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Reproductive performance of northern Australian beef herds. 3. Descriptive analysis of major factors affecting reproductive performance

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ABSTRACT

Context. The performance of commercial beef-breeding herds in northern Australia is highly variable. Identifying and understanding the major factors that influence this is critical in determining which management interventions should be implemented to best manage these factors. **Aims.** This study aimed to describe the occurrence and magnitude of the risk factors identified as being strongly associated with one or more measures of cow performance in northern Australia. **Methods.** A prospective epidemiological study was conducted in a cross-section of commercial beef-breeding herds in northern Australia, to determine and quantify the major associations of up to 83 candidate herd management, nutritional and environmental risk factors with cow performance. Descriptive analyses of significant risk factors were conducted. **Key results.** Unfavourable levels of risk factors were observed for all country types and across three cow-age groups. However, generally, adverse property-level nutritional, environmental and management risk factors had a higher incidence in the Northern Forest, which was associated with significantly lower performance of heifers and cows. This was reflected in generally lower body condition of heifers and cows in this country type. Although the performance of heifers and cows was generally higher in the Southern Forest, the irregular incidence of adverse risk factors contributed to the observed quite variable performance. **Conclusions.** The factors significantly affecting the performance of cows in the major beef-breeding regions of northern Australia are described. These factors were additively more adverse in the Northern Forest. **Implications.** In this study, the necessary understanding of the factors most likely to be affecting the performance beef cows in this environment has been described. This is required to make appropriate decisions about management interventions to control these factors.

Keywords: beef production, cattle, fetal and calf loss, herd management, mortality, northern Australia, pregnancy, reproduction, risk factors.

Introduction

The profitability of northern Australian beef-cattle breeding is partially a function of production, which in turn is largely an outcome of growth, survival and reproductive performance of female breeding cattle. Large variability in the reproductive performance of northern Australian beef-cattle herds has long been recognised (Entwistle 1983; O'Rourke *et al.* 1992). This variability is due to a multitude of risk factors that constantly prevail to variable degrees across the region. Being able to consistently attain achievable cow performance and production is dependent on understanding the integrated impacts of these risk factors and implementing strategies to ameliorate negative impacts.

Research relevant to northern Australian beef-breeding systems has identified numerous herd-, property-, management group- and animal-level factors that have an impact on beef-cattle reproduction (Hasker 2000), with many of these having been comprehensively reviewed by Burns *et al.* (2010). However, as low cow performance is often the consequence of multiple interacting risk factors, understanding their specific impacts is required.

A large prospective, epidemiological study was established across northern Australia between 2007 and 2011, to quantify commercial breeding beef female performance and production and the associated risk factors. The outcomes are delivered in a series of eight papers that provide a situation analysis and provide in-depth analysis of risk factors associated with primary cow-performance traits. The project was known as Cash Cow as it investigated primary drivers of liveweight production from northern Australian breeding herds, which is the principal indicator of business income.

This paper quantifies the scale and variation of risk factors affecting female reproduction and survival, as highlighted in other papers in the series; that is, it describes the operational environment of beef breeding in northern Australia by using the risk factors identified as strongly associated with cow reproduction and survival.

Materials and methods

Data background

McCosker (2016) provided a detailed description of study design. Briefly, a large prospective population-based epidemiological study of the performance of breeding cows in northern Australian commercial beef herds was conducted between 2007 and 2011. Cow-performance and associated risk-factor data were collected from 78 sites (Fig. 1) where approximately 78 000 cows managed in 165 breeding groups were monitored.

A comprehensive system for monitoring and collection of cow-performance and risk-factor data was implemented by McGowan *et al.* (2014). A project data collection manual, annual participant workshops and regular calibration of data recorders underpinned the project. Data recorded against individual electronic animal identification devices facilitated collection of animal performance data. Body condition, lactation status and risk-factor data for each heifer or cow enrolled in the project were collected at least twice each calendar year at the branding and or weaning muster and again at the pregnancy diagnosis muster. Pregnancy diagnosis and fetal ageing were conducted using rectal palpation by accredited veterinarians once per year (approximately September in continuously mated herds, or at least 6 weeks after the removal of bulls in control-mated herds). The age the fetus was estimated using half-monthly increments between 1 and 5 months, and, after that, fetal age was estimated using increments of 1 month.

To evaluate the impact on reproductive performance of selected endemic infectious diseases, a cross-sectional sample

