Prediction of mortality and conception rates of beef breeding cattle in northern Australia

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Abstract. In current simulation packages for the management of extensive beef-cattle enterprises, the relationships for the key biological rates (namely conception and mortality) are quite rudimentary. To better estimate these relationships, cohort-level data covering 17 100 cow-years from six sites across northern Australia were collated and analysed. Further validation data, from 7200 cow-years, were then used to test these relationships. Analytical problems included incomplete and non-standardised data, considerable levels of correlation among the 'independent' variables, and the close similarity of alternate possible models. In addition to formal statistical analyses of these data, the theoretical equations for predicting mortality and conception rates in the current simulation models were reviewed, and then reparameterised and recalibrated where appropriate. The final models explained up to 80% of the variation in the data. These are now proposed as more accurate and useful models to be used in the prediction of biological rates in simulation studies for northern Australia.

Introduction

In northern Australia, the task of evaluating optimal strategies to manage extensive properties is challenging. Regardless of the criterion chosen for optimisation (usually economics or profitability), all management decisions interact with climatic and other natural features of each dynamic system (Mayer *et al*. 1998). The only realistic method of investigating these interactions is with simulation models that encompass the whole system, from rainfall and soils, to pasture production and animal intake (McKeon *et al*. 1990; Hall *et al*. 1998), herd dynamics, and through to the economics of animals turned off (Freer *et al*. 1997).

Herd dynamics models currently in use, such as BREEDCOW and DYNAMA (Holmes 1995), are generally accountancy-type packages. In these, the key biological rates covering the processes of reproduction and mortality need to be user-supplied, rather than being estimated within the model. Hence, changes in these rates from alternate managerial strategies, such as stocking rate or supplementation (and the resultant effects on herd structure and profitability), cannot easily be evaluated. The GRAZPLAN ruminant biology model (Freer *et al*. 1997) was largely developed for animals grazing temperate pastures in southern Australia, and is currently being used widely in these regions. Its relationships for conception, however, rely on an assumption that all females come into oestrus each year, and its equation for mortality

assumes constant death rates with age once stock are mature. Neither assumption can be expected to hold in the more tropical regions of northern Australia, where cattle are routinely subjected to long periods of nutritional stress. We, therefore, hypothesised that alternate or adapted relationships would be required for these areas.

The present study compares predictions from current models with historical data from across northern Australia, and then develops more accurate and useful models to be used in the prediction of conception and mortality rates. Biological data from a range of beef-producing environments across northern Australia were collated and analysed. The following sections describe the data sources used, and then the model comparisons and analyses that identified improved predictive models for mortality and conception rates. Following this, further data were sourced to validate these relationships.

Data sources

Data were collated from six sites (two each in the Northern Territory, northern Queensland and central Queensland), as summarised in Table 1. The performance of cohorts or groups of animals was targeted from each site, on a four-way interaction basis (year by breed by age by lactation status). These data were variously available from published sources and theses, unpublished summaries and internal departmental memos, and

**Table 1. Breeder experiments – background and biological data**

Ix, *Bos indicus* crosses; Ax, Africander crosses; Br, British; Eu, European; F, filial generation. All cow weights (kg) are adjusted for conceptus products. Values for mortality, pregnancy rate, conception rate and weights are means with ranges shown in parentheses

Site	Kidman Springs	Mount Bundey	Fletcherview	Swan's Lagoon	Belmont	Brigalow
Location	16°07'S, 130°57'E	25°02'S, 122°12'E	19°53'S, 146°11'E	20°05'S, 147°14'E	23°16'S, 150°26'E	24°50'S, 149°48'E
Years	1981–1989	1980–1984	1981–1987	1972–1986	1969	1980–1985
Breeds	Ix (F_n)	Ix (F_n)	Ix (F_n)	Ix (F_1,F_n)	Ix,Ax,Br	Ax,Br,Eu
Observations (cow-years)	3570	3590	1010	5700	430	2790
Mortality (%/year)	11.3 (0 to 25.6)			2.5 (0 to 6.7)	3.2 (1.5 to 6.0)	2.3 (0.3 to 11.8)
Pregnancy rate (%/year)	59 (4 to 100)	64 (13 to 97)	73 (7 to 100)	74 (8 to 100)	56 (50 to 62)	76 (12 to 100)
Conception rate (%/cycle)	10 (1 to 28)	20 (2 to 45)	32 (2 to 60)	31 (2 to 62)	30 (26 to 34)	38 (4 to 65)
Weight at start of year (kg)	270 (177 to 326)	353 (298 to 374)	387 (267 to 487)	348 (213 to 454)	435 (423 to 443)	419 (287 to 594)
Weight at end of wet period (kg)	319 (223 to 404)	333 (258 to 410)	437 (296 to 522)	393 (268 to 498)	378 (354 to 392)	459 (330 to 643)
Weight at end of dry period (kg)	322 (250 to 426)			366 (270 to 482)		
Weight change in wet period (kg/month)	9.1 (–3.4 to 25.4)	–0.1 (–6.6 to 11.8)	13.7 (–2.3 to 27.7)	18.8 (0.4 to 48.8)	18.8 (17.2 to 19.8)	17.3 (–2.2 to 38.3)
Weight change in dry period (kg/month)	–5.4 (–17.6 to 8.4)			–0.1 (–10.5 to 15.0)	–7.3 (–8.7 to –6.0)	

