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Northern Australian beef fertility project: CashCow

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Abstract

The causes of poor reproductive performance in northern Australian beef herds are multi-factorial and quantification of the impact of individual factors on performance of breeding mobs is lacking. The reproductive performance of ~78,000 cows managed in 142 breeding mobs located on 72 commercial beef cattle properties was measured over three to four consecutive years (2008-11) using a crush-side electronic data capture system. Percentage of lactating cows pregnant within four months of calving, annual pregnancy rate, percentage foetal/calf loss between pregnancy diagnosis and weaning, and annual percentage of pregnant cows missing (mortality) were used to define performance, with the commercially achievable level of performance proposed as the performance of the 75th percentile mob or cow for each measure. Also, methods of estimating liveweight production from breeding herds were developed, and an achievable level determined for each country type. The impacts of 83 property, environmental, nutritional, management, and infectious disease factors on performance were investigated. The major factors affecting performance included country type, time of previous calving, wet season phosphorous status, cow body condition, hip-height, cow age class, cow reproductive history, severity of environmental conditions, and occurrence of mustering events around the time of calving. Producer/manager opinion that wild dogs were a problem, evidence of recent pestivirus infection and vibriosis were factors that did not contribute to the final model, but did significantly affect animal performance when present. A framework was developed for conducting economic analyses to assess the impact of factors affecting performance.

Executive summary

To date, there have been no population-based studies of the reproductive performance of commercial breeding herds in northern Australia, or of the major factors affecting performance in these herds. The former would provide producers with a commercial rather than biologically achievable level of performance, and the latter would enable producers to focus management changes and investment on those factors that have been shown to be contributing most to herd reproductive outcomes. Therefore, a four year prospective epidemiological study of region-, property-, mob-, and animal-level factors affecting the reproductive performance of commercial breeding mobs was developed. Approximately 78,000 cows managed in 142 breeding mobs located on 72 commercial beef cattle properties distributed across the major beef breeding regions of northern Australia were enrolled in the CashCow project and monitored for three or four consecutive years (2008-11) using a crush-side electronic data capture system. Co-operating properties were classed into four country types using broad vegetation criteria. Foetal ageing was used at the time of annual pregnancy diagnosis to enable the month of conception and calving to be estimated.

Workshops and training sessions were conducted at the commencement of the project and during the course of the project to ensure uniformity of data collection by all technical persons involved in the project. This enabled assessment of the impacts of environmental, nutritional, management, animal and infectious disease factors on:

1. how efficiently cows become pregnant,
2. the likelihood of pregnant heifers and cows rearing a calf, and
3. the likelihood of cows going missing (i.e., dead, lost ID tag, moved paddocks).

The measures used to define the performance of the CashCow mobs were percentage pregnant within four months of calving (P4M; percentage of cows likely to wean a calf in consecutive years), annual pregnancy rate, percentage foetal/calf loss, and annual percentage of pregnant cows missing (an estimate of mortality rate). For each measure of performance, the impact of approximately 83 selected management, environmental, nutritional, and infectious disease factors was assessed by univariable screening. Then, using the factors identified as having a significant impact on performance, candidate multivariable models were developed. These models enabled identification and quantification of the major factors affecting performance.

There was marked variation in the reproductive performance of enrolled breeding mobs both within and between country types. The median performance (50th percentile) and interquartile range (25th to 75th percentile) for cows by country type are presented in **Table A**. The mean annual incidence of pregnant cows missing, expressed as a percentage, for the Southern Forest, Central Forest, Northern Downs and Northern Forest was 10%, 9%, 8%, 17%, respectively.

Table A. Observed performance (median, inter-quartile range*) of cows (≥ 4years old) by country type.

Measure	Southern Forest	Central Forest	Northern Downs	Northern Forest
P4M (%)	74 (39-85)	77 (56-84)	68 (60-76)	17 (7-31)
Annual Pregnancy rate (%)	87 (77-93)	88 (79-92)	82 (75-91)	66 (56-74)
Foetal/calf loss (%)	5 (2-9)	6 (4-9)	7 (3-15)	14 (9-19)
Pregnant cows missing (%)	8 (3-13)	6 (1-11)	7 (4-13)	12 (6-18)

*25th to 75th percentile values

A good indicator of what is a commercially achievable level of performance is the 75th percentile mob or cow performance within country type (note for percentage foetal calf loss, the achievable level of performance is the 25th percentile). Therefore, from Table A, the achievable percentage P4M for cow mobs is 89% in the Southern Forest, 88% in the Central Forest, 81% in the Northern Downs, and 47% in the Northern Forest. The achievable foetal/calf losses are 2% in the Southern Forest, 5% in the Central Forest, 5% in the Northern Downs, and 9% in the Northern Forest.