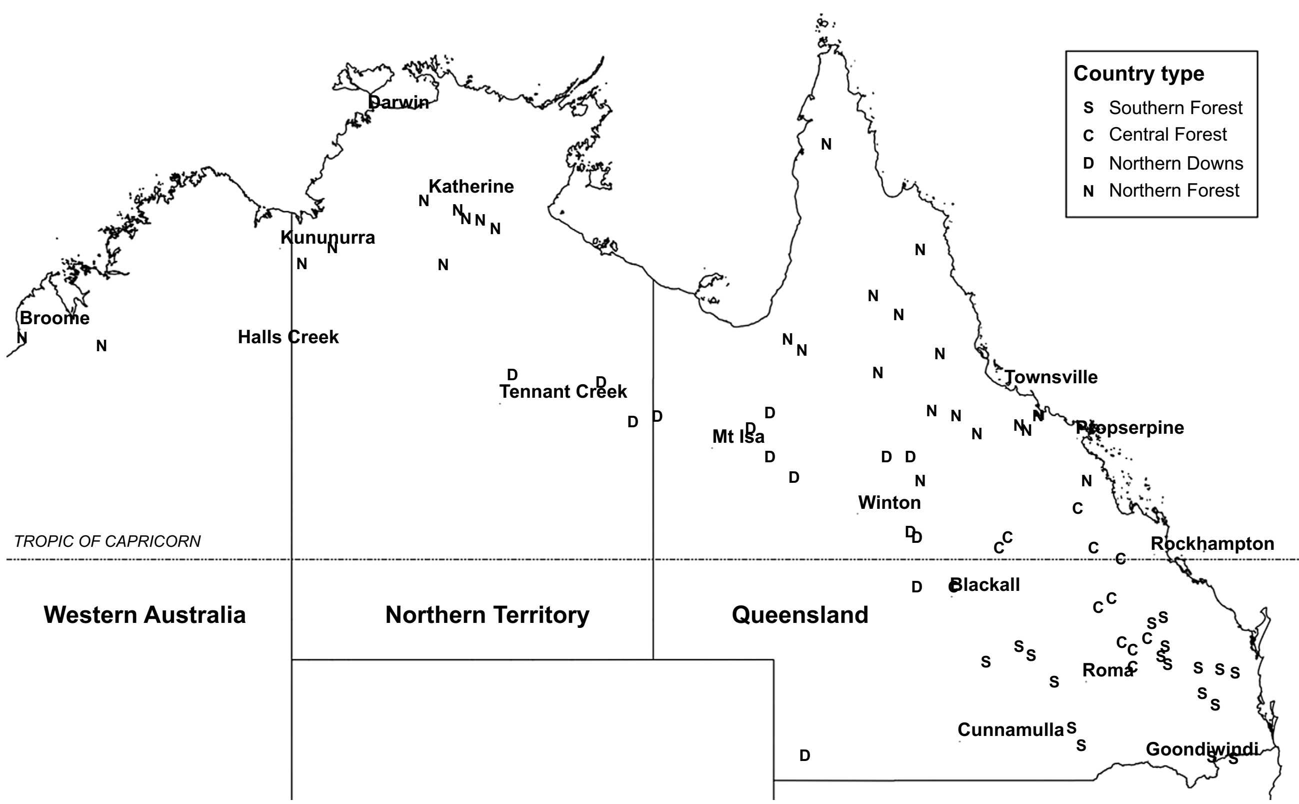

Fig. 1. Location of cooperating properties by country type.

of cattle in each enrolled management group had a blood sample collected (approximately 10–30 per management group) at the time of pregnancy diagnosis and at the time of branding/weaning in 2009 and 2011. No effort was made to sample the same animals at each time point. In both years, serological testing was conducted for the following: bovine viral diarrhoea virus (BVDV) exposure by using the agar gel immunodiffusion test (AGID; (McGowan *et al.* 1993; Kirkland and MacKintosh 2006); *Neospora caninum* by using an indirect ELISA (Björkman *et al.* 1997); *Leptospira borgpetersenii* serovar *hardjo* type Hardjobovis (*Leptospira hardjo*) and *Leptospira interrogans* serovar *pomona* (*Leptospira pomona*) by using the microscopic agglutination test (MAT; Smith *et al.* 1994); bovine ephemeral fever (BEF) virus by using a virus neutralisation test (VNT; 2011 samples only; Cybinski 1987). Also, at the time of pregnancy diagnosis, a vaginal mucus sample was collected from the same test animals for an ELISA for antibodies to *Camplyobacter fetus* subsp. *venerealis* (*Cfv*) (Hum *et al.* 1994). Population estimates of prevalence of infection and prevalence of recent infection (except for *Cfv*) were then calculated for each testing year.

The impact of 83 potential risk factors was assessed on the following: the probability of lactating cows becoming pregnant within 4 months of calving while lactating (P4M; McCosker *et al.* 2022*a*); the probability of cows becoming pregnant within a 12-month cycle (Pregnant; McCosker *et al.* 2022*b*); the incidence of fetal and calf loss (FCL; Fordyce *et al.* 2022*a*); and the incidence of pregnant cows missing (Mortality; Fordyce *et al.* 2022*b*). Candidate risk factors were initially classed as being measures of management (e.g. mustering about the time of calving or use of specific vaccines), the environment (e.g. country type, wet-season onset, and temperature–humidity index), available nutrition (e.g. pasture quality and supplements fed), infectious reproductive disease (e.g. exposure to bovine viral diarrhoea virus and pathogenic *Campylobacter*) or the animal (e.g. age, body condition, weight, and breed). Significant risk factors were then regrouped as having effect at either the animal or property level (Table 1). Analyses accounted for some risk factors not being consistently present across years.

Statistical analyses

The starting dataset contained 116 192 cases representing an individual animal throughout a year and containing a valid entry for at least one cow-performance outcome. Only 93%, 54%, 42% and 35% of the cases had complete data for P4M, Pregnant, FCL and Mortality respectively, with 11% having valid data for all four outcome variables.

The main forms of summary and data analysis were frequencies by category and cross-tabulation by country type. Estimates of proportions and confidence limits were produced using the -proportion- command in Stata for Windows (Ver. 13.1, StataCorp, College Station, TX, USA). The calculated standard errors of prevalence estimates for animal-level risk factors included an adjustment for clustering at the property level by specifying the -cluster- option within the -proportion- command in Stata. The limits of confidence interval were calculated using a logit transform so that the endpoints were within 0 and 1.

The analyses for first-lactation cows relate specifically to those cows that experienced lactation for the first time. Therefore, heifers that either became pregnant but failed to wean their calf or heifers that failed to become pregnant have been omitted.

Results

A quarter of Northern Forest properties experienced low mustering efficiency. Although this did not appear to occur in either the Central Forest or Northern Downs, one in six Southern Forest properties also experienced significant mustering inefficiencies (Table 2).

Across the project, 57–86% of properties considered that the risk of wild-dog predation was likely to significantly affect the number of calves weaned. Frequency of baiting to control wild dogs increased as quantity and quality of pasture decreased (Table 2).

Wet-season protein deficiency was rare in the Southern Forest, occurred in about a quarter of years in the Central Forest and Northern Downs, and a third of years in the Northern Forest, with about 30–50% of properties outside the Southern Forest experiencing this problem in at least 1 year (Table 3). Low dry-season pasture digestibility occurred in two-thirds of years in all country types, with this occurring in 90% of properties in at least one study year (Table 3).

