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Reproductive performance of northern Australia beef herds. 7. Risk factors affecting mortality rates of pregnant cows

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Abstract

Context. There are multiple reports of high annual cow mortality rates in northern Australia, but no reports clearly indicating the overall rates and the impact of primary risk factors.

Aims. The research aimed to determine which measured region-, property-, management group- and animal-level risk factors are associated with missing pregnant females.

Methods. Risk factors for the annual rate of pregnant-cow mortality were investigated in an epidemiological study using outcomes for 21 554 cows from 52 beef herds in 2009 and 2010 in four primary country types within the mostly-dry tropical north Australian environment. Modelling of 2001–2011 Australian beef-herd statistics was used to corroborate and further quantify findings.

Key results. In the epidemiological study, the overall predicted annual mean incidence of missing pregnant cows, a surrogate for mortality, was 10.9%, including lost tags and unrecorded cow movement that were estimated to constitute up to 9% missing cows. Risk factors associated with higher pregnant-cow mortality were as follows: not having follow-up rainfall more than 30 days after the first wet-season storms (4 percentage point increase); <2 t/ha of available pasture biomass in the early dry season (2–6 percentage point increase); pasture dry-season biomass <2 t/ha interacting with less than moderate mid-dry-season body condition score (3–10 percentage point increase); and, calving between April and September (non-significant trend for a 1–2 percentage point increase). Feed-quality measures did not affect mortality rate. Population modelling of Australian beef herd statistics suggested an average annual cow mortality rate in the Northern Forest region of ~7% compared with 2% in more nutritionally endowed regions.

Conclusions. The major risk factor for cow mortality is under-nutrition, related either to generally-low soil fertility, seasonally-dry conditions, or management that exposes animals to poor nutrition. Annual mortality of pregnant cows appears 6–9 percentage points higher in the low-fertility Northern Forest region than elsewhere.

Implications. Beef cow mortality is a major business cost in northern Australia. The efficacy of targeted management to achieve high cow performance was demonstrated by losses in a third of studied businesses in the Northern Forest being kept to the same or lower levels as median loss in endowed regions.

Keywords: beef cattle, mortality, northern Australia, production systems.

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Introduction

Female beef cattle liveweight production is a function of growth, reproduction and survival. Female cattle as a proportion of total slaughtered in Queensland averages ~40% over an extended period (Anon 2012), which is a clear indication of high average annual female mortality rates. Recently, Henderson *et al.* (2013) used a livestock-scheduling method on 36 north Australian beef businesses to demonstrate annual cow mortality rates ranging between 3% and 12%. This is higher than the estimated range of 1–7%

previously derived from a benchmarking project of 182 north Queensland beef businesses (Kernot 1998). Several reports for specific situations in northern Australia's nutritionally non-endowed regions, which regularly endure climatic extremes, have indicated that losses can exceed 10% at a herd or individual animal-class level (Fordyce *et al*. 1990, 2009; Jayawardhana *et al*. 1992; Jubb *et al*. 1996; Sullivan and O'Rourke 1997).

Niethe and Holmes (2008) showed that for each 1 percentage point reduction in female mortality rate for north-west Australian beef herds, there was an increase in business gross margin of approximately AU$2 per adult equivalent (450 kg). Specific opportunities to remediate mortality are indicated by the risk factors associated with loss, but these have not previously been completely identified for commercial herds in this region.

A large epidemiological study involving commercial beef herds across northern Australia (McGowan *et al*. 2014) was conducted to answer several questions, one of which was as follows: which measured region-, property-, management group- and animal-level risk factors are associated with pregnant females that subsequently went missing? This epidemiological research has provided the opportunity to quantify the incidence of missing cows and the impact of major risk factors. An analysis of published statistics was conducted as a reference for average mortality rates of cows in the study area.

Materials and methods

Much of the methods are the same as previously reported in this series (e.g. McCosker *et al*. 2020), and will be summarised here. Full details are provided by McGowan *et al*. (2014).

Ethics

The University of Queensland Animal Ethics Committee approved the conduct of this research as per certificates SVS/756/08/MLA and SVS/729/07/MLA.

Environment, cattle and management

Because of the large number of cattle and businesses in the study, a broad description of the north Australian environment, cattle and management follows.

Northern Australia is transected by the Tropic of Capricorn. Summer temperatures are high. Winters are warm in the north and cooler in the south. Frosts are common in inland areas south of the Tropic of Capricorn. Australia is relatively dry, with 50% of the country having a median rainfall of less than 300 mm per year and 80% receiving less than 600 mm, well below annual pan evaporation which averages at least 2 m in most tropical areas (Anon. 2014). A north Australian 'wet' season, when most rain falls and grass grows, generally occurs from December through to March. The remainder of the year is called the 'dry' season. Four major country types were distinguished: low-fertility soils of the Northern Forest contrasted with moderate- to high-fertility soils in other regions; the predominant trees in Northern Forest and Southern Forest areas are eucalypts, and *Acacia harpophylla* in the Central Forest areas; Northern Downs denotes treeless black-soil plains. Estimated median annual yearling growth for the Northern Forest, Northern Downs, Central Forest and Southern Forest is 100 kg, 170 kg, 180 kg and 200 kg respectively (McGowan *et al*. 2014).