re-analyses of raw data. Across these locations, consistency of data measurements and structures remains a problem. Although the timing varies, all sites generally experience 'favourable' (wet) and 'unfavourable' (dry) periods each year. Mustering and data-collection dates varied with site, but where possible animal weights at approximately the start and end of these two periods were obtained, also allowing estimation of average weight changes. As the stage of pregnancy was recorded, all animal weights were adjusted for weight of the conceptus and products, via the method for specific breeds (O'Rourke *et al.* 1991) or earlier general relationships (Silvey and Haydock 1978). When applied in a practical sense to estimating cow weights, the differences between these methods are insignificant (P. K. O'Rourke, pers. comm.). The 283 observations in this dataset total 17 100 cow-years, giving an average of 60 animals per cohort. Example data for some of these site–year–breed–age–lactation status cohorts are illustrated in Fig. 1.

Main effects for the Kidman Springs data were presented in Sullivan *et al.* (1992). For our study, the full interaction means were re-extracted from the raw data. This site operated under continuous mating, starting with non-pregnant animals in June of each year. Pregnancy within 12 months was defined as a 'success', but calving would be some time after this if pregnancy occurred late in the year.

All other sites were managed under controlled mating, generally coinciding with the wet period (early in the calendar year). Animals found to be pregnant calved later that year, setting up an approximately annual cycle. The Mount Bundey data were extracted from O'Rourke (1994). The overall average weight change during the wet season was slightly negative for these data, which is a reflection of both the harsher environment and the fact that many of these animals were lactating through this period, and were unable to gain weight (although their calves were gaining weight).
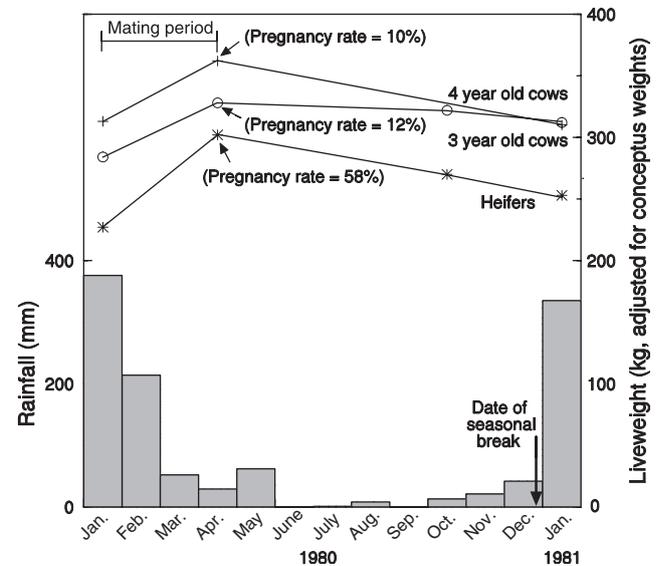
Fig. 1. Rainfall (bars) and liveweights (lines) for three age-cohorts of F_n *Bos indicus* crosses at Swan's Lagoon during 1980–1981.

Data from the James Cook University Tropical Veterinary Research Station at Fletcherview were available from Anderson (1989). The available age classes were '3-year olds' and 'mature animals', with both lactating and non-lactating groups within each of these.

For Swan's Lagoon, data for the various animal classes were extracted from Anderson (1989), Holroyd *et al*. (1990*a*, 1990*b*), Fordyce *et al*. (1993) and O'Rourke (1994). Reproductive and weight data were available on a year-by-breed-by-age and lactation status basis. Mortality data were available only for lactating animals on a year-by-breed basis. Previous statistical analyses of the age effects (O'Rourke 1994, p. 183) had indicated few important or consistent differences between ages, so these pooled mortality rates (across ages) were used.

From Belmont, animal weights were readily available only for the drought year of 1969 (Frisch 1973), although these studies ran from 1957 to 1984 (Mackinnon *et al*. 1989). Mortality and calving rates were listed by breeds, being averaged across ages and lactation status. Pregnancy rates (which were not reported) were back-estimated from calving rates by using breed-specific differences from the comprehensive and comparable Brigalow dataset.

Pregnancy rate and weight data for Brigalow are listed in O'Rourke *et al*. (1992), by year and breed with age and lactation status pooled into four classes, namely heifers, 3-year-old lactating, 4-year-old and older lactating and 3-year-old and older non-lactating cows.

The range of production systems across northern Australia are illustrated by the data in Table 1. Annual mortality rates in the more favourable environments averaged ~3%, but ranged up to 12%. At Kidman Springs, however, 11% was the average, with a much greater range. These values were also typical in the Kimberley region of Western Australia, where Pratchett and Young (1989) reported average mortalities of 19% for unweaned cows, and 10% for the weaned treatments. The Northern Territory sites also had lower conception rates, weights and weight gains (Table 1), due to harsher conditions. These trends, along with the partial confounding of sites with breeds (only *Bos indicus* at the harsher environments, and none of these at Brigalow) caused problems with analyses.