Phosphorus deficiency was apparent in all country types and highest, ~90%, in the Northern Forest. Two-thirds of Northern Downs properties were considered at risk of phosphorous deficiency; however, less than half of the Southern and Central Forest properties were considered at risk (Table 3).

Across the project, dry-season biomass averaged <2 t/ha in a third of years, although 40–70% of properties experienced this in at least 1 year (Table 3). A late follow-up to wet-season rainfall occurred about a third of the time, except in the Northern Forest where the incidence was ~50% (Table 3). Most properties in Central and Southern Forest experienced late follow-up rainfall to a break in the season during the study, but only about half of Northern Downs and Northern Forest properties experienced this.

Across country types, most heifers (69–79%) were of moderate height with less than 10% being considered short. However, about 28% of heifers in the Central Forest and Northern Downs were classified as being tall. This pattern was reflected in first-lactation and mature cows, but the prevalence of tall cows in the Central Forest and Northern

Table 1. Definition of major risk factors for northern Australian beef-cow performance.

Factor	Detail	Associated outcomes
	Property-level factors	
Country type	Properties with forested land-types and fertile soils in the central and south-eastern regions of Queensland were differentiated by being outside (Southern Forest) and within (Central Forest) the northern Brigalow forest. In the northern areas of Queensland, Northern Territory and Western Australia, properties with land types that were predominantly large, treeless, moderate-fertility, black-soil plains (Northern Downs) were segregated from those with forested land-types and low-fertility soils (Northern Forest).	P4M, Preg, FCL, Mort
Interval to follow up rain after onset of wet season	Either ≤30 days or >30 days until 50 mm of rainfall within ≤14 days following the onset of the wet season (50 mm of rainfall within ≤14 days between 1 September and 31 March).	Mort
Minimum available dry-season biomass	Either <2000 kg/ha or ≥2000 kg/ha minimum dry-season pasture (mean of estimates 1 May–31 October) reported by property owner/manager.	Mort
Dry-matter digestibility (DMD) during the dry season.	Mean estimated DMD categorised as either <55% and ≥55% derived from F.NIRS for samples collected during the dry season (1 May–31 October).	Preg
Wet-season pasture protein deficiency	A mean ratio categorised as either <8:1 or ≥8:1 of estimated DMD (%) to dietary crude protein (CP; % DM) derived from F.NIRS for all samples collected during the wet season (1 November–31 March) indicated adequate or inadequate pasture protein, respectively (Dixon and Coates 2005).	P4M, Preg
Risk of phosphorus deficiency adversely affecting performance	Mean ratio of estimated faecal P (mg/kg) to calculated metabolisable energy (MJ ME/kg DM) derived from DMD for each sample collected during the wet season (1 November–31 March). Note: producers did not remove P supplements from paddocks prior to collecting faecal samples. FP:ME was categorised to indicate either High (<500 mg P/MJ ME) or Low (≥500 mg P/MJ ME) phosphorus deficiency risk.	P4M, Preg, FCL
Days in the month of calving when THI is >79	Using interpolated data (Australian Bureau of Meteorology), daily THI was calculated as: $0.8 \times$ Ambient temperature + (((Relative humidity $\div$ 100) $\times$ (Ambient temperature $-$ 14.4)) + 46.4) (Hahn *et al.* 2009) Data were categorised as being >14 days within the month or not.	FCL
Mustering efficiency	The efficiency of mustering was categorised as usually being able to recover 90% or more of cattle from a paddock or not. Low efficiency occurs in large heavily vegetated hilly paddocks.	FCL
Wild-dog predation	Perceptions and actions of the owner/manager were categorised as being either no significant predation, intermittent control of predation, and regular baiting of dogs to prevent on-going predation	FCL
	Animal-level factors	
Cow age	A heifer was in a cohort of female cattle up to the time the majority had their first calf, after which the cohort was classed as first-lactation cows. Mature cows were older than first-lactation cows.	P4M, Preg, FCL
Height	Height was categorised as Short (<125 cm), Moderate (125 to <140 cm) and Tall (≥140 cm) at the level of the hips. It was measured once at the pregnancy diagnosis muster for heifers, first-lactation cows, and older cows.	FCL
Body condition score (BCS)	Body condition score (BCS, 1–5; Hunt 2006) and was categorised as ≤2.0, 2.5, 3.0, 3.5 or ≥4.	P4M, Preg, Mort
BCS change between pregnancy diagnosis and weaning/branding	Categorised as either lost, maintained or gained body condition.	P4M
Annual lactation	Categorised as either having being suckled (recorded as lactating) or not between one annual pregnancy diagnosis muster and the next, typically 12 months later.	FCL
Reproductive outcome	As for annual lactation, with non-lactating females divided into those diagnosed pregnant or not; the former were considered to have experienced foetal or calf loss.	Preg
Expected month of calving	The predicted month of calving was calculated using fetal age at the date of earliest pregnancy diagnosis and projected forward using a gestation length of 287 days and 30.4 days per month (Casas *et al.* 2011).	P4M, Mort
Mustered about the time of calving	Pregnant females were categorised as either having been mustered or not mustered between 1 month prior to and 2 months after calculated month of calving.	FCL

Preg, pregnancy risk during the year; P4M, pregnant within 4 months of calving while lactating; FCL, risk of fetal and calf loss; Mort, pregnant cow mortality risk; THI, temperature–humidity index; F.NIRS, faecal near-infrared spectroscopy.

Table 2. Frequency of significant property-level risk factors for female beef cattle performance in all northern Australian country types.

Risk factor	Southern Forest		Central Forest		Northern Downs		Northern Forest	
	Mean	95% CI	Mean	95% CI	Mean	95% CI	Mean	95% CI
Mustering efficiency <90%								
N	19		15		13		29	
	15.8	(4.6, 42.2)	0.0		0.0		24.1	(11.4, 44.0)
Wild-dog predation								
N	19		14		10		29	
No problem[A]	21.1	(7.3, 47.3)	7.1	(0.7, 44.1)	10.0	(0.9, 57.8)	6.9	(1.6, 25.4)
Intermittent control	21.1	(7.3, 47.3)	35.7	(13.7, 66.0)	20.0	(3.7, 62.2)	6.9	(1.6, 25.4)
Routine baiting	57.8	(33.5, 78.9)	57.1	(28.4, 81.7)	70.0	(31.0, 92.4)	86.2	(67, 95.1)

[A]Opinion and actions of business owner or manager.
CI, confidence interval.