Low-input ('extensive') management is a feature of beef production in northern Australia. Cattle diets are almost exclusively pasture. Stocking rates are low and, in some areas, they are as low as one cow per 150 ha (Tothill and Gillies 1992). Management groups of 300–1000 cattle are common. The majority of cows are continuously mated, with peak calving occurring late in the calendar year. Seasonal mating is usually between 3 and 7 months of duration, often starting in November–December, where suitable bull-control infrastructure is available. Cattle handling for husbandry is infrequent and occurs typically twice annually in April–July and August–September (Bortolussi *et al*. 2005). Mustering using aircraft and on-ground vehicle support is used on ~50% of properties (McGowan *et al*. 2014).

Collaborating beef businesses ($n = 78$) from across northern Australia for this study were identified using a non-random process (McGowan *et al*. 2014) that enrolled representative herds where it was highly likely that good cooperation would be achieved. Each participating herd usually enrolled two groups of females to enable study of first-lactation, mature and aged cows. Management groups enrolled in the study were mostly between 100 and 500 cows in size. In groups of females of more than 500 cows, a representative subset of 300 cows was enrolled. The present paper reports on the percentage of 21 554 pregnant cows of all ages in 2009 and 2010 that went missing from 52 herds (Table 1). The analysis was restricted to pregnant cows because most non-pregnant cows in any one year were culled as part of routine commercial management. The data were drawn from a larger set but restricted to those with confirmed pregnancy and having a full data complement on measured risk factors; only 5.6% of these had full data for more than 1 year. A large range of breeds was represented and, for 56 994 cattle in the project, 23%, 39% and 38% were judged to be <50%, 50–75% and >75% *Bos indicus* respectively (McGowan *et al*. 2014).

Animal measurements

All cows were individually identified using National Livestock Identification System (NLIS; www.nlis.com.au, verified 12 November 2020) electronic tags and, in most cases, a backup visual ear tag. NLIS tags were replaced if the tag was missing or was present but could not be read. In the event

Table 1. Observations included in the analysis of missing pregnant cows

Country type	Herds	Total animal-production years
Southern Forest	12	3 591
Central Forest	13	4 957
Northern Downs	10	8 888
Northern Forest	17	4 118
Total	52	21 554

of an NLIS tag being replaced, data linkages to previous performance records were often able to be established by the separate visual identification tag.

Pregnant animals were identified and fetal age was determined by rectal palpation by persons whose fetal ageing was known to be accurate (maximum error of up to 1 week per month of gestation), including veterinarians accredited by the Australian Cattle Veterinarians (National Pregnancy Diagnosis Scheme), each year at or near the last annual weaning muster in June–October. Breed and age were recorded. Liveweight, body condition score (5-point scale; Gaden 2005) and height at the hips were recorded at this time.

A missing cow was defined as one diagnosed pregnant with no record of being culled and was not recorded at any subsequent muster. Any cow that was not present at one or more musters, but subsequently reappeared in another management group, whether in the trial or not, was not classed as missing. Checks were made using visual tag and brand records of all cows that lost tags, so as to ascertain whether they were retagged. The national database of livestock transactions was cross-referenced, which verified that 27.7% of absent cows had been sold. Missing cows still included some cows that lost their ear tag, or were un-reportedly relocated within the property and not sold before the end of the project. These extensive and thorough checks eliminated potential sources of confounding and allowed missing cows to be used with confidence as a surrogate for pregnant-cow mortality, with differences among levels within independent variables in analyses being an accurate measure of differences due to mortality.

Other risk-factor measurements

A large number of management group-level measures of potential risk factors was recorded (Table 2). All weather conditions were measured using interpolated data (https://www.longpaddock.qld.gov.au/silo/point-data, verified 17

Table 2. Primary cow- and herd-level risk factors and number of levels within factors considered during univariable screening of pregnant cows at risk of missing, and potentially considered in the multivariable-model building process

BCS, body condition score; BVDV, bovine viral diarrhoea virus; CP, crude protein; DMD, dry-matter digestibility; FP, faecal phosphorus; ME, dietary metabolisable energy; THI, temperature–humidity index

Risk factor	Levels	Risk factor	Levels
	Management		
Herd size	3	Cow culling policy	3
Management group size	3	Manager tenure	3
Length of mating	4	Leptospirosis vaccination	3
Mustering efficiency >90%	2	Campylobacter vaccination	3
Use of aerial mustering	2	Bovine ephemeral fever vaccination	3
Bull : female ratio	3	Botulism vaccination	2
Bull selection policy	3	Tick fever vaccination	2
Bull health-management policy	3	Pestivirus (BVDV) vaccination	3
	Environment		
Country type	4	Days THI >71 during calving month	2
Wet season onset	3	Days THI >79 during calving month	2
Wet season duration	3	Average THI during calving month	2
Wet season rainfall	3		
Rainfall follow-up after season break	2	Paddock % within 2.5 km of water	3
Days temp >32 during calving month	2	Paddock area	3
	Nutrition		
Dry-season pasture biomass	3	Dry-season DMD : CP	2
Wet-season DMD	2	Wet-season DMD : CP	2
Dry-season DMD	2	Wet-season FP : ME	2
Wet-season CP	2	Dry-season urea fed	2
Dry-season CP	2	Wet-season phosphorus fed	2
	Animal		
Age	3	Change in BCS: pregnancy diagnosis to branding	3
Breed	3	Hip height	3
Weaned a calf previous year	2	Weight pregnancy-diagnosis muster	3
Outcome from previous mating, including calving month	8	Weight branding or weaning muster	3
BCS pregnancy diagnosis muster	5	Change in weight: pregnancy diagnosis to branding or weaning	3
BCS branding or weaning muster	5		