Estimation of biological relationships

A two-fold approach was used for the analyses of mortality and conception rates. The first was a formal statistical analysis, fitting generalised linear models (McCullagh and Nelder 1989) of both discrete factors and continuous variates to the dependent variables. Second, the relationships incorporated in some of the decision-support packages (largely derived under southern Australian conditions) were tested. In some instances, internal parameters of these models were tuned to achieve an acceptable fit to the observed data. Both analytical methods struck some problems with correlations among the (assumedly) independent variates. As expected, the highest dependencies (r = up to 0.92) were among the weight variables at different times during the year. Only one of these terms may, therefore, reasonably be fitted in any model. The site factor was significantly associated with several predictor variables, which along with the partial confounding introduces some degree of uncertainty into

interpretation. The rates of weight changes at various times of the year also tend to be reasonably correlated (r = up to 0.68) with actual weights, despite having the potential to be important additional predictors of animal wellbeing and, hence, performance.

In all analyses, the number of observations (cow-years) in each cohort or group was used as a weighting factor. The factors investigated in these analyses were 'site', 'breed' (both as listed in Table 1), and 'age and lactation status' (four defined levels: heifers – 2 years old; 3 years old, lactating; 4 years old and older, lactating; and non-lactating cows).

To fit the GRAZPLAN models (Freer *et al*. 1997, 2009), the internal parameters of 'standard reference weight' (SRW) and 'normal weight' (N, the potential or expected bodyweight at any given age) need to be determined first. SRW is defined as the weight of a mature animal of average body condition. This was estimated from our data as 520 kg for the European animals, and 425 kg for other breeds. Attempts to fit these SRWs as extra parameters in non-linear regression models were largely unsuccessful (Mayer *et al*. 1996), due to parameter correlations – other parameters in the models ended up being adjusted to compensate for any shift in SRW. Fitted models using the SRW values listed above appeared to be biologically appropriate.

The calculation of N, the expected bodyweight for age of animals at average condition, proved to be more problematic. Brody (1945) theorised an exponential model describing weight from birth (Wt_{birth}) to maturity, given adequate nutrition, as follows:
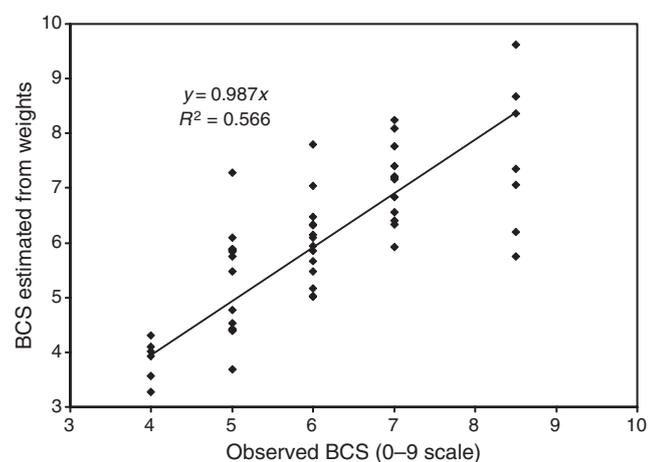
$$N = SRW - (SRW - Wt_{birth}) \exp[-k \times age/(SRW^{0.27})], \quad (1)$$

Taylor (1965, 1968) further developed this equation, tabulating potential growth rates by species of animal. The tabulated value for sheep of 1.8 back-converts to a k-value (the growth rate, with age measured in days) of 0.0157, as was originally used in GRAZPLAN (Freer *et al*. 1997). However, for cattle, the tabulated values convert to k-values of 0.008–0.01, indicating slower proportionate growth. The Brody exponential model fitted to the observed weight data of Table 1 (ignoring all other factors) estimated k as 0.0104, with a standard error of 0.0006. Hence, a value of 0.01 appears reasonable for these data, and was adopted for all analyses. Subsequent to this research, k for cattle in the current GRAZPLAN model (referred to in Freer *et al*. 2009; as the growth rate constant, C_{N1}) has been revised to 0.0115

The definition N for any age allows the formulation of GRAZPLAN's measure of body condition ratio (BCR), defined as the ratio of liveweight to N. BCR values equal to 1 will be obtained for animals that are at their expected weight-for-age. BCRs <1 indicate underweight animals (of poor body condition) and *vice versa*. For datasets where only body condition score (BCS), on a 0–9 scale (NRC 1996), was recorded, Table 2 shows the conversion adopted. This was derived via expert opinion of researchers in the DroughtPlan project team. It has subsequently been validated with independent data from Alexandria Station (Savage *et al*. 2004), which had both weights and condition scores for 53 cohorts of animals. Fig. 2 shows the relationship between the estimated (via Table 2) and

Table 2.   Equivalence of body condition score (BCS) scale to body condition ratio (BCR)