Table 3. Incidence of major environmental and nutritional (property-level) risk factors associated with cow performance in northern Australia.

Risk factor and country type	Property-years with risk factor (%)			Properties with risk factor in ≥1 year (%)		
	N	Mean	95% CI	*N*	Mean	95% CI
Interval between onset of wet season and follow-up rain >30 days						
Southern Forest	58	34.5	(25.3, 45.0)	19	84.2	(59.5, 95.1)
Central Forest	42	35.7	(26.5, 46.1)	13	92.3	(58.1, 99.0)
Northern Downs	35	31.4	(20.2, 45.3)	13	61.5	(32.9, 83.9)
Northern Forest	79	15.2	(9.8, 22.8)	28	42.9	(25.7, 62.0)
Minimum dry-season biomass averages <2000 kg/ha						
Southern Forest	59	33.9	(21.6, 48.8)	19	68.4	(44.1, 85.6)
Central Forest	48	35.4	(21.0, 53.0)	15	66.7	(39.3, 86.1)
Northern Downs	41	29.3	(13.3, 52.8)	13	46.2	(21.3, 73.1)
Northern Forest	87	37.9	(28.4, 48.4)	31	74.2	(55.6, 86.8)
Mean dry-season pasture DMD ≤55%						
Southern Forest	59	67.8	(49.4, 82.0)	19	89.5	(64.8, 97.5)
Central Forest	48	68.8	(50.5, 82.6)	15	86.7	(57.6, 96.9)
Northern Downs	41	68.3	(46.7, 84.1)	13	92.3	(58.1, 99.0)
Northern Forest	87	72.4	(58.8, 82.8)	31	87.1	(69.5, 95.2)
Wet-season pasture protein deficiency						
Southern Forest	33	3.0	(0.4, 19.0)	17	5.9	(0.7, 34.3)
Central Forest	28	21.4	(8.9, 43.1)	13	30.8	(11.3, 60.8)
Northern Downs	28	28.6	(16.5, 44.8)	12	58.3	(29.2, 82.6)
Northern Forest	45	33.3	(20.5, 49.3)	26	46.2	(27.8, 65.6)
Phosphorus deficiency indicated						
Southern Forest	50	40.0	(24.3, 58.1)	19	52.6	(30.2, 74.0)
Central Forest	40	32.5	(16.8, 53.5)	13	53.8	(26.9, 78.7)
Northern Downs	35	68.6	(46.3, 84.6)	13	84.6	(52.7, 96.4)
Northern Forest	65	89.2	(74.5, 95.9)	26	96.2	(75.9, 99.5)

CI, confidence interval; DMD, dry-matter digestibility (%).

Downs increased to about 40% (Tables 4–6). The majority of first-lactation cows across country types (66–79%) lost condition between the pregnancy-diagnosis muster and subsequent branding-weaning muster. However, for mature cows, less than half (38–47%) of cows lost condition between these musters in the Southern and Central Forest and

Table 4. Incidence (%), within country type, of animal-level risk factors for performance of maiden beef heifers in northern Australia.

Risk factor	Southern Forest		Central Forest		Northern Downs		Northern Forest	
	Mean	95% CI	Mean	95% CI	Mean	95% CI	Mean	95% CI
Body condition score (1–5) at pregnancy diagnosis muster[A]								
N	2743		2591		3822		8232	
≤2.0	2.6	(0.6, 11.1)	15.6	(1.7, 65.9)	6.4	(0.8, 37.6)	2.5	(1.0, 6.2)
2.5–3.0	26.7	(10.0, 54.5)	9.6	(3.0, 26.5)	32.0	(9.9, 66.8)	53.3	(35.8, 70.0)
≥3.5	70.7	(43.4, 88.4)	74.8	(31.9, 95)	61.7	(28.9, 86.5)	44.3	(26.9, 63.2)
Reproductive outcome								
N	2120		2333		3235		5853	
Non-pregnant	25.8	(16.2, 38.5)	24.2	(11.7, 43.5)	22.5	(10.8, 41.1)	33.6	(19.5, 51.3)
Weaned a calf	68.6	(56.3, 78.7)	69.0	(50.8, 82.8)	65.0	(53.1, 75.3)	54.8	(38.7, 70.0)
Fetal or calf loss	5.7	(3.4, 9.2)	6.8	(4.6, 9.9)	12.4	(7.3, 20.4)	11.6	(7.7, 17.2)
Expected months of calving								
N	2139		2020		3030		5831	
July–September	56.2	(42.5, 69.1)	38.9	(18.6, 63.9)	9.1	(2.1, 31.4)	12.4	(4.6, 29.3)
October–November	34.6	(25.9, 44.5)	41.7	(31.1, 53.2)	41.0	(21, 64.5)	32.6	(25.9, 40)
December–January	8.6	(2.7, 23.9)	17.4	(6.4, 39.3)	31.8	(18.1, 49.7)	40.2	(29, 52.5)
February–March	0.3	(0.1, 1.7)	0.8	(0.2, 4.5)	14.5	(5.0, 35.1)	13.2	(7.8, 21.6)
April–June	0.2	(0.0, 1.5)	1.1	(0.1, 9.9)	3.6	(0.6, 19.1)	1.6	(0.9, 3.1)
THI exceeded 79 for >14 days during expected month of calving								
N	2753		2592		3828		8273	
	34.5	(22.9, 48.2)	49.1	(24.3, 74.4)	89.4	(74, 96.2)	89.9	(81.2, 94.9)
Mustered about expected time of calving								
N	1696		1789		2574		4209	
	7.5	(2.6, 19.8)	11.2	(3.9, 28.2)	10.8	(2.8, 33.9)	5.8	(2.3, 13.7)
Height								
N	2284		2155		3354		3718	
Short	6.9	(2.4, 18.3)	2.6	(0.7, 9.3)	3.2	(1.1, 8.9)	8.0	(4.5, 13.9)
Moderate	77.4	(71.6, 82.3)	69.2	(46.1, 85.5)	69.4	(40.3, 88.3)	79.2	(62.6, 89.7)
Tall	15.8	(10.4, 23.2)	28.2	(11.2, 54.8)	27.4	(8.9, 59.4)	12.8	(3.7, 35.9)

[A]Mean interval from PD muster to predicted calving was 4.4 months.
CI, confidence interval; THI, temperature–humidity index.