November 2020). Interpolation is to a specific point in Australia on the basis of data collected since 1889. Start of the wet season was defined as having at least 50 mm of cumulative rainfall within a 14-day period after 1 September. Pasture assessments each 3 months included standing pasture per hectare, estimated by the business owner on the basis of photo standards for the pasture type. At the same time, a bulk faecal sample from 10 to 15 animals in each management group was collected, dried and stored, to subsequently estimate diet dry matter digestibility (DMD) and crude protein by using near-infrared reflectance spectrometry (Dixon and Coates 2005). The threshold for protein adequacy was a crude protein : DMD percentages ratio of 0.125. The measure of phosphorus adequacy (Jackson *et al*. 2012) used was the ratio of faecal phosphorus (mg/kg; wet-chemistry measure) to dietary metabolisable energy (MJ ME/kg from near-infrared reflectance spectrometry measures: $0.172 \times \text{DMD} - 1.707$). Supplements were not withdrawn from cattle before sampling. Land condition was assessed on an A–D scale (Chilcott *et al*. 2003). Each paddock was mapped to calculate the proportion within 2.5 km of permanent water.

Statistical analyses

All analyses were conducted in Stata, ver. 12 (www.stata.com, verified 12 November 2020). A multivariable Poisson model clustered for property-level effects to adjust for correlations among cows within the same property, was used to investigate the impact of risk factors on the incidence of missing animals where 1 denoted missing and 0 denoted not missing. The period an animal was at risk of going missing was used as an offset in the analysis and was defined as the period (months) at risk of going missing during the current reproductive cycle, commencing at the fetal ageing muster. For those animals that went missing, the mid-point between the last muster present and the first muster missing was assumed. Models were built using a manual stepwise approach (Dohoo *et al*. 2009). Variables were screened one at a time and retained for consideration in the final multivariable model if the univariable screening P-value was <0.25. Correlation matrices of all candidate explanatory variables were used to identify explanatory variables that were highly correlated ($r > 0.9$) and, where this occurred, only one of the correlated variables was considered in the multivariable model.

The model-building process started with all candidate animal-level explanatory variables being added to the starting model and non-significant variables dropped one at a time, starting with the non-significant variable with the highest P-value. This process was continued until only significant variables remained in an interim, animal-level model. Explanatory variables measured at the management group or property level were then considered for inclusion in the model and retained if they were associated with a significant P-value, creating a candidate main-effects model that included animal- and management group-level variables.

Biologically plausible two-way interactions were then considered and retained if they were associated with a significant P-value and an interpretable association based on assessment of marginal means and plots of effects. Country type was forced into models and two-way interactions were considered between country type and other explanatory factors, because of specific interest in the effects represented by country type.

Predicted incidence rates for cows missing per year were generated as marginal means from the final multivariable model for each of the explanatory variables in the final model. The marginal means for any one variable were adjusted for the effects of all other variables in the model. Pair-wise statistical comparisons were conducted to generate P-values for comparisons among different levels within each variable or interaction term from the final model. Risk-factor levels that were significantly different were thought to be equated to differences in cow mortality because there was no evidence that tag loss or cattle movement differed significantly among levels of any risk factor.

Calculation of cow-mortality rates from Australian cattle-herd statistics

Published data for statistical regions in Australia over the period of 2001–2011 (Anon. 2012), which preceded and was contemporary for the epidemiological research, was used in an interactive model of national herd structure. The model was constructed to explain numbers of female breeding-age cattle in Australia, the number of cattle slaughtered each year in Australia by gender, and the number cattle exported live from Australia each year. It was assumed that 30% of exports are females on the basis of general observation of consulted live-export personnel, as gender is not recorded for live-cattle shipments, and there are no known publicly available data available to verify the figure in that period. Two primary regions were defined, namely, southern and eastern Australia (South Australia, Tasmania, Victoria, New South Wales) and northern and western Australia. Further analyses differentiated cow performance in the endowed region of northern and western Australia (southern half of Queensland and south-western Western Australia where conditions match those found in southern and eastern Australia – Australian Bureau of Statistics Zones 312, 314, 321, 322, 331, 332a, 521, 522, 531; Anon. 2020), and the non-endowed region of northern Australia equivalent to the Northern Forest and some areas of Northern Downs (northern Queensland, Northern Territory, north-western Western Australia).

Basic assumptions made in the model were as follows: average mortality rate within gender was the same for each year group; all cattle are sold by 10.5 years of age; average herd structure, females mated, and weaning, culling and mortality rates were similar within regions; most males over 3.5 years of age were bulls; and bull to mated female ratios were ~4% in northern and western Australia and 2% in southern and eastern Australia. Input parameters nationally and within state for each year when required included the following: 9.5-year-old cow numbers; mortality rates; proportion sold for slaughter or export in each age and gender group; proportion of yearlings mated; and liveweights and values of cattle that die. Liveweights were estimated for cows in body condition score 1.5 and for males in score 4 (5-point scale). Inputs were adjusted by iteration, with the aim of achieving less than 1% difference between the following: the published and model output male and female slaughter and live-export numbers for Australia; the calculations combined for states and the overall calculations for Australia; numbers for adult female beef cattle by state and territory and calculated females aged 2.5 years and older.