Beef production from enrolled breeding mobs was calculated using three different measures: weaner production, annual net liveweight production per (retained) cow, and annual net liveweight production / average liveweight of cattle in the paddock over a cattle year. Weaner production is an easily derived measure and it was shown to be a useful indicator of annual liveweight production from breeding mobs. There was marked variation in weaner production between country types. Achievable weaner production was 240 kg/yr (Southern Forest), 220 kg/yr (Central Forest), 183 kg/yr (Northern Downs), and 112kg/yr (Northern Forest). Estimated average annual steer growth was very similar to average weaner production, and it was concluded that achievable steer growth may be a very useful guide to breeding cattle productivity within specific situations.

The major factors affecting performance of enrolled breeding cows and mobs, and the predicted impact of each on performance are summarised below (*NB: the predicted impact of each factor is independent of the impacts of the other identified major factors, and all percentage differences are absolute values*):

Body Condition Score (BCS) at the PD muster: The percentage P4M for cows in poor body condition (BCS<2.5 using a 1 to 5 scoring system) was 7.8%, 13.7%, 18.1% and 21.6% lower (P<0.05) than cows in fair (BCS 2.5), moderate (BCS 3.0), good (BCS 3.5), and very good to fat (BCS 4-5) condition, respectively. However, for cows in the Northern Forest P4M was low regardless of BCS, and thus the magnitude of the differences between BCS categories was consistently much lower (average of 2% difference between BCS categories) compared to those in the other country types.

Cows in poor BCS had a higher incidence of mortality and, where the risk of wet season phosphorous deficiency adversely affecting performance was considered high, they were predicted to have a higher percentage foetal/calf loss than cows in good condition.

Risk of phosphorous deficiency adversely affecting performance: First-lactation, second-lactation, mature, and aged (>9yrs) cows considered at high risk (average wet season [Nov-Mar] FP:ME <500 mgP/MJ ME) were predicted to have 24.3%, 0.8%, 4.1%, and 9.5% lower P4M than those cows considered at low risk (FP:ME ratio ≥500 mgP/MJ ME), respectively. These differences were all significant except for second-lactation cows.

Previous calving period: P4M was significantly lower (20 to 50%) in cows calving in July-September, compared to December–March, and this was consistent across country types.

Seasonal pasture quality: Foetal/calf loss was 4% higher in cows that grazed pastures with a low crude protein to dry matter digestibility ratio (CP:DMD<0.125) during the dry season prior to calving. P4M was 7.5% lower in cows grazing pasture with an average wet season CP:DMD<0.125.

Seasonal environmental conditions: Prolonged hot conditions (temperature-humidity index >79 for ≥15days) during the month of calving were associated with 9% higher foetal/calf loss, except in the Northern Forest. A delay of >1 month in follow-up rainfall after the annual break in the season was associated with an average 4% higher percentage of pregnant cows missing.

Country type: When all other factors were taken into account, the median P4M in the Northern Downs and Northern Forest were significantly lower (23% and 59%, respectively) than P4M of cows in the Southern Forest. Also, percent foetal/calf loss was significantly higher (7%) in the Northern Forest compared to that in the Southern Forest.

Mustering: First-lactation cows mustered within two months of calving and poor mustering efficiency (<90%) were both associated with 9% higher foetal/calf loss.

Cow hip height: P4M was 4.8% lower and foetal/calf loss was 3.7% higher in taller cows (hip height >140 cm) compared with shorter cows (hip height <125 cm). These findings were independent of breed.

Cow age class: Overall, P4M was significantly lower for first-lactation cows compared with second-lactation, mature, and aged (>9years) cows (4.9%, 12.6% and 16.1% lower, respectively).