Northern Downs, compared with 57% for cows in the Northern Forest.

At the time of pregnancy diagnosis (typically early to mid-dry season), the majority of heifers (62–75%) in all country types except the Northern Forest (44%) were in good body condition BCS ≥ 3.5). However, for first-lactation cows, only about a third were in good body condition in the Southern and Central Forest, with only 18% and 10% in the good condition in the Northern Downs and Northern Forest respectively. For mature cows, about half were in good body condition at the time of pregnancy diagnosis in the Southern and Central Forest, and Northern Downs, but only 23% were in good condition in the Northern Forest (Tables 4–6).

Three-quarters of heifers were pregnant after their first mating, except in the Northern Forest where only two-thirds were pregnant (Table 4). The difference was much greater after first lactation when about 70% of cows were pregnant except in the Northern Forest where only a quarter were pregnant (Table 5). In older cows, only about 55% achieved pregnancy annually in the Northern Forest, compared with 85% elsewhere (Table 6).

Most heifers in the Southern and Central Forest were predicted to calve in July–November, much earlier than in the Northern Downs and Northern Forest where a majority were expected to calve in November–January (Table 4). This general pattern continued through to older cow ages (Tables 5, 6). In the Northern Downs and Northern Forest, about a quarter of

Table 5. Incidence (%), within country type, of animal-level risk factors for performance of first-lactation cows in northern Australia.

Risk factor	Southern Forest		Central Forest		Northern Downs		Northern Forest	
	Mean	95% CI	Mean	95% CI	Mean	95% CI	Mean	95% CI
Body condition score at first annual branding/weaning muster[A]								
N	1358		1646		1819		2320	
≤2.0	12.4	(4.3, 31.0)	22.5	(7.8, 49.9)	7.9	(2.7, 21.2)	32.2	(15.3, 55.4)
2.5–3.0	56.6	(42.2, 70.0)	40.0	(25.9, 55.9)	52.7	(37.7, 67.2)	59.3	(42.5, 74.2)
≥3.5	31.0	(18.8, 46.5)	37.5	(17.2, 63.5)	39.4	(21.6, 60.4)	8.5	(3.4, 19.7)
Body condition score (1–5) at pregnancy-diagnosis muster								
N	1560		1584		1712		2342	
≤2.0	14.4	(6.4, 29.1)	8.8	(4.3, 17.1)	29.8	(15.7, 49.1)	31.0	(21.8, 42.1)
2.5–3.0	54.9	(43.7, 65.6)	55.4	(43.9, 66.4)	52.3	(42.5, 62)	59.4	(47.6, 70.2)
≥3.5	30.8	(20.7, 43.1)	35.8	(25.4, 47.7)	17.9	(9.4, 31.3)	9.6	(2.7, 28.8)
Change in body condition between pregnancy-diagnosis and subsequent branding/weaning muster								
N	1352		1645		1723		2293	
Lost	76.1	(54.4, 89.5)	78.0	(57.7, 90.2)	66.2	(46.5, 81.5)	79.1	(61.4, 90)
Maintained	14.9	(7.1, 28.5)	13.0	(6.6, 24.1)	22.3	(12.5, 36.5)	14.7	(7.3, 27.1)
Gained	9.0	(3.3, 22.6)	9.0	(3.1, 23.3)	11.5	(6.3, 20.3)	6.2	(2.7, 13.9)
Reproductive outcome								
N	1130		1349		1362		1224	
Non-pregnant	28.9	(18.7, 42.0)	23.8	(16.1, 33.6)	33.2	(16.0, 56.3)	75.6	(50.6, 90.3)
Weaned a calf	66.8	(54.0, 77.6)	70.9	(61.3, 78.9)	62.2	(41.2, 79.4)	21.7	(8.7, 44.8)
Fetal or calf loss	4.2	(2.6, 6.8)	5.3	(3.6, 7.9)	4.6	(2.7, 7.7)	2.7	(1.1, 6.7)
Expected months of calving								
N	1204		1200		1225		725	
July–September	17.9	(8.2, 34.6)	15.1	(3.8, 44.3)	2.7	(0.6, 11.6)	1.7	(0.5, 5.9)
October–November	63.2	(47, 76.9)	51.5	(36.5, 66.3)	22.4	(8.1, 48.6)	29.8	(15.5, 49.6)
December–January	16.1	(8.8, 27.6)	30.9	(15.7, 51.9)	45.9	(33.1, 59.2)	24.8	(17.8, 33.4)
February–March	2.6	(0.8, 7.6)	2.5	(0.8, 7.7)	18.6	(9.7, 32.7)	17.9	(9.3, 31.7)
April–June	0.2	(0, 2.5)	0.0		10.4	(2.4, 35.3)	25.8	(12.6, 45.6)
THI exceeded 79 for >14 days during expected month of calving								
N	1595		1668		2297		2556	
	45.3	(34.8, 56.1)	60.4	(45.5, 73.6)	93.7	(88.0, 96.8)	94.5	(87.7, 97.7)
Mustered about expected time of calving								
N	865		1026		914		330	
	5.2	(1.5, 16.1)	20.0	(5.3, 52.5)	32.8	(19.9, 49)	37.3	(23.4, 53.6)
Height								
N	1393		1577		1973		1645	
Short	5.4	(1.6, 16.9)	0.1	(0.0, 0.6)	0.8	(0.2, 4.3)	5.5	(2.5, 11.5)
Moderate	69.5	(57.7, 79.2)	56.0	(32.4, 77.2)	59.6	(33.0, 81.5)	76.5	(53.1, 90.4)
Tall	25.1	(13.5, 42.0)	43.9	(22.6, 67.6)	39.6	(17.6, 66.8)	18.0	(5.0, 47.8)

[A]All females were lactating at the time of being visually assessed.
CI, confidence interval; THI, temperature–humidity index.

cows were expected to calve in February–June. Few cows calved in July–September, except in the Southern and Central Forest where 10–15% of cows calving for the second time were expected to calve at this time (Table 5).