Final input mortality rates and output mortality numbers were taken as close to actual values. The value of cattle mortalities was calculated as the sum of products of average weight and net value per kilogram within each age × gender × state group. The final model also produced number of calves weaned and mating-age females in each state, thus, weaning rates.

Results

Epidemiological study of missing cows

The percentage of missing pregnant cows was high and highly variable in all country types and across all ages of cow (Fig. 1). Although losses were highest in the Northern Forest, a third in this country type were at or below the median levels for the other country types.

The final Poisson model explained 32.3% of the property-level variance (Table 3). The overall predicted mean incidence of missing pregnant cows was 10.9% (95% CI: 8.7–13.1%) per animal-year (Table 4). Four factors were found to have a significant influence on the percentage of pregnant-cow mortality, with two of these interacting. Between 6 and 9 percentage point higher pregnant-cow mortality occurred in the Northern Forest region than in the other more fertile regions. Having follow-up rainfall more than 30 days after the first wet-season storms increased the percentage of dead pregnant cows by an average of 4 percentage points. The effect of pasture availability during the early dry season was dependant on body condition score at the pregnancy-diagnosis muster, with the occurrence of mortality increasing by between 1.5 to 7 percentage points under conditions of low available-pasture biomass (<2 t/ha) across the different body condition scores. The impact of body condition score on mortality appeared to be greater if pasture biomass was higher (≥2 t/ha), with increases in the occurrence of mortality ranging between 4 and 10 percentage points for pregnant cows with a mid-dry season body condition score of ≤3, compared with between 2 and 6 percentage points under conditions of low available-pasture biomass (Table 4). There was a non-significant trend for a 1–2 percentage point higher mortality rate when calving between April and September, that is, the early–mid-dry season, than when calving at other times of the year (Tables 3, 4).

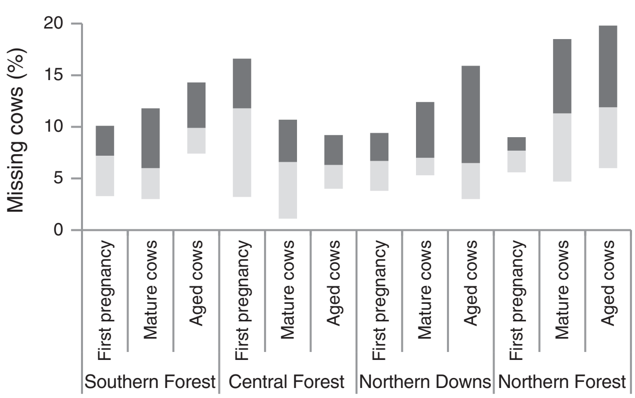

Fig. 1. Interquartile range in occurrence of missing pregnant cows annually within country type and cow age: raw data: 25–50 percentile (light bars), and 50–75 percentile (dark bars).

Cow-mortality prediction from Australian cattle-herd statistics

Estimated average number of annual female and male cattle slaughtered and exported during 2001–2011 was 3 958 153 and 4 668 301 respectively, thus giving a national female to total slaughtered and exported ratio of 46.1%.

Although the herd model was unable to be fully reconciled, the best fit achieved between published data and data calculated either nationally or on a state by state basis indicated a much higher weaning rate in southern and eastern Australia than in northern and western Australia, and the annual mortality rate of female cattle was twice that of male post-weaning-age cattle in Australia (Table 5). Annual mortality rates in northern and western Australia were estimated to be higher than average in females, and slightly lower than average in males, compared with rates in southern and eastern Australia. More than one million post-weaning-age cattle were estimated to die annually in Australia, with more than half of these losses being females in northern and western Australia (Table 5). An average of 6.9% and 25.3% of female cattle and 3.2% and 3.4% of male cattle weaned in southern and eastern and in northern and western Australia respectively, are estimated to become 'on-farm' mortalities. The value of cattle that die annually in Australia is estimated at AU$309 million, using representative market rates during that period (Table 5).

If the annual female-cattle mortality rate in nutritionally endowed zones of northern and western Australia is similar to that in southern and eastern Australia (2.0%), then, from the data in Table 5 and relative cattle populations in the two groups of statistical regions, the female-cattle mortality rate in the nutritionally non-endowed agricultural regions of northern and western Australia is in the vicinity of 7.2%.