Description of animal	BCS value (0–9 scale)	Nominal BCR 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

Fig. 3.   Fitted mortality surface for the interaction between age (years) and body condition (ratio).
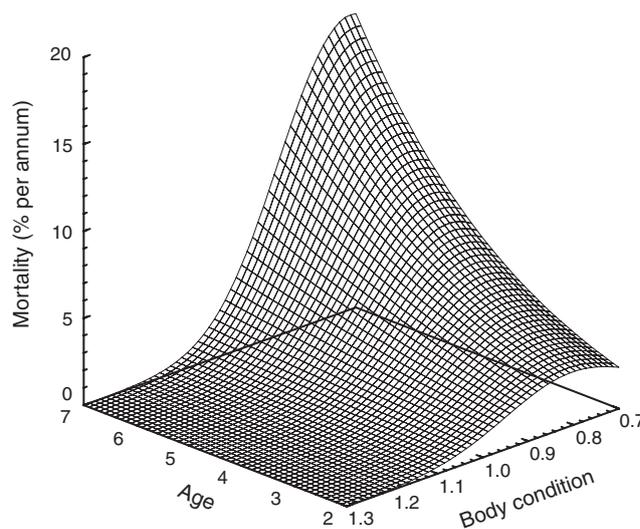

Fig. 2.   Validation of the relationship between observed and estimated body condition scores (BCS), for Alexandria Station data.

observed condition scores. While there is some degree of variability in these data, the fitted slope is very close to 1.

Analyses of mortality rates

Statistical analyses

As a considerable portion of the mortality data is in the 0–5% range, the assumption of a normal distribution is clearly inappropriate. Generalised linear models with the binomial error distribution and logit link function (McCullagh and Nelder 1989) were fitted using GENSTAT (version 12.1, VSN International Ltd, Oxford, UK). It is obvious that a range of potential predictors exist. Initial analyses showed that body condition ratio measures were superior predictors to actual weights. Using step-forward regression with the factors and quadratics for all the variates, annual average BCR was the best single predictor ($R^2 = 42\%$). Animal age came in next, followed by weight change during the dry period (which is the critical period for mortality, P. K. O'Rourke, pers. comm.). No further single terms gave a significant ($P < 0.05$) improvement to this three-term model. Importantly, this indicates that the key

effects of site, breed, and lactation and pregnancy status are all being adequately covered by the three terms in the model. As a final step, all multiplicative and divisive interactions between BCR, age and weight change during the dry period were screened. The BCR by age interaction was the only significant ($P < 0.05$) interaction, and lifted the adjusted R^2 for this final model to 67.3%. The fitted statistical equation for mortality is

$$\text{mortality}\,(\%) = 100/(1 + e^{-\text{logit}}),$$

where

$$\text{logit} = -21.3 + 40.7 \times \text{BCR} - 24.2 \times \text{BCR}^2 + 1.05 \times \text{Age} - 0.0255 \times \text{Weight change} - 0.893 \times \text{Age} \times \text{BCR}, \tag{2}$$

This model includes a complex interaction between BCR and age, as shown in Fig. 3. This pattern appears biologically meaningful, and agrees with researchers' expectations. Young animals do exhibit a rise in mortality rates as BCR declines, but these animals tend to be more resilient and are still capable of surviving reasonably well under poorer conditions. The older the animals get, however, the more mortality rises in these circumstances. In particular, underweight old animals appear to be highly vulnerable. For example, 7-year-old cows with a BCR of 0.7 and weight change of −10 have a predicted mortality rate of 19.2%, and one such cohort of animals in the base data had an observed mortality rate of 26%. The other term in the mortality equation, namely weight change in the dry period, was also important. With observations adjusted to their mean values of BCR and age, the effect of the observed range of weight changes (back-transformed through the logit) was an extra 5.4% mortality.

This mortality model was further checked using a tree-based regression analysis. This is a binary recursive technique, searching the data for discrete cut-off points that maximise the degree of discrimination for the dependent variable. This analysis also identified the average BCR as the dominant independent variable affecting mortality rates, with age and weight change

Table 3. Observed and predicted average mortality rates from alternate models, by animal classes

Animal class	Observed mortality (%/year)	Annual liveweight gain (kg)	Predicted mortality (%/year) from ENTERPRISE	Predicted mortality (%/year) from GRAZPLAN
Heifers	2.8	34	21.4	4.2
3-year-olds	2.7	19	25.1	4.2
Matures	11.2	10	34.6	4.2

in the dry period also contributing significant discrimination. This analysis confirms the appropriateness of these terms in the statistical model above.

Alternate models

The ENTERPRISE decision-support package (MacLeod *et al.* 2004) has mortality as an exponential function of annual liveweight gain, with an apparently arbitrary constant of 50 being added first. Separate functions are used for breeders and dry stock. Table 3 shows the comparison of these predictions against our observed data. In GRAZPLAN, predicted mortalities are low-level and random at 0.0118% per day (4.2% per annum), unless extra mortality is introduced when BCR falls below a defined critical limit (which is related to relative size, and hence age). For these data, which generally show a saw-tooth weight gain over time, minimum weight during the year usually occurs at the end of the dry period. Given the ratio of end-of-dry weight to end-of-wet weight as an estimate of worst BCR for each cohort in each year, this was plotted against age for our data. All values were above GRAZPLAN's defined critical BCR limit; hence, the predicted mortalities throughout are 4.2% per annum, as also shown in Table 3.