The temperature–humidity index exceeded 79 (indicating that cattle are at risk of experiencing the adverse effects associated with significantly increased body heat load) for over half the month of expected calving for about 90% of

Table 6. Incidence (%), within country type, of animal-level risk factors for performance of cows in northern Australia.

Risk factor	Southern Forest		Central Forest		Northern Downs		Northern Forest	
	Mean	95% CI	Mean	95% CI	Mean	95% CI	Mean	95% CI
Lactated during the production year								
N	12 166		9965		22 926		29 170	
	91.2	(87.6, 93.8)	92.9	(88.2, 95.8)	88.5	(83.9, 91.9)	68.9	(65.2, 72.3)
Body condition score (1–5) of lactating cows at branding/weaning muster								
N	8594		8215		13 658		15 567	
≤2.0	9.7	(6.1, 15.1)	10.2	(4.2, 22.5)	7.1	(2.1, 21.1)	28.7	(18.2, 42.0)
2.5–3.0	54.5	(45.6, 63.2)	45.7	(34.5, 57.4)	61.2	(49.8, 71.5)	60.9	(48.3, 72.1)
≥3.5	35.8	(25.7, 47.3)	44.1	(29.0, 60.4)	31.7	(25.4, 38.8)	10.5	(7.4, 14.7)
Body condition score (1–5) of non-lactating cows at branding/weaning muster								
N	1057		744		1876		10 527	
≤2.0	2.6	(1.1, 6.1)	2.4	(1.0, 5.9)	0.7	(0.2, 2.6)	2.3	(0.7, 6.7)
2.5–3.0	25.7	(10.1, 51.7)	13.2	(6.8, 23.9)	10.6	(5.5, 19.3)	27.2	(21.9, 33.3)
≥3.5	71.6	(45.2, 88.6)	84.4	(73.3, 91.4)	88.7	(79, 94.2)	70.5	(63.1, 77.0)
Body condition score at pregnancy-diagnosis muster								
N	12 144		10 119		26 066		30 035	
≤2.0	9.9	(5.6, 17.0)	9.7	(3.0, 27.2)	11.8	(3.5, 32.5)	24.3	(16.6, 34.0)
2.5–3.0	40.3	(32.2, 48.9)	34.5	(24.5, 46.0)	39.9	(37.8, 42.1)	52.6	(42.3, 62.6)
≥3.5	49.8	(38.4, 61.2)	55.8	(41.5, 69.2)	48.3	(35.1, 61.8)	23.1	(18.8, 28.1)
Change in body condition of lactating cows between PD and subsequent branding/weaning muster								
N	4578		5564		8929		7630	
Lost	43.0	(36.0, 50.3)	37.5	(31.2, 44.1)	46.8	(37.8, 55.9)	57.1	(50.8, 63.2)
Maintained	25.3	(21.6, 29.5)	28.5	(24.1, 33.4)	29.9	(22.2, 39.0)	23.0	(19.8, 26.5)
Gained	31.7	(24.3, 40.1)	34.0	(29.0, 39.5)	23.4	(10.5, 44.2)	19.9	(13.9, 27.6)
Reproductive outcome								
N	6798		6122		16 278		17 767	
Non-pregnant	16.7	(10.3, 25.8)	13.9	(7.6, 23.9)	17.6	(15.6, 19.8)	42.2	(38.4, 46.1)
Weaned a calf	77.0	(68.0, 84.0)	79.6	(71.2, 86.1)	73.7	(70.3, 76.9)	48.9	(45.8, 52.0)
Fetal or calf loss	6.4	(4.4, 9.2)	6.5	(4.8, 8.8)	8.7	(6.6, 11.3)	8.9	(6.4, 12.3)
Expected months of calving								
N	10 225		8665		21 998		18 065	
July–September	34.7	(22.1, 50.0)	13.9	(8.3, 22.5)	3.7	(1.1, 11.6)	8.7	(4.4, 16.3)
October–November	40.4	(31.0, 50.5)	54.7	(46.0, 63.1)	19.4	(12.9, 28.1)	34.7	(30.3, 39.3)
December–January	17.2	(9.9, 28.2)	30.2	(19.2, 44.1)	45.1	(36.0, 54.5)	31.8	(27.2, 36.9)
February–March	5.1	(1.8, 13.4)	1.2	(0.5, 2.7)	18.0	(13.3, 23.9)	15.4	(11.9, 19.7)
April–June	2.6	(0.8, 8.2)	0.0	(0.0, 0.2)	13.8	(7.8, 23.3)	9.4	(6.9, 12.7)
THI exceeded 79 for >14 days during expected month of calving								
N	13 753		10 812		28 827		33 772	
	50.9	(39.6, 62.1)	65.3	(57.3, 72.5)	90.1	(83, 94.4)	93.9	(89.8, 96.4)
Mustered about expected time of calving								
N	6149		5305		13 638		10 813	
	12.9	(7.8, 20.8)	13.3	(6.2, 26.3)	14.3	(7.7, 25.2)	12.0	(7.8, 18.2)

(*Continued on next page*)

Table 6. (*Continued*).