Discussion

Our estimates of Australian beef-cattle mortality and weaning rates may be as close to actual as can be achieved given the data available. However, these estimates should be used with caution as numbers were not fully reconcilable with published data, and no confidence intervals were calculable. Most calculations were similar to published data, except for total herd size, which was calculated from state and national data at 2.4 million and 4.9 million higher respectively, than published data. One suggested reason for this is under-reporting of stock numbers by farmers in surveys. This has been borne out in the 2012–2015 low-rainfall years when the Queensland cattle herd has not increased, while an average of 16% more cattle have

Table 3. Final model in analysis of missing pregnant cows from north Australian beef-breeding herds
Bold values are generalised Wald-test *P*-values; others are Wald-test values

Variable	Coefficient	s.e.	IRR	95% CI of IRR		*P*-value
				Lower	Upper	
Country type						**0.02**
Southern Forest	0.210	0.270	1.23	0.73	2.09	0.44
Central Forest	0.10	0.261	1.32	0.79	2.20	0.29
Northern Downs	Ref					
Northern Forest	0.705	0.244	2.02	1.25	3.26	<0.01
Available dry-season biomass						**<0.001**
2000+ kg/ha	Ref					
<2000 kg/ha	0.633	0.169	1.88	1.35	2.62	<0.001
Body condition score at previous pregnancy diagnosis						**<0.001**
<2.5	0.748	0.122	2.11	1.66	2.68	<0.001
2.5	0.379	0.120	1.46	1.15	1.85	<0.01
3.0	Ref					
3.5	–0.115	0.101	0.89	0.73	1.09	0.26
>3.5	–0.108	0.107	0.90	0.73	1.11	0.31
Interval to follow-up rain after season break						**0.04**
<30 days	Ref					
30+ days	0.335	0.162	1.40	1.02	1.92	0.04
Predicted period of calving						**0.101**
July–Sep.	0.186	0.075	1.20	1.04	1.39	0.01
Oct.–Nov.	Ref					
Dec.–Jan.	0.011	0.066	1.01	0.89	1.15	0.86
Feb.–Mar.	–0.044	0.095	0.96	0.79	1.15	0.64
Apr.–June	0.097	0.117	1.10	0.88	1.39	0.41
Interaction: available dry-season biomass × body condition score at pregnancy diagnosis						**0.03**
<2000 kg/ha: <2.5	–0.546	0.187	0.58	0.40	0.84	<0.01
<2000 kg/ha: 3.0	–0.265	0.164	0.77	0.56	1.06	0.11
<2000 kg/ha: 3.5	–0.122	0.151	0.89	0.66	1.19	0.42
<2000 kg/ha: >3.5	–0.002	0.156	1.00	0.74	1.35	0.99
Intercept	**–5.520**	**0.219**	**0.00**	**0.00**	**0.01**	**<0.001**
Alpha	0.332	0.081		0.206	0.535	

been slaughtered and exported than in previous years (Anon. 2015).

Calculated national mortality and weaning rates from national statistics appear to be relatively high and low respectively, in relation to some previous reports (O'Rourke *et al*. 1992; Bortolussi *et al*. 2005). An annual mortality rate of ~2% or less for both female and male cattle appears to be likely across the country, except for female cattle in the nutritionally non-endowed regions of northern Queensland, most of Western Australia and all of the Northern Territory, where the average annual female-cattle mortalities may exceed 7%. This is not dissimilar to a recent study using business records in the non-endowed region of northern Australia, where annual cow mortality rate was found to be 3–18%, with a median of 5.7% (Henderson *et al*. 2013). Our finding of 6–9 percentage point increase for cows missing annually in the Northern Forest compared with more fertile regions is consistent with these reports, as our analysis was only of pregnant cows, which are at a higher risk of mortality than are all cows.

If the calculated average pregnant-cow mortality rates are accurate, then up to an approximate average of 9% of cows were missing because of unrecorded movement, that is, to another management group within the same business. The specific level will be lower where the identity of cows was lost when tags were lost and the new and old tags could not be matched. This level of unrecorded movement is not unexpected as animal control can be very difficult in this region, especially during wet-season floods that break fences.

There are few accurate measures of cattle mortality rates in herds in the nutritionally non-endowed regions of northern Australia, but several that have been made indicate losses can exceed 10%, primarily due to under-nutrition in this region of climatic extremes (Fordyce *et al*. 1990; Jayawardhana *et al*. 1992; Jubb *et al*. 1996; Sullivan and O'Rourke 1997). In our study, low available feed biomass was a major risk factor for higher mortality rates. No diet-quality measures, such as digestibility or protein and phosphorus adequacy, were associated with pregnant-cow mortality in the final multivariable model, except those that were expressed through country type. In contrast, Henderson *et al*. (2013) reported that phosphorus supplementation achieves small reductions in annual mature-cow mortality rates, but a large

Table 4. Predicted mean incidence of missing cows from north Australian beef herds presented as animal-years per 100 years expressed as a percentage for risk factors affecting the incidence of missing cows

Means within a risk factor followed by the same letter, or no letters, are not significantly different (at $P = 0.05$)