Cow reproductive history: Cows that did not lactate in the previous year were predicted to have 3.6%-7.6% higher foetal/calf losses in the current year.

Infectious disease: A high prevalence of recent infection with bovine viral diarrhoea virus (BVDV; pestivirus), or widespread evidence of *Campylobacter fetus venerealis* infection (indicator of risk of vibriosis), was associated with higher foetal/calf losses (8% and 7%, respectively) compared to mobs with only a low prevalence.

Wild dog presence: Foetal/calf loss was approximately 5% higher in areas where wild dogs were considered by property owners/managers to be adversely impacting on herd productivity.

The establishment of ongoing monitoring of performance of commercial breeder herds is critical to evaluate the effects of various management strategies designed to address the major factors affecting performance identified in the CashCow project. Further, to take advantage of the findings of this project and other research outcomes relevant to breeding cow herds in northern Australia, producers must have a good understanding of how their beef breeding business is performing, so that the cost-benefit of applying changes can be accurately gauged and efficiently implemented. An Excel spreadsheet-based method requiring a small amount of readily measured beef business inputs was developed as part of the Cash Cow project to generate satisfactory estimates of business indicators, such as operating margin. These data can be utilised in BREEDCOW, and then using the estimates of the effect of specific factors on cow performance derived from the Cash Cow project, estimates of the effects of each factor on gross margin for herds and partial returns per cow can be determined.

Glossary of terms used in this report

The purpose of this glossary is to provide a working definition for terms used in this report. It is not intended to represent a single "correct" definition for the various terms.

Adult equivalent	Measure of pasture intake. Usually defined as the amount eaten by a 454 kg (1,000 pound) steer at maintenance.
Aged cow	Cow with diminishing ability to forage or diminishing fertility. Start usually ranges from 8 years of age where environments cause early wearing, fracture and loss of teeth, to 13 years of age when stores of ova become depleted in some cows. For CashCow analyses, cows older than 9 years were considered aged.
AGID	Agar gel immuno-diffusion. A pathology lab test for antibody. Commonly used for pestivirus screening.
Annual liveweight production	Annual net live weight production per (retained) cow = Average live weight of cows at the end of the measured period x (1 – mortality rate) + Average weight of weaners produced x Lactation rate - Average cow live weight at the start of the measurement period.
Annual percentage of pregnant cows missing	Annual percentage of pregnant cows missing was defined as the percentage of cows that had been enrolled in the study and diagnosed pregnant, but without any record of being ***culled***, did not contribute any further data at any of the subsequent musters.
Annual production cycle	The period from the end of one pregnancy testing muster to the end of the pregnancy testing muster in the following year. Musters conducted to diagnose pregnancies were routinely conducted approximately 12 months apart.
Annual pregnancy rate	Percentage of cows in a management group (mob) that became pregnant within a one-year period. For continuously mated herds, this included cows that became pregnant between September 1 of the previous year and August 31 of the current year.
Antibody	Large protein constructed by white cells that binds to foreign chemicals in the body. Neutralises foreign chemical effects and facilitates elimination from the body.
Antigen	Chemical or particle foreign to the body.
Average	Total divided by the number of observations. This may be similar or very different to the median.
BBSE	Bull breeding soundness evaluation. This is a process

	that assesses five elements against standards that relate to calf-getting ability during natural mating.
Beef CRC	A multi-agency research conglomeration that studied the genetics and genomics of beef cattle production across Australia with Federal Government support.
BEF	Bovine ephemeral fever. Technical term for 3-day sickness. Viral disease spread by biting insects that causes waves of high fever and lameness over several days.
Body condition score	Subjective assessment of the body tissue (fat and muscle) reserves of an animal. Five-point scale (1=poor 2= backward 3=moderate 4=forward/good 5=fat).
Bos indicus	Sub-species of cattle originating in tropical southern Asia. Brahmans are derived predominately from *Bos indicus* cattle.
Bos taurus	Sub-species of cattle originating in Europe, and includes British and continental breeds.
Botulism	Lethal disease that presents as flaccid paralysis. Caused by very common bacteria (same family as tetanus and blackleg) that produce extremely deadly toxins. The toxins are usually consumed when cattle develop depraved appetites, most often when diets become deficient under seasonal extremes.
Box and Whisker plots	A graphic demonstration of data distribution. The whiskers indicate extreme values. The central box extremities are the 25th and 75th percentiles. The box midline is the median.
Branding rate	An ambiguous term that is most accurately defined as calves branded as a percentage of cows mated the previous year. It is very similar to weaning rate, but does not include calf mortality between branding and weaning.
Breedcow	Computer program for conducting economic analyses using herd structure, animal performance, and variable costs.
Breeder	Synonym for cow in a breeding herd.
Bull	Entire male cattle.
Bullock	Steer after it reaches mature height and weight.