Given the general lack of agreement in Table 3, and that mortality is a function of liveweight gain only in ENTERPRISE, and BCR only in GRAZPLAN, no retuning of parameters of these models was attempted. The statistical model (Eqn 2), which incorporates the effects of BCR, age and weight gains during the critical dry period, and agrees with expert opinion, was therefore adopted as the best prediction equation for mortality.

Validation of mortality model

Datasets with the levels of detail necessary to test Eqn 2 were difficult to obtain. Some earlier (pre-1985) datasets were ruled out, because there was some contention as to whether the breeds and circumstances back then remain representative of the current industry. For example, one cohort of animals in 'very poor–poor' condition, and going into a drought in a dry tropical environment (Fordyce *et al.* 1990) lost 54 of 105 animals. In a commercial situation under these circumstances, managerial intervention (supplementation, agistment, sales) seems more likely than 'letting them die', so it is probable that mortality levels this high are unlikely to occur in practice.

Three independent datasets were used for validation. The first was a herd of 570 *Bos indicus* cross animals in the Gulf district of the Northern Territory (Schlink *et al.* 1994a). Of the 4 years presented, only 1987 had the necessary weight-change data. Here, the observed mortality rate was 13%, which is somewhat higher than the predicted rate of 8.2% from the mortality model. This predicted value was largely influenced by a low average BCR of 0.74, plus higher weight losses during the dry period of that year.

The remaining two datasets come from the Producer Demonstration Sites of 1989 across southern Queensland (Department of Agriculture, Fisheries and Forestry, Queensland, unpubl. data). At Mundubbera, 2 of 42 Brahman cross cows died, giving a mortality rate of 4.5%. With their average BCR of 0.87, the predicted mortality rate was 3.7%. Conversely, in a similar herd at Monto, with an average BCR of 0.86 and a predicted mortality rate of 3.8%, none (0%) of the 103 Santa Gertrudis cows died. The random nature of mortality, particularly with cohorts of smaller numbers, obviously affects these comparisons. However, it is evident that the mortality predictions are of the correct order of magnitude.

Analyses of conception rates

Conception and pregnancy rates are usually interpreted as representing the same measure, under a binary definition (pregnant or not) at each measurement time. Calving rates are measured much later, and will usually be somewhat lower. Initially, we analysed pregnancy rate (PR) on a per cent per annum basis, as this is the usual basis for presentation. This approach identified the obvious problem of the Kidman Springs animals (being continuously mated) apparently being more fertile than those at the other seasonally mated sites, simply because they had more opportunities (cycles) to achieve pregnancy. To standardise for this effect, for the present paper, we define conception rate (CR) as per 21-day cycle, calculated as follows:

$$CR = 1 - (1 - PR)^{1/n}, \qquad (3)$$

where n is the number of cycles. This is a probabilistic calculation, and the discreteness of the binary response can cause problems when all animals get pregnant in the period (as occurred with 12 cohorts in our data, averaging 12 animals per cohort). Here, the calculated CR is also 100%, implying that all animals get pregnant each cycle, which is unrealistic. Graphically, these CR points were far removed from the rest. Rather than delete these points (as they are valid representations of good conception rates), we nominally deleted 'a quarter of a cow' from PR for the calculation of CR. This adjustment is based on the view that the 'all pregnant' result would not have been observed if there were a higher number of animals in that cohort, and that the observed result in reality approximately covers the range from 'all animals in cohort (*n*) pregnant' to '(*n* – 0.5) animals pregnant'. The half-way point in this range, namely (*n* – 0.25), has been adopted as its best overall representation. For example, with 12 animals in the group and three cycles, 11.75 were deemed to be pregnant, and the estimated CR is now 72%. This change shifted these values to about the top of the scatterplots, and these are a more realistic interpretation. With the low numbers of animals and, hence, statistical weighting
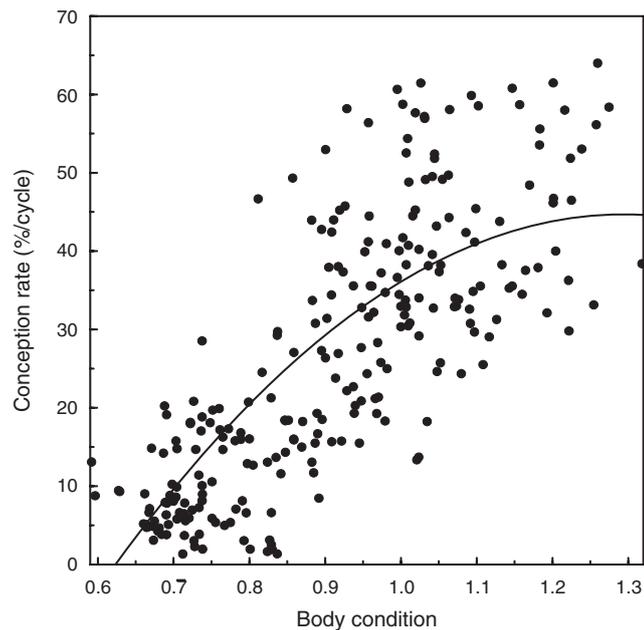
Fig. 4. Fitted quadratic relationship and data for conception rate against body condition ratio.

of these observations, this adjustment probably had little effect on the overall degree of fit.