Risk factor	Level		Mean (%)	95% confidence interval Lower	Upper
Country type					
	Southern Forest		11.0a	6.8	15.2
	Central Forest		11.8ab	7.7	15.9
	Northern Downs		8.9a	5.3	12.5
	Northern Forest		18.1b	12.3	23.9
Available dry-season biomass × body condition score at pregnancy diagnosis					
	<2000 kg/ha	<2.5	18.5a	12.6	24.5
		2.5	17.0a	12.3	21.6
		3	15.1ab	11.1	19.2
		3.5	11.9c	8.8	15.1
		>3.5	13.6bc	10.3	16.8
	≥2000 kg/ha	<2.5	17.0c	11.8	22.2
		2.5	11.7b	7.9	15.5
		3	8.0a	5.6	10.4
		3.5	7.2a	4.9	9.4
		>3.5	7.2a	5.0	9.4
Interval to follow-up rain after season break					
	<30 days		10.2a	8.3	12.1
	≥30 days		14.2b	9.7	18.8
Predicted period of calving					
	July–Sep.		13.8	10.5	17.1
	Oct.–Nov.		11.5	9.0	13.9
	Dec.–Jan.		11.6	9.1	14.1
	Feb.–Mar.		11.0	8.2	13.7
	Apr.–June		12.6	9.0	16.2

impact on cows aged over 10 years. The Northern Forest is characterised by a higher incidence of low diet quality throughout the year (McGowan *et al*. 2014). The confounding between country type and diet quality may partially explain the lack of pasture-quality effects on the percentage of pregnant cows dying. Winks *et al*. (1979) showed that supplementation over ~6 months of the dry season with urea-based supplements conserves 0.5–1.0 body condition scores (on a 5-point scale), with compensation in the following wet season of at least two-thirds of the difference being achieved by supplementation. Therefore, the effect in reducing mortalities with urea-based supplements is expected to vary from nil, where basic management (especially water and pasture availability plus strategic weaning) conserves body condition, to high, where basic management does not adequately conserve cow condition.

Despite the non-significant effect of urea-based supplements on survival, the impact of these factors on the ability to conceive and rear a calf to weaning (Fordyce *et al*. 2020; McCosker *et al*. 2020) may be larger. This is because their primary impact is exerted at the reproductive level, and if cows do not conceive or rear a calf because of dietary inadequacy, they have a much lower probability of dry-season mortality.

At the onset of the wet season, feed intake drops dramatically (McLean *et al*. 1983), as a variable and usually large proportion of the dead and dried standing pasture is destroyed. Body-tissue reserves are drawn on until pasture regrowth occurs and intake is restored. However, grass growth will discontinue without follow-up rainfall. The short green feed appearing after first rains attracts cows to walk further during grazing, thus increasing energy expenditure of cows. Further, the change in the diet quality in this period is likely to elevate basal metabolic rate, thus exacerbating the effect of any energy deficiency. This explains the large effect on pregnant-cow mortality that we found due to delayed follow-up rainfall.

Nutritional effects on cow survival were further emphasised by the 3–10 percentage point higher loss when cows were in less than moderate body condition in the mid-dry season. This effect was lower when there was less available pasture biomass, as the proportion of missing cows in forward body condition was much higher under these conditions. This suggests that when available pasture is over-utilised, better body condition of cows will not save them as liveweight loss is expected to be high in all classes. Further, cows in better body condition are more likely to calve earlier, accelerating their condition loss compared with later-calving cows.

Fordyce *et al*. (1990) reported that cows aged over 8 years had a higher risk of dry-season mortality and related this to deteriorating condition of incisor teeth in particular; that is, aged cows have a lower foraging ability and, thus, poorer nutrition. Henderson *et al*. (2013) also found mortality rates to be 6 percentage points higher in cows aged over 10 years than

Table 5. Calculated national herd structure and performance, 2001–2011
Estimates for Australia were derived from separate analysis and not by summing regional estimates

Parameter	Category		Southern and eastern Australia	Northern and western Australia	Australia
			Inputs		
Yearlings mated (%)			75	10	
Females slaughtered and exported (%)	0.5–1.5 years		35	16	20
	1.5–2.5 years		35	16	20
	Annually thereafter		15	5	10
Males slaughtered and exported (%)	0.5–1.5 years		50	20	20
	1.5–2.5 years		80	50	70
	2.5–3.5 years		85	90	85
	Annually thereafter		25	25	25
Annual mortality (%)	Female		2.0	4.6	3.7
	Male		2.0	1.5	1.8
Average weight of females dead (kg)	0.5–1.5 years		200	150	
	1.5–2.5 years		250	200	
	2.5–3.5 years		300	250	
	3.5–4.5 years		350	300	
	>4.5 years		400	350	
Average weight of males dead (kg)	0.5–1.5 years		250	200	
	1.5–2.5 years		425	350	
	2.5–3.5 years		600	500	
	3.5–4.5 years		750	600	
	>4.5 years		800	700	
Dead females net value	AU$/kg live		AU$1.30	AU$1.10	
Dead males net value	AU$/kg live		AU$1.50	AU$1.30	
			Outputs		
Herd size (*n*)	Females	‘000	9205	11 773	22 643
	Males	‘000	4292	4873	10 001
Mating-age females (*n*)	Females	‘000	6107	8098	15 433
	Bulls	‘000	110	257	510
Weaners (*n*)	Number	‘000	5354	4287	9529
	Rate (%)		88	53	62
Annual mortality (*n*)	Females	‘000	184	542	838
	Males	‘000	86	73	180
Net value of mortalities (AU$)	Females	‘000	71 331	163 939	235 270
	Males	‘000	42 954	30 822	73 777

in younger cows. It is unclear why age was not a significant risk factor in our study.