Risk factor	Southern Forest		Central Forest		Northern Downs		Northern Forest	
	Mean	95% CI	Mean	95% CI	Mean	95% CI	Mean	95% CI
Height								
N	10 223		7915		11 535		18 452	
Short	4.3	(2.0, 8.7)	6.5	(0.9, 34.3)	0.6	(0.3, 1.3)	2.4	(1.0, 5.6)
Moderate	71.0	(61.6, 78.9)	52.0	(41.7, 62.2)	60.4	(44.9, 74.0)	74.4	(70.1, 78.3)
Tall	24.7	(17.3, 34)	41.5	(29.4, 54.6)	39.0	(25.3, 54.7)	23.1	(18.2, 28.9)

CI, confidence interval; PD, pregnancy diagnosis; THI, temperature–humidity index.

cows in the Northern Downs and Northern Forest, compared with about 60% of expected calvings in the Central Forest and less than half in the Southern Forest (Tables 4–6).

Across country types, about 6–11% of maiden heifers and 12–14% of cows were mustered during the month of expected calving (Tables 4–6). However, in the Northern Downs and Northern Forest, almost a third of first-lactation cows were mustered during the month of their second expected calving.

About half of all females tested across country types and years had been infected at some time with BVDV (Table 7). The prevalence of recent infection during the current reproductive cycle was higher in 2009 (15–22%) than in 2011 (5–8%; $P < 0.05$). About 10% of female cattle tested in both years and across country types had evidence of infection with *C. fetus* subsp. *venerealis* (Table 8).

Overall, about 90% of cows lactated during the year over all country types except the Northern Forest where only two-thirds did so (Table 6). In the Southern and Central Forest, 6–9% of all pregnancies resulted in fetal or calf loss, compared with 11–17% for cows in the Northern Forest; loss was intermediate in the Northern Downs (Tables 4–6).

Discussion

This paper has demonstrated the specific challenges for breeding beef cattle in northern Australia, which includes tropical and subtropical regions, most of which are classified as dry or arid where average annual rainfall is below or well below average annual evaporation rates. A primary feature of the project was demonstration of the difference between the Northern Forest and other northern Australian country types. Although these country types were based on geography, soils and vegetation, they were fundamentally based on anticipated differences in performance and productivity of cattle. The underlying reason is most certainly that all of the prevailing risk factors within a country type combine to affect liveweight production. This was reflected in outcomes from the project where country type was a consistently significant risk factor (McCosker *et al.* 2022*a*, 2022*b*; Fordyce *et al.* 2022*a*, 2022*b*). Although useful as a general descriptor, variation in productivity within country type across years and among specific areas is large (McGowan *et al.* 2014). On the basis of the concepts presented by Fordyce *et al.* (2022*c*), annual yearling growth within a paddock for a year is a more accurate reference point than is country type, for assessing prevailing production and performance of breeding cattle.

A key facet of the study is that only a small percentage of many putative risk factors was significantly associated with cow performance. One reason for this may have been partial or complete confounding between country type and some risk factors. A good example of a risk factor that did not feature was breed. There are clear industry perceptions that increasing levels of *Bos indicus* are advantageous with an increasing intensity of the tropical nature of environments, i.e. for tolerance of pathogens and climates associated with the tropics. Part of the reason for no breed effect discerned is that few cattle in tropical regions have no *B. indicus* content. However, famers appear to have also created environmental changes and management that substantially obviate the susceptibility to tropical stressors of cattle with a low *B. indicus* content.

Pasture digestibility, and adequacy of protein and phosphorus were all aligned with average cow performance, i.e. cattle on Northern Downs had intermediate performance compared with those in the Northern Forest and those in the Southern and Central Forests. Inadequate intake of dietary phosphorus is a known issue for much of northern Australia (Miller *et al.* 1990) where it reduces growth and reproductive performance (Winks 1990). In the Cash Cow project, adequacy of phosphorus was measured using the ratio of faecal phosphorus to estimated metabolisable energy (Jackson 2012). The threshold value of 500 mg faecal P per 1 MJ of metabolisable energy was the inflection point in the relationship between this value and cow performance (Fordyce *et al.* 2022*a*, 2022*b*; McCosker *et al.* 2022*b*). The effect of dietary phosphorus adequacy interacted with other risk factors, including cow age class, wet-season protein availability, country type and body condition score. This project has verified the widespread prevalence of inadequate dietary phosphorus across northern Australia (McCosker and Winks 1994). Evidence of some degree of deficiency even occurred in high production zones but was almost universal

Table 7. Bovine viral diarrhoea virus (BVDV) seroprevalence and prevalence of recent BVDV infection in unvaccinated heifers and cows in northern Australia.

Animal class	Year	Number of samples	Mean seroprevalence (%) and (95% CI)	Mean prevalence (%) of recent infection[A] and (95%CI)
Heifers	2009	538	55.4 (42.5, 68.4)	22.2 (13.6, 30.7)
	2011	203	50.3 (31.9, 68.6)	5.1 (1.3, 8.9)
Cows	2009	1115	50.3 (50.3, 69.2)	14.8 (11.0, 18.7)
	2011	927	53.1 (53.1, 70.5)	7.6 (5.0, 10.1)

[A]AAGID test result of ≥3.

Table 8. Cattle that were vaginal-mucus ELISA positive for *Campylobacter fetus* subsp. *venerealis*.

Animal class	Year	Number of samples	Mean prevalence (%) and (95% CI)
Heifers	2009	722	12.1 (6.1, 18.2)
	2011	273	12.6 (6.0, 19.1)
Cows	2009	1629	7.4 (4.8, 9.9)
	2011	1192	9.7 (5.1, 14.2)

in the Northern Forest where phosphorus supplementation is a routine component of best-practice management.

Pasture protein deficits occurred across northern Australia during the dry season. Wet-season pasture protein deficiency also had a high incidence outside the Southern Forest, with the highest incidence in the Northern Forest, as previously described by McCosker *et al.* (1991). The ability of cattle to respond to phosphorus supplements is limited by dietary protein conentrations, with the corollary also being true (Winks 1990). This current project justifies the inclusion of low levels of inorganic N and S into wet-season phosphorus supplements for northern Australian beef cattle. The efficacy of protein supplementation to cows during the wet season where phosphorus is adequate is expected to be low, although in years of low rainfall, an early start to feeding of dry-season supplements based on N and S is justifiable.