BVDV/Pestivirus	Bovine viral diarrhoea virus or bovine pestivirus. Common viral infection of cattle. Infection of naïve unvaccinated cattle around the time of mating and during gestation may result in reduced pregnancy rates and increased percentage of losses between pregnancy diagnosis and weaning.
Calf/foetal loss	See Reproductive wastage.
Central Forest	Forested areas associated with the Brigalow areas of central Queensland.
Calf output	Number of calves produced.
Cattle year	Twelve month period ending at a natural point in livestock transactions and handling, usually after the last weaning muster in north Australian beef business.
Closing numbers	Number of cattle at the end of the cattle year.
Conception rate	Number of animals known to have conceived over a defined period, divided by the number of non-pregnant animals mated.
Confidence intervals	Values calculated in statistical analyses are estimates based on one set of measurements. The range within which 95% of estimates would occur if recalculated from independent sets of measurements is called the confidence interval.
Controlled mating	Non-continuous mating. The longest controlled mating is 7 months. Five months may allow mating after first weaning. Three months enables most calving to be complete before the next mating. Six weeks enables a maximum pregnancy rate of 90% in healthy cycling beef heifers and cows.
Cow	Female cattle after first mating, whether non-pregnant or from mid-pregnancy.
Crude protein	Weight percentage of nitrogen in a feed multiplied by 6.25; this is because protein averages 16% nitrogen by weight.
Development	Testing and demonstrating practical application of research outcomes in beef business.
Economics	Assessing the relative merits of business choices for the future.

Energy	Force holding molecules together, which is released as heat when molecules are split. The heat drives biochemical reactions in the body, thus life.
Extension	Provision of alternate information and skills to primary producers and support of appropriate integration to improve their business.
Digestible energy	Amount of energy in the diet that is digested and absorbed from the intestine, expressed as Megajoules per kg of dry matter.
Dry cow	Non-lactating cow, i.e. cow not suckling a calf.
Dry matter	Non-water part of a feed sample. For example, early wet season pasture may have as little as 30% dry matter, in contrast to late dry season feed which may have in excess of 90% dry matter.
Dry matter digestibility	Proportion of dry matter in a diet that is not excreted as faeces. For example, 60% digestible means that a cow eating 10 kg of dry matter will excrete 4 kg of that dry matter as faeces.
Dry matter intake	Dry matter eaten daily by an animal, usually expressed as a percentage of liveweight, and typically between 1.5% (very poor diets) and 2.5% (feedlot diets).
Dystocia	Difficult birth, often requiring human intervention to prevent loss of the dam and or offspring.
ELISA	Enzyme-linked immunosorbent assay. A commonly used lab test for disease agents or their antibodies.
EMAI	Elizabeth Macarthur Agricultural Institute.
Epidemiology	Study of all the interactive processes that result in disease.
EBV	Estimated breeding value. An unbiased estimate of the genetic merit for a specified trait in relation to breed average when first published. Each EBV has an accuracy estimate indicating the likely range that the true value is within.
EID	Electronic identification device. An implant or tag containing an RFID.
Exposure	Direct or indirect exposure to an infectious agent such as pestivirus.
Fertility	Having attributes that enable reproduction.