Statistical analyses

With conception rates generally above 10%, the normal distribution was assumed, and general linear models were fitted to the untransformed percentage conception per cycle. The binomial distribution with the logistic link function was tried, but produced almost identical results, so the normal (which produced acceptable residual plots) was preferred for simplicity. As with the mortality models, the BCRs were better predictors than were weights. Mid-mating BCR, with R^2 of 63% (Fig. 4), was used as a starting point for the step-forward multiple models, because it best reflects the average during the mating period. The age and lactation status factor was the dominant and significant ($P < 0.05$) next addition, followed in a similar fashion by breed, giving a three-term model (with 10 coefficients), with an adjusted R^2 of 75%. While the further additions of both site and weight gain during the mating period were statistically significant ($P < 0.05$), these had only relatively low contributions (increasing the adjusted R^2 by <3%), so were not included. All interactions between BCR, age and lactation and breed were then screened, but none was included because the best increased adjusted R^2 by only 0.8%.

Using S-Plus, a tree-based regression analysis confirmed these relativities, with the first two break-points using BCR. Further divisions involved age, breed, lactation status and weight gain. These break-points reflected biological effects, and the resultant average conception rates within each group were biologically informative, and largely as expected.

While the final statistical model initially appeared appropriate, concerns regarding the functional form were identified – for

example, a sigmoidal curve may be more appropriate, given the data patterns in Fig. 4.

Alternate models

The GRAZPLAN model for conception rates in cattle is based on a logistic equation (Freer *et al.* 1997), as follows:

$$CR = \left[1 + \exp\left(- \left(\frac{2(\ell n(0.95) - \ell n(0.05))}{\beta - \alpha} \right) \left(\frac{\text{Weight}}{\text{SRW}} - \frac{\alpha + \beta}{2} \right) \right) \right]^{-1}, \quad (4)$$

where CR is conception rate per cycle, Weight is liveweight of the animal, SRW is the 'standard reference weight' parameter, α and β are empirical response parameters, corresponding to the estimated values of Weight/SRW for 5% and 95% CR respectively.

The default GRAZPLAN coefficients for cattle produced a clearly inadequate fit to our data – for BCR of 1.0, Fig. 4 shows our CRs range between 15% and 60%, averaging ~35%. Whereas fig. 16 in Freer *et al.* (2009) indicates that animals with BCRs of 1.0 should average CRs of 65– 95%. Hence, retuning of this equation was required. Initially, SRW was taken as an unknown parameter to be estimated, and this non-linear regression problem was fitted via GENSTAT (version 12.1, VSN International Ltd) and a simulated annealing algorithm. However, no unique set of parameter values was found under either approach. This generally indicates an over-parameterised model, where there exists an almost infinite number of combinations of the parameters that fit the data equally well. Further investigations of the functional form proved this to be the case, as this conception rate equation can be reparameterised to remove SRW, as follows:

$$CR = \left[1 + \exp\left(- \left(\frac{2(\ell n(0.95) - \ell n(0.05))}{\beta_1 - \alpha_1} \right) \left(\text{Weight} - \frac{\alpha_1 + \beta_1}{2} \right) \right) \right]^{-1}, \quad (5)$$

where α_1 = SRW α, and β_1 = SRW β. SRW must thus be *a priori* set to biologically realistic values, and then the other parameters tuned to these. The previously listed values of SRW were adopted, namely 520 kg for European breeds and 425 kg otherwise. On the basis of the data patterns in Fig. 4, a third parameter (representing the upper asymptote) was also added to this non-linear regression model; however, the degree of fit was disappointing, with an adjusted R^2 of 47%.

It was noted that the driving independent predictor in Eqn 4, namely Weight/SRW, was derived in GRAZPLAN as the product of 'body condition' (BCR = Weight/N) by 'relative size' (Z = N/SRW) (Freer *et al.* 1997). The statistical analyses showed BCR alone to be a reasonably good predictor of conception rate. Further statistical investigations of the effect of Z on conception rates (not presented here) showed this latter term to have little practical contribution, either in the linear or multiple models. Hence, it appears that GRAZPLAN's hypothesised relationship between skeletal growth and reproduction maturity (as modelled by Weight/SRW) may not apply so well for cattle in northern Australia.