The impact of dry-season nutrition was exemplified by Henderson *et al*. (2013) who reported 10 percentage point lower mortality rates when cows were segregated over the dry season for differential management on the basis of expected calving date, than when this practice was not used. This is because late gestation and lactation create much higher maintenance-energy requirements for cows. Although we found a trend for higher mortality rates when cows calved in the early–mid-dry season, when available dietary energy is lowest, this effect was not as dramatic as in the study of Fordyce *et al*. (1990; 21% mortality) because overall mortality rates were much lower and there is likely to have been more widespread use of interventions to reduce cow mortalities.

The major infectious disease associated with cow mortality in northern Australia is botulism (Lane *et al*. 2015). As there are no available tests for animal or environmental samples with sufficient specificity and sensitivity, its impact on cow performance could not be evaluated either in our study or the study by Henderson *et al*. (2013). Lane *et al*. (2015) provided an estimate of the impact of this disease that was small, mainly because a high percentage of susceptible cattle are vaccinated. These authors suggested that <0.2% cow mortality is due to this disease, thus emphasising the primary importance of under-nutrition.

Determination of absolute levels of mortality in our epidemiological study was not possible. This is consistent with the typical north Australian beef business, where inadequate information is usually available for analysis of cow performance, such as mortality rates (Henderson *et al*. 2013; McGowan *et al*. 2014). Therefore, a simple method using annual stock takes and transaction records to accurately calculate mortality and a range of herd-performance and production measures was developed and is now commercially available (Moravek 2015).

As under-nutrition is a key risk factor for cow mortality, strategies to ameliorate loss must focus on reducing dietary needs, and rectifying specific dietary deficits. Strategies should aim to achieve moderate body condition score in the mid-dry season to reduce the costs associated with crisis strategies to minimise cow mortalities. Good practice (Holroyd and Fordyce 2001) includes the following:

- Weaning management, which heads preventative strategies. Good weaning management targets conservation of cow condition, as much as calf weaning weight.
- Water quality and distribution to readily satisfy animal requirements and minimise energy expenditure for access.
- Stocking rate and pasture management to achieve adequate nutritional value and access (quantity and distribution) of feed.
- Timing mating, if it is not continuous, to avoid dry-season lactation, which is a major cause of condition loss.

Our study showed that in the Northern Forest where cow mortality is highest, losses are kept to the same level as, or lower levels than is the median loss in endowed regions in a third of situations. This demonstrates the efficacy of targeted management.

Conclusions

The conclusion of the study is that cow mortality is a major annual feature of beef production systems in northern Australia, and especially in the low-fertility Northern Forest region where the rate appears to be in the vicinity of 7% annually, and closer to 2% elsewhere. The major risk factor for cow mortality is under-nutrition, related either to generally low soil fertility, seasonally dry conditions, or management that exposes animals to poor nutrition.

Conflict of interest

The authors declare they have no conflicts of interest.

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References

Anon. (2012) ‘7121.0 – agricultural commodities, Australia, 2011–12: livestock.’ (Australian Bureau of Statistics) Available at http://www.abs.gov.au/ausstats/abs@.nsf/Lookup/7121.0main+features82011-12 [Verified 17 November 2020]

Anon. (2014) ‘Climate of Australia.’ Available at http://en.wikipedia.org/wiki/Climate_of_Australia [Verified 17 November 2020]

Anon. (2015) ‘Statistics database.’ (Meat and Livestock Australia: Sydney, NSW, Australia). Available at http://statistics.mla.com.au/Report/List [Verified 17 November 2020]

Anon. (2020) ‘ABS maps.’ (Australian Bureau of Statistics). Available at https://itt.abs.gov.au/itt/r.jsp?ABSMaps [Verified 17 November 2020]

Bortolussi G, McIvor JG, Hodgkinson JJ, Coffey SG, Holmes CR (2005) The northern Australian beef industry, a snapshot. 2. Breeding herd performance and management. *Australian Journal of Experimental Agriculture* **45**, 1075–1091. doi:10.1071/EA03097

Chilcott CR, McCallum BS, Quirk MF, Paton CJ (2003) ‘Grazing land management education package workshop notes: Burdekin.’ (Meat and Livestock Australia: Sydney, NSW, Australia)

Dixon RM, Coates DB (2005) The use of faecal NIRS to improve nutritional management of cattle in northern Australia. *Recent Advances in Animal Nutrition in Australia* **15**, 65–75.

Dohoo I, Martin W, Stryhn H (2009) ‘Veterinary epidemiologic research.’ (Ed. SM McPike) University of Prince Edward Island, Charlottetown, Canada.

Fordyce G, Tyler R, Anderson VJ (1990) Effect of reproductive status, body condition and age of *Bos indicus* cross cows early in a drought on survival and subsequent reproductive performance. *Australian Journal of Experimental Agriculture* **30**, 315–322. doi:10.1071/EA9900315

Fordyce G, Coates R, Debney M, Haselton S, Rebgetz R, Laing AR, Cooper NJ, Hall RL, Holmes WE, Doogan VJ (2009) A systems evaluation of high-input management using fortified molasses for beef production in Australia’s dry tropics. *Animal Production Science* **49**, 177–191. doi:10.1071/EA07225

Moravek T (2015) ‘Beef rough indicator calculator of key performance indicators (BRICK).’ (Department of Agriculture and Fisheries: Brisbane, Qld, Australia). Available at https://futurebeef.com.au/knowledge-centre/brick/ [Verified 17 November 2020]