First-lactation cow	Cow during the period when the majority of her cohort is experiencing their first lactation.
Foetal ageing	Diagnosing age of a foetus using rectal palpation with or without the aid of ultrasound.
Follow up rain	The next rainfall event following a seasonal break, which is sufficient to sustain pasture growth.
Genotype	Similar to breed. Specifically, the grouping for an animal as defined by its genes.
Growth rate	Change in weight divided by the time period.
Head (of)	Colloquial term for number of cattle. Almost always can be excluded without loss of meaning.
Heifer	Young cohort of female cattle up to the time the majority should have calved, after which the cohort is classed as first-lactation cows.
Heritability	Proportion of a trait that is transferred from one generation to the next; alternatively, the proportion of a trait that is due to variation in DNA.
Hip height	Height at the peak of the sacrum which is adjacent to the hip joints. Note: hook bones, not hip joints, protrude.
Incidence	The proportion of a population that becomes affected during a defined time period.
Intercalving interval	The interval between two consecutive calvings.
Interquartile	The range between the 25th and 75th percentiles.
Lactation rate	Cows weaning a calf as a percentage of closing numbers (number of cattle at the end of the cattle year) within a group.
Land condition	Assessment of land systems as A = Pristine to D = Very poor (severe erosion or scalding, weed predominance).
Leptospirosis	Zoonotic bacterial disease spread in urine that can cause reproductive loss in cattle.

Liveweight production ratio	Annual net live weight production / Average live weight of cattle in the paddock over a cattle year. (The latter represents feed intake and = Average cow live weight over the year + Average weight due to weaners over the year.) For example, a live weight production ratio of 0.45 equates to 45 kg net increase in live weight for every 100 kg of cattle grazing that paddock on average over a one year period.)
Maiden heifer	Heifer prior to first mating.
Mating outcome	Events and result for an individual cow over a reproductive cycle.
Mating percentage	Number of bulls divided by the number of heifers and or cows in a mating group expressed as a percentage.
Mature cow	Cow after the time when her cohort has weaned their second age group of calves.
Mean	Synonym for average.
Median	Point where half the population is higher and half is lower = 50^{th} percentile.
Metabolisable energy	Approximately 80% of digestible energy, with 20% lost in storing and using the energy.
Missing	Animals that fail to return for routine measures, but not including irregular absentees. It comprises mortalities, animals whose individual identity is lost, and those that permanently relocate either of their own accord or without being recorded by a manager.
Mob	A synonym for management group, in contrast to a herd which is the entire population of animals within a business entity.
Mob-year	A collective term referring to a management group of females within a property that were recorded during a common annual production cycle.
Mortality rate	Cattle that have died as a percentage of the number known to be alive at a previous time.
Multivariable model	More than one variable is included in a statistical analysis, so the effects of all variables are accounted for in calculating the independent effect of each factor on the outcome variable.
Mustering efficiency	One minus the estimated proportion of absentee animals from a muster.

Naïve	A naïve animal is one that has not been challenged by a specific infectious agent, and therefore has no immune system evidence (antibody) of this.
Naturally immune	Immunity is gained by exposure to an infectious agent under field conditions rather than by vaccination or experimental challenge.
Neonatal	New-born, generally within a week of birth.
Neospora	Protozoan parasite that can cause mid-term abortion, especially in dairy cattle. Spread from cow to calf during pregnancy. Source of infection is faeces from infected canines, including domestic dogs, wild dogs, and foxes.
NIRS	Near-infrared reflectance spectroscopy. A system of using light bands absorbed/reflected from a sample material to describe its properties. Digestibility and crude protein levels of cattle diets can be estimated from NIRS of a dried faecal sample.
Nitrogen	Element found in all proteins.
NLIS	National Livestock Identification Scheme. Animals are given an EID that has a unique external printed number and matching unique internal electronic number.
Northern Australia	Queensland, the Northern Territory, Pilbara, and Kimberley regions of Western Australia.
Northern Downs	Downs (naturally non-forested with black soil) areas of western Queensland, the Barkly Tableland, and Kimberley.
Northern Forest	Non-downs areas, north of a line from approximately Bowen to Karratha.
Opening numbers	Same as closing numbers from the previous year.
Operating margin	The return per kilogram of liveweight sold minus the cost of producing a kilogram of liveweight, expressed as $/kg.
Pasture yield	Standing dry matter per hectare of a pasture.
PCR	Polymerase chain reaction. Chemical reaction that copies a segment of DNA defined by primers used in the reaction. About 35 sequential PCRs provide enough DNA for a test that differentiates whether the DNA sequence was present (positive) or absent (negative).
PD round	The muster of a herd of breeding cattle for pregnancy diagnosis.