Table 4.   Observed and predicted conception rates (CR,%/cycle) for the validation datasets

Source	Years	Animal class	No. of animals	Observed CR	Predicted CR
Schlink *et al.* (1994*a*)	1986–1989	Mature	570	10.1	9.3
Schlink *et al.* (1994*b*)	1992	Conventional	80	14.7	34.4
		Early-weaned	45	30.0	42.3
Department of Agriculture, Fisheries and Forestry, Queensland, (unpubl. data)	1989	Late-weaned	195	37.0	36.7
		Early-weaned	171	52.8	31.5
Savage *et al.* (2004)	1997–2001	Heifers	2147	36.0	36.7
		Lactating 3-year-old	847	27.4	26.4
		Lactating mature	148	25.4	28.9
		Non-lactating mature	3030	40.8	41.5

It was suggested that BCR by itself may be a better independent variate for Eqn 4, and this proved to be the case. Following on from the statistical results, BCR at the middle of the mating period was used, and this gave an adjusted R^2 of 64%, being slightly superior to the statistical model of quadratic BCR, for the same number of parameters.

After adjusting for BCR, the statistical analysis had then identified age and lactation status and breed as important factors. These were fitted in the sigmoid by allowing each of the three constants to have a different value for each level of the factors. This raised the adjusted R^2 to 80%, again being superior to the fitted statistical model. This reparameterised GRAZPLAN model was thus adopted as the prediction equation for conception rates.

Validation of conception model

As with the validation of mortality rates, the first available dataset was from the Gulf district of the Northern Territory (Schlink *et al.* 1994*a*). In this harsher environment, overall pregnancy rates were 71%, with conception rates per oestrus cycle correspondingly lower. Schlink *et al.* (1994*b*) reported conventional and early weaned cohorts in 1992 at Lansdown Station near Townsville, with pregnancy rates of 47% and 76% respectively. The Producer Demostration Site at Mount Tom, Miriam Vale, in 1989 (Department of Agriculture, Fisheries and Forestry, Queensland, unpubl. data) also reported on late and early weaning cohorts, with pregnancy rates of 65% and 82% respectively. Finally, for the Alexandria Station 1997–2001 study in the Barkly Tableland region of the Northern Territory, data at the individual cohort level were obtained from the principal investigator (D. Savage, pers. comm.). This well managed herd, in an endowed region which received above-average rainfall during the study period, generally had pregnancy rates of 90% or better. For these more recent 'tropical composite breed' animals, SRW was set at 465 kg (D. Savage, pers. comm.).

In each of these validation datasets, the animals were all *Bos indicus* crosses. The comparisons of observed *v.* predicted fertility, as listed in Table 4, are again for conception rates per oestrous cycle, which were calculated from the listed pregnancy rates accounting for the length of the mating period.

In this table, we have six points with good agreement, two that over-predict (although these were the cohorts with only 80 and 45 animals, respectively), and one that under-predicts (171 animals).

The Alexandria data, totalling 6200 observations, showed good agreement for all animal classes.

Given the wealth of the validation data (over 7200 cow-years, which represents 42% of the size of the original dataset), it was deemed appropriate to then include these data in a combined analysis, to give an overall final model. The refitted simplified sigmoidal relationship, for mature lactating F_n *Bos indicus*, is thus

$$CR\,(\%) = a/(1 + e^{(-b(BCR-c))}), \qquad (6)$$

where a = 55.1, b = 6.66 and c = 0.983. For the other breeds and animal classes, each of these three coefficients is incremented by further amounts, as listed in Table 5. Figure 5 shows the fitted effect for the 'age and lactation status' factor, and the breed differences are displayed in Fig. 6.

One further suggestion from team members was that, for conception rates in heifers, actual weights were more biologically important than BCR scores. For the heifer data, with 62 cohorts containing 5200 cow-years, this alternative gave a marginal improvement. Equation 6 was refitted using just the heifer portion of our data, giving a five-coefficient model (models with extra coefficients either would not converge, or gave lower adjusted R^2 values), with an adjusted R^2 of 63%. Then, BCR was replaced by weights, taken as relative to SRW (as per the original GrazPlan formulation in Eqn 4), to factor in the different sizes between breeds. Here, the adjusted R^2 stayed the same. For completeness, this equation using liveweights (at the middle of the mating period) is as follows:

Table 5.   Increments to be applied to the coefficients of Eqn 6, for different animal classes and breeds

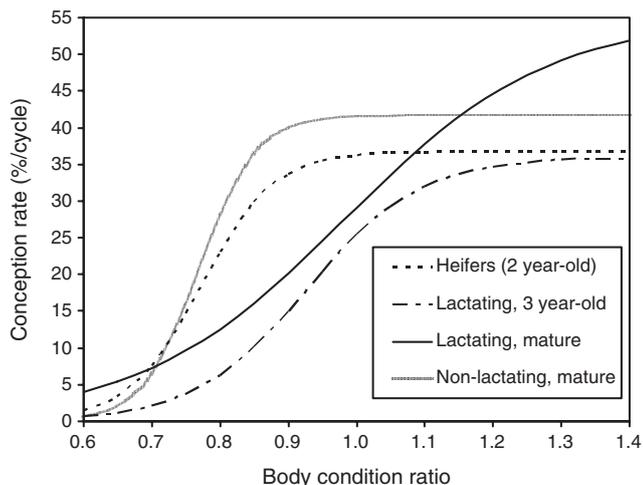| Parameter	a	b	c
Animal class			
Heifers	−18.3	12.02	−0.211
Lactating 3-year-olds	−19.1	5.47	−0.055
Non-lactating matures	−13.5	17.57	−0.213
Breed			
British	2.4	−1.76	0.002
Africander	15.2	0.35	0.009
F_1 *Bos indicus*	−0.10	−0.18	−0.081
European	−0.51	1.04	−0.002