Fordyce G, McCosker KD, Barnes T, Smith DR, Perkins NR, O’Rourke PK, Marquart L, Menzies D, Newsome T, Joyner D, Phillips N, Burns BM, Morton J, Jephcott S, McGowan MR (2022) Reproductive performance of northern Australia beef herds. 6. Risk factors associated with reproductive losses between confirmed pregnancy and weaning. *Animal Production Science*

Gaden B (2005) Final report, Project LIVE.120. Meat and Livestock Australia, Sydney, NSW, Australia. Available at https://www.mla.com.au/contentassets/c66b3ffdfe0d416f8683daa115518ae1/live.120_final_report.pdf [Verified 17 November 2020]

Henderson A, Perkins N, Banney S (2013) Determining property-level rates of breeder cow mortality in northern Australia. Final report B.NBP.0664. Meat and Livestock Australia, Sydney, NSW, Australia. Available at https://www.mla.com.au/contentassets/ec07dba1026a41619057f5d94ca05257/b.nbp.0664_literature_review_final_report.pdf [Verified 17 November 2020]

Holroyd RG, Fordyce G (2001) Cost effective strategies for improved fertility in extensive and semi-extensive management conditions in northern Australia. In ‘The 4th international symposium on animal reproduction’, Huerta Grande, Cordoba, Argentina, 22–24 June 2001. pp. 39–60. (International Congress on Animal Reproduction)

Jackson D, Rolfe J, English B, Holmes B, Matthews R, Dixon R, Smith P, MacDonald N (2012) ‘Phosphorus management of beef cattle in northern Australia.’ (Meat and Livestock Australia Limited, Sydney, Australia).

Jayawardhana GA, McCool CJ, Zuill DQ, Olm TC (1992) The effect of stocking rate on breeder productivity in the Victoria River district. In ‘Proceedings of the north west Australia pastoral conference’, Katherine, NT, Australia, 28–29 October 1992. pp. 72–80. (Department of Primary Industry and Fisheries, Northern Territory)

Jubb TF, Vassallo RL, Annand TE (1996) Estimating deaths in breeder-age female cattle in the Kimberley region of Western Australia. *Australian Veterinary Journal* **73**, 152–153. doi:10.1111/j.1751-0813.1996.tb10009.x

Kernot JC (1998) Sustainable beef production on tropical tallgrass using the local best practice (LBP) approach. Final report, Project DAQ.092/NAP3.306. Meat and Livestock Australia, Sydney, NSW, Australia. Available at https://www.mla.com.au/contentassets/e2ff6ae92d1f405a8e3087af81cc52f0/daq.092_final_report.pdf [Verified 17 November 2020]

Lane J, Jubb T, Shepherd R, Webb-Ware J, Fordyce G (2015) Priority list of endemic diseases for the red meat industries. Final report, Project B.AHE.0010. Meat and Livestock Australia, Sydney, NSW, Australia. Available at https://www.mla.com.au/contentassets/5c4a6eb332a94448b15602249c9fa6f1/b.ahe.0010_final_report.pdf [Verified 17 November 2020]

McCosker KD, O'Rourke PK, Fordyce G, Smith DR, Perkins NR, McGowan MR (2020) Reproductive performance of northern Australia beef herds. 5. Factors influencing risk of non-pregnancy. *Animal Production Science*

McGowan MR, McCosker K, Fordyce G, Smith D, O'Rourke PK, Perkins N, Barnes T, Marquet L, Morton J, Newsome T, Menzies D, Burns BM, Jephcott S (2014) North Australian beef fertility project: cash cow. Final report, Project B.NBP.0382. Meat and Livestock Australia, Sydney, NSW, Australia. Available at https://www.mla.com.au/research-and-development/search-rd-reports/final-report-details/productivity-on-farm/northern-australian-beef-fertility-project-cashcow/370 [Verified 17 November 2020]

McLean RW, McCown RL, Little DA, Winter WH, Dance RA (1983) An analysis of cattle live-weight changes on tropical grass pasture during the dry and early wet seasons in northern Australia. 1. The nature of weight changes. *Journal of Agricultural Science* **101**, 17–24. doi:10.1017/S0021859600036315

Niethe GE, Holmes WE (2008) Modelled female sale options demonstrate improved profitability in northern beef herds. *Australian Veterinary Journal* **86**, 458–464. doi:10.1111/j.1751-0813.2008.00366.x

O'Rourke PK, Winks L, Kelly AM (1992) 'North Australia beef producer survey 1990.' (Meat and Livestock Australia: Sydney, NSW, Australia)

Sullivan RM, O'Rourke PK (1997) A comparison of once- and twice-yearly weaning of an extensive herd in northern Australia 1. Cow liveweights, mortalities and fertility. *Australian Journal of Experimental Agriculture* **37**, 279–286. doi:10.1071/EA95097

Tothill JC, Gillies C (1992) 'The pasture lands of northern Australia: their condition, productivity and sustainability. Occasional publication, no. 5.' (Tropical Grassland Society of Australia, Meat Research Corporation)

Winks L, Laing AR, O'Rourke PK, Wright GS (1979) Factors affecting response to urea-molasses supplements by yearling cattle in tropical Queensland. *Australian Journal of Experimental Agriculture and Animal Husbandry* **19**, 522–529. doi:10.1071/EA9790522

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