climatic and GRASP climatic and pasture measures which could be potential predictors are indirect measures of the same parameter (availability and quality of diet and the animals' condition), and are correlated. A screening analysis was undertaken to determine those variates which individually explained the most variation. As before, models were determined using the step forward method of successively including the next best predictor. Predictors selected from the prospective predictors from the climatic, soil moisture and pasture measures in this way are defined in Table 1.

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.

Table 1. Range of Predictors when liveweight unknown for Prediction Data Set (Validation Data Sets in brackets).

Predictor	Mean	Minimum	Maximum
swi_{j-1} (number of days the soil water index was higher than 0.4 in the two years prior to mid joining)	181 (448,329)	89 (209,230)	537 (600,460)
$tswi_{j-1}$ (as above except average temperatures must also be greater than 14^0C for Mitchell grass and 9^0C for mulga)	164 (339,281)	89 (172,211)	364 (455,354)
age (years)	6(4,3)	1.5(1.5,2)	12(7.5,6)
dm (dry matter (kgs) at mid joining)	980 (1797,1360)	208 (686,544)	1964 (2384,2697)
ΔN (change in proportion nitrogen from mid joining to marking)	0.33 (0.1,0)	-0.75 (-0.5,-0.3)	1.1 (0.43,0.6)
Δf (measure of frost and its severity on pasture as defined by ∑(2- minimum temperature) if minimum temperature 2^0C or less in the period from mid joining to marking)	5 (40,9)	0 (0,0)	71 (128,54)
rd_{j-1} (rainfall in the previous growing season prior to joining. Beginning of the growing season was defined as 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. End of season was specified by date of the last similar event before 30 June of the next year)	312 (546,490)	118 (223,323)	568 (722,668)
day_{j-1} (days from end of previous growing season to mid joining)	563 (328,388)	313 (282,299)	664 (537,632)
rddays (number of rain days in the growing period)	22 (37,39)	8 (8,15)	56 (53,54)
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 to mid joining recorded as a separate variable)	10 (1,47)	0 (0,0)	196 (18,247)

Results

GRAZPLAN model The unmodified GRAZPLAN equations developed with southern data overestimated the probability of pregnancy particularly at low levels. When the parameters C_{F1}, $C_{F,2}$ and $C_{F3,1}$ were re-estimated using the Queensland data sets, however, the GRAZPLAN equations predicted pregnancy rate well (R^2 = 87%, C_{F1} =0.33, $C_{F,2}$ =0.60, $C_{F3,1}$ = 1.03).

In this data set, however, the time of joining (spring vs autumn) is completely confounded with site (north-west and south-west Queensland). This gives rise to some concern that a possible difference between north-west and south-west Queensland data is being attributed to the photoperiod effect. No significant differences were found to exist between reproduction from autumn and spring joinings in north-west Queensland [11].

If the time-of-year effect was omitted from the GRAZPLAN equations (i.e. C_{f1} set to zero), they still explained 85% of the variation in regnancy rate ($C_{F2,1}$ =0.58, $C_{F3,1}$ = 1.41).

As the proportion of ewes served is of the order of 100% in southern Australia but sometimes lower than 70% in north-west Queensland, an investigation was conducted into the effect of predicting the proportion served and then the proportion of mated ewes which conceive. Gompertz curves predicted the proportion of ewes served, S, well (R^2 = 89%) (Figure 1).

$$S = 0.244 + 0.683 \exp^{-\exp(0.956(W-33.0))} \quad \text{for maiden ewes,}$$
$$= 0.286 + 0.699 \exp^{-\exp(-0.320(W-30.6))} \quad \text{for adult ewes.}$$

The GRAZPLAN equations, with C_{F1} = 0, were then fitted to the proportion of mated ewes which fell pregnant per oestrus cycle. The best fit had an R^2 of 61%, with $C_{F2,1}$ = 0.30 and $C_{F3,1}$ = 1.48. The proportion of mated ewes which fell pregnant was then determined from conception rate of mated ewes per cycle. The overall result of this staged process is that 13.8% of the variation in pregnancy rate is left unexplained (Figure 2).