Fig. 5. Fitted effects of age and lactation status on conception rates, illustrated for F_n *Bos indicus* breeds.
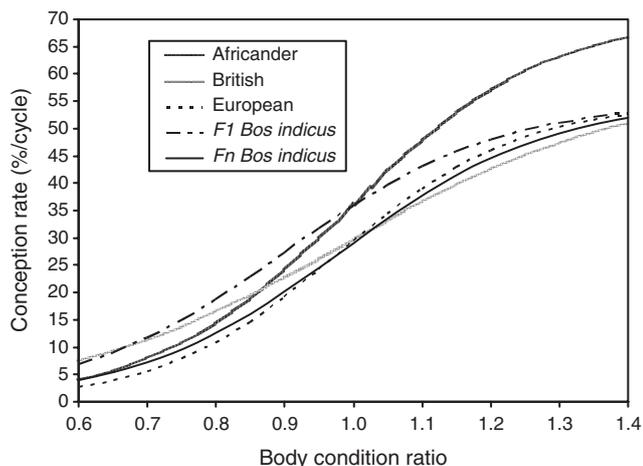

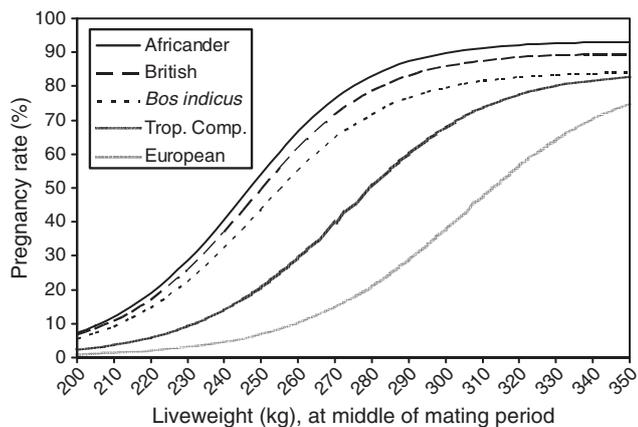**Fig. 6.** Fitted effects of breeds on conception rates, illustrated for lactating mature animals.

Fig. 7. Effects of breeds on pregnancy rates *v.* weights, for heifers under a 12-week mating period.

$$CR\,(\%) = a/(1 + e^{(-b(Weight/SRW-c))}), \qquad (7)$$

where a = 37.0 for *Bos indicus* and European, 43.6 for British, or 49.0 for Africander; SRW = 520 for European breeds, 465 for recent tropical composites, and 425 otherwise; b = 22.4 and c = 0.614. Figure 7 shows the predicted pregnancy rates from this equation, for heifers experiencing a 12-week mating period.

Discussion

While these analyses are based on good sample numbers, which were taken from locations across the area of interest, care must still be taken in generally extrapolating these findings. The base data came from research stations and collaborative producers' properties, and these would represent 'good management'. The biological rates applicable to the 'lower end' of producers can only be speculated on. For example, undiagnosed or untreated disease problems will have a negative effect on the animals, resulting in higher mortalities and lower conception rates. Despite these reservations, the above equations can be taken as 'targets'. They are based on expert opinion and good sample numbers, and provided that no disease or other problems exist in a herd, should provide reasonable predictions of expected biological rates. Hence, they are appropriate for adoption into rangelands simulation models, to then be used when investigating alternate management scenarios and strategies.

One further possible concern is the adaptation and evolution of the composite breeds in northern Australia. Recent unpublished data from the Cooperative Research Centre for Beef Genetic Technologies (G. Fordyce, pers. comm.) showed average weights for mature animals of ~510 kg for Brahmans, and 545 kg for 'tropical composite breeds'. These weights were from animals in middle body condition, fasted, and corrected for conceptus products, this being the usual definition of standard reference weight. This apparent problem of 'shifting' SRW is, however, an issue separate from the estimation of biological rates. SRW is a key parameter in these prediction equations, because it accounts for the effect of frame sizes of different breeds. After an appropriate SRW is determined for any class of animal, the prediction equations in the present paper should remain relevant, because they incorporate the key driving factors of the system (primarily, body condition ratio). Hence, it will be the responsibility of future model users to determine and then specify appropriate SRWs for each herd being studied.

Overall, the improved prediction equations for mortality and conception rates are based on a sizable database across northern Australia, agree with expert opinion, and give good accuracy of predictions. These models thus appear appropriate for general use in this region.

Acknowledgements

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