Cow body condition reflects the interaction among nutrition, management and reproductive state (Entwistle 1983). The poorer nutrition available in the Northern Forest, coupled with less efficacious lactation management, shows up cows in this country type having the lowest performance in this study. The most disadvantaged class of animal was first-lactation females, which have the additional challenge of maintaining condition on a skeleton that continues to grow till an average of 4.5 years of age (Fordyce *et al.* 2013). These cattle have the highest risk of mortality, calf loss and low pregnancy rates (McCosker *et al.* 2022*a*, 2022*b*; Fordyce *et al.* 2022*a*, 2022*b*).

Two nutritional indicators that were not less favourable in the Northern Forest or Downs were the incidence of dry-season biomass and the incidence of a delayed follow-up rainfall after a seasonal break, risk factors that are both associated with higher cow mortality (Fordyce *et al.* 2022*b*). This suggests that the reasons for higher pregnant-cow mortality rates are more associated with feed quality and reproductive state causing cows to be in a lower body condition and at higher risk than with feed quantity.

Calving patterns are primarily a function of mating management and bull control. Most calving in the Southern and Central Forest occurred in the mid–late dry season, reflecting small paddocks, herds and management-group sizes and more effective infrastructure. Mating in the Northern Downs and Northern Forest is typically continuous as the infrastructure to achieve control mating is not often adequate, especially when grossly too many bulls are being used. A consequence is that a quarter of cows calve in the first half of the year, exposing many of these to dry-season lactation, and thus a high risk of mortality (O'Rourke 1994). Fordyce *et al.* (2022*b*) reported average pregnant-cow mortality rates of approximately 7% in the region. The solution to this problem appears to be improved infrastructure, segregation of animals at high risk of mortality for preferential nutritional treatment, and a reduction in bull numbers.

Incidences of low mustering efficiency and mustering about the time of calving occurred across northern Australia. How these risk factors increase calf loss (Fordyce *et al.* 2022*a*) is unclear in all situations, although is expected to be mediated with mismothering. Some mustering inefficiencies were caused by flooding, and not just difficult terrain, large insecure paddocks and vegetation. The solutions are very much aligned with those to achieve low-risk calving and lactation periods, as described above, plus more appropriate scheduling of handling.

Wild dogs are prevalent throughout all beef-production areas of northern Australia (West 2008) and have been associated with annual production losses of $AU23.4 million (Fleming *et al.* 2012). This study found that the majority of producers attempted to actively control the wild-dog population. This is partially driven by legislation making wild-dog control compulsory for Western Australia and Queensland study participants. However, effective control of wild-dog impacts is currently under some debate. Allen (2014) reported findings that the use of conventional methods to control wild-dog populations may result in an increased risk of calf predation. In the Cash Cow project, the highest incidence of dog control occurred in the Northern Forest where nutrition is consistently poor. The latter may be risk factors for impaired neonatal milk delivery, which independently increases mortality risk of calves (Silva *et al.* 2022), thus enhancing the likelihood of predation by wild dogs.

A high temperature–humidity index for over half the month of most calvings in northern country types and of about half those in Central and Southern Forests suggests that moving time of calving may have some benefit by disassociating this risk factor with fetal and calf loss (Fordyce *et al.* 2022*a*). However, earlier calving is expected to adversely affect cow and calf survival and cow re-conception rates through large negative impacts on body condition. Calving later increases the chances of calving into equally hot and humid conditions, increases the chances of dystocia, and reduces calf growth to weaning. Overall, moving time of calving is expected to produce herd liveweight production and efficiency. Therefore, solutions to a high temperature–humidity index may include better access to high-quality water and ensuring that adequate feed that can achieve at least maintenance is available to cows before and after calving.

With *B. indicus* content increasing with a decreasing latitude, it was expected that cattle in the Southern and Northern Forests would be shortest and tallest respectively, as Brahmans are taller than *Bos taurus* types (Fordyce *et al.* 2013); however, Northern Forest cows were as short as Southern Forest cows. This may be a function of stunting as skeletal growth is impeded by under-nutrition, exacerbated by the energy demands of pregnancy and lactation (Fordyce and Chandra 2019).

BVDV and campylobacteriosis were endemic across northern Australia, with the data suggesting that outbreaks of BVDV may occur within herds about every 10 years. These diseases cause reproductive wastage and a combined net cost of >AU$50 million to the northern Australian beef industry (Shephard *et al.* 2022). Control methods are well documented.

The discussion above focusses on risk factors for beef breeding-herd performance in northern Australia. However, a risk factor is not an action. Management strategies have the effect of ameliorating adverse impacts of risk factors. Management options are well documented and have previously been categorised as management for either the feedbase, lactation, health and stress, or breeding (McGowan *et al.* 2016).

Conclusions

Despite its large scale, the Cash Cow project was very successful and has, for the first time, identified and quantified the major risk factors affecting cow performance in northern Australian commercial beef herds. The primary conclusion from the research is that unfavourable levels of risk factors were observed in all country types and across all cow-age groups of beef females in northern Australia. Additive adverse effects of risk factors, particularly nutritional (e.g. pasture protein and phosphorus adequacy), environmental (e.g. temperature and humidity) and management (e.g. time of calving and lactation) factors, on cow performance are least in the Southern Forest and greatest in the Northern Forest. Central Forest is marginally less favourable than the Southern Forest as a country type for beef cattle-breeding herds, with Northern Downs being intermediate between Central and Northern Forests. Some management solutions exist for adverse risk-factor effects.

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Data availability. The data that support this study were obtained from individual enterprises in the northern Australian beef industry by permission. Data will be shared according to established guidelines upon reasonable request to the corresponding author with permission from Meat and Livestock Australia and the University of Queensland.

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