Mortality rates for the period pre-joining to marking were not well estimated by the GRAZPLAN model as the minimum relative condition did not fall below the critical relative condition. Estimates of mortality thus reduced to a constant.

Generalised Linear models when liveweight known The screening analyses showed relative condition at postjoining weight (BC_{post}) to be the best single predictor for conception rate of mated ewes per oestrus cycle. A model with BC_{post}, age class and their interaction, explained 76% of the variation.

$$CR|\text{mated} = 1.72\, BC_{post} - 0.99 \quad \text{for maiden ewes,}$$
$$= 1.04\, BC_{post} - 0.46 \quad \text{for adult ewes.}$$

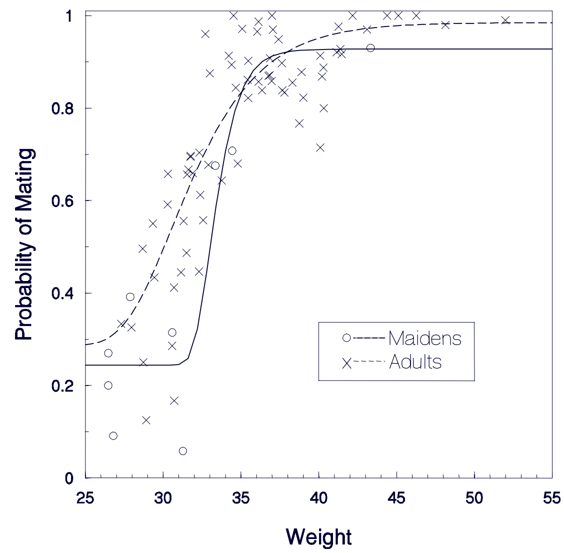

Figure 1. Mating rate for adult and maiden ewes.

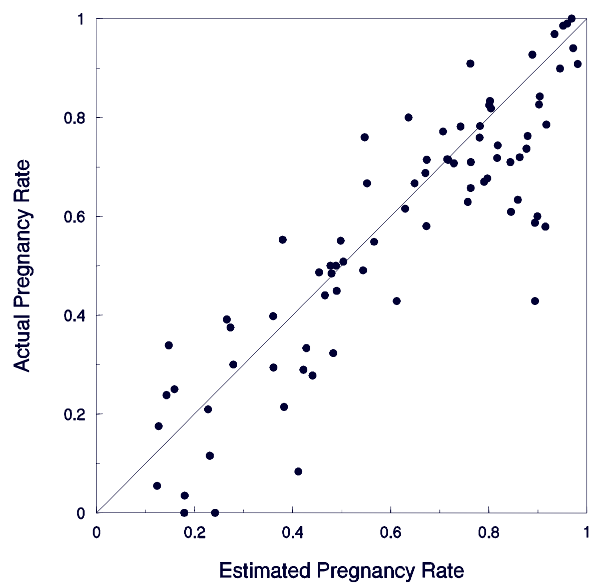

Figure 2. Actual vs estimated pregnancy rates from modified GRAZPLAN models.

Using these generalised linear models to determine the probability of conception per cycle given mating occurred, estimates of overall pregnancy rate were calculated as before and compared with observed pregnancy rates. The estimated unexplained variation in pregnancy rates from this model was 11.7%.

The screening analysis showed that minimum relative condition (BC_{min}) was a best single predictor for mortality. A model with condition BC_{min}, age, pregnancy rate, and the interaction between pregnancy rate and BC_{min} explained 78% of the variation.

$$MR = 1/(1+e^{-y})$$
$$y = 14.51 + 0.20A - 22.41BC_{min} - 13.07P + 17.59BC_{min}\,PR$$

where A = age(years),

BC =minimum condition at pre-joining, post-joining, pre-lambing, and marking,

PR= pregnancy rate (0-1).

The interaction of body condition and age are shown in figure 3 for pregnant ewes (75% pregnancy rate).