Percentage foetal/calf loss	The percentage of cows diagnosed pregnant that either fail to wean a calf or were not found to be lactating after expected month of calving.
Percentage points	When comparing the difference(s) between percentages for each measure of performance the absolute difference will be expressed in terms of percentage points increase or decrease. For example, the median percentage foetal/calf loss was 8 percentage points higher in cows in the Northern Forest (13%) compared to cows in the Southern Forest (5%).
Percentile	Demarcation point for a specified percentage of a population; e.g., 75^{th} percentile is the point below which there is 75% of the population.
Perinatal	Within 48 hours of birth.
Pestivirus	See BVDV.
Phosphorous	Element, most of which is found in the body in cell membranes, the body's energy storage system, and in bone.
Plasma	Blood collected into an anticoagulant, with red and white cells extracted.
Population attributable fractions	These are the proportional reduction in average risk of the outcome (e.g., mortality) that would be achieved by eliminating the effects of one particular factor, while leaving the effects of other risk factors unchanged.
Postnatal	Beyond 48 hours after birth.
Pregnancy diagnosis	Diagnosing whether a heifer or cow is not pregnant (empty) or pregnant.
Pregnancy rate	Heifers or cows pregnant at a specific time as a percentage of those mated.
Pregnant within four months of calving (P4M)	Lactating cows that became pregnant within four months of calving.
Prevalence	The proportion of a population with a trait at a specific time point.
Property-year	A collective term referring to females within a property that were recorded during a common annual production cycle. A synonym for herd-year.
Protein	Large molecule built by DNA-RNA using amino acids that contain an average of 16% nitrogen by weight.

Pyometra	Pus-filled uterus as a result of infection.
Q-fever	Infectious zoonotic disease caused by a bacterium-like agent. Harbours in female cattle reproductive tract, and has been associated with sporadic abortion in cattle.
Quartile	A range within which 25% of animals occur.
Reproduction	Replication of an independent living being. In cattle, the most commonly used end point is weaning.
Reproductive wastage	Proportion of animals within a stage of the reproductive cycle that do not advance to a nominated subsequent stage. Most-commonly used for the percent of pregnant cows that fail to wean a calf.
Research	Scientific discovery and assessment of new methods built on hypotheses and using biometrics.
RFID	Radio frequency identification device. A sealed transponder that emits a unique number when energised by an external device such as that in a wand or panel reader.
Seasonal break	Time in tropical and sub-tropical areas at the end of the dry season when there has been sufficient rainfall to achieve significant new pasture growth, usually 50+ mm of rain within two weeks after 01 September or before 31 March.
Second-lactation cow	A cow between confirmed pregnancy and weaning in the year after the majority of her cohort weaned their first calf.
Semen quality	Attributes of semen, primarily percent motile and percent morphologically normal, that indicate fertilising capacity.
Seroconversion	The production of antibodies detectable in serum as an indicator of acquired immunity.
Seronegative	Denoting that a lab test for a serum component found a negative result.
Seropositive	Denoting that a lab test for a serum component found a positive result.
Seroprevalence	The proportion of animals that are seropositive.
Serum	Fluid fraction of blood after extraction of red and white cells and clotting proteins. The plural is sera.
Southern Forest	Non-downs areas outside the Brigalow country of central and southern Queensland.

Standard deviation	Statistic for a normally (evenly) distributed population whereby approximately two-thirds are within one standard deviation of the average and 95% are within two standard deviations of the average.
Start of the wet season	The time of a seasonal break.
Steer	De-sexed bull prior to full maturity.
Stocktake	Computer program that assists in grazing land management decisions.
Supplement	Addition to the diet to balance primary deficiencies, speeding up digestion, thereby increasing the rate of pasture or hay consumption, thus energy intake.
Temperature-humidity index (THI)	Environmental comfort index calculated from ambient temperature (T) and relative humidity (H) THI = 0.8T + H * (T - 14.4) + 46.4.
Three-day sickness	Common name for BEF.
Tick fever	Deadly disease caused by protozoan parasites (*Babesia* and *Anaplasma*) that damage red blood cells. Spread by cattle ticks. Infected young cattle are not affected and become immune.
Trichomoniasis	Venereal disease closely resembling vibriosis, but caused by a protozoan parasite living in the prepuce.
Vaccine	Injectable (usually) product that causes development of immunity against an