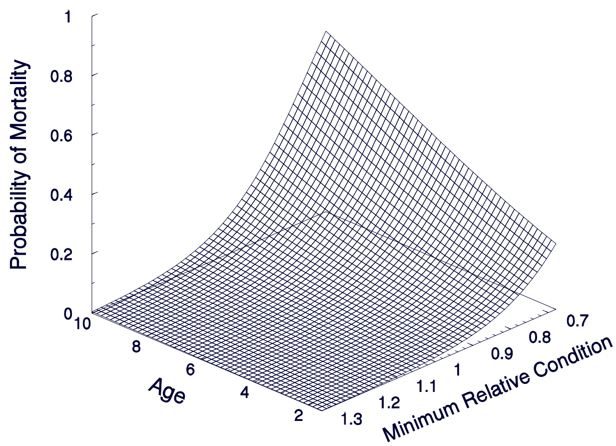

Figure 3. Fitted mortality surface for the age by body condition interaction.

Generalised linear models to predict reproduction when liveweight unknown Eighty one percent and 63% of the variation in marking (MR_j) and mortality rates (DR) respectively could be explained by age, climatic and pastures measures of the current and previous season. The latter indirectly describe the condition of the animal. MR_j was defined as the number of lambs at marking as a proportion of the number of ewes at joining and was predicted either by:-

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

or

$$MR_j = 0{\cdot}360 + 0{\cdot}000862\ swi_{j-1} + 0{\cdot}1391\ age - 0{\cdot}01336\ age^2 - 0{\cdot}363e^{-.00262dm} + 0{\cdot}0734\ \Delta N + 0{\cdot}00476\ rddays - 0{\cdot}00321\Delta f - 0{\cdot}000801\ day_{i-1}.$$

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

where $y = -3{\cdot}218 + 0{\cdot}2383\ age - 0{\cdot}00226\ tswi_{j-1} - 0{\cdot}000619\ dm + 0{\cdot}01586\Delta f - 0{\cdot}01026\ rdbreak + 0{\cdot}002513\ day_{i-1} - 0{\cdot}001345\ rd_{i-1}$.

Marking rate (MR_m) as defined by the number of lambs as a proportion of the number of ewes at marking was calculated as $MR_m = \frac{MR_j}{(1-DR)}$.

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, the equation with the exponential term was used to give a plateau effect. The predictors can be validly interpolated in most other cases.

For the first validation set, the comparison of predicted marking rate (lambs per ewes joined), mortality, and marking rate (lambs per ewe present at marking) with observed values gave correlation coefficients of 0.77, 0.62 and 0.70 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%. 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%. (Figure 4).

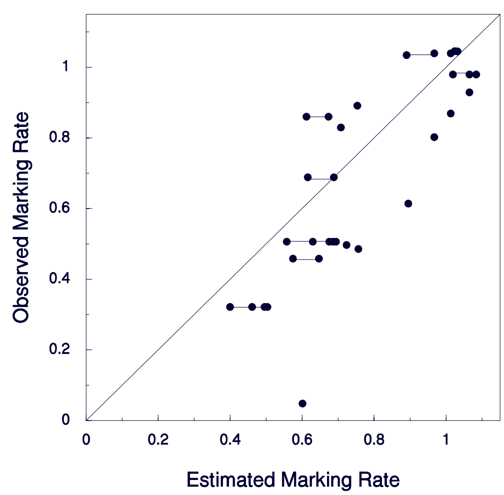

Figure 4. Validation of Marking Rate.

For the second validation set, the comparison for marking rate (lambs per ewes present at marking) gave a correlation coefficient of 0.30. For the Mulga properties with observed marking rates (Mr_m) from 0.79 to 0.91, the predictions (0.42 to 0.56) 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 0.83 to 0.92. At the other end, a maiden flock in the Blackall district was observed to have a MR_m of 0.32 but 0.75 was predicted from satisfactory climatic and pasture measures.

Conclusion

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 solely climate inputs and simulation of soil moisture and pasture growth and from the modified GRAZPLAN model for reproduction (86%).

The results of the first validation set confirm that predictions 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 [6]. 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 application of the Mitchell grass model to properties in mulga communities in Queensland was not successful. The major problem is likely to be a significant contribution of browse from mulga shrubs to the diet and the differences in nutritional qualities between the two pasture communities. GRASP simulated the annual biomass component but did not simulate the availability of browse.

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 (eg 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 [6]. In consultation with graziers and extension officers, the sheep models provide tools to further examine 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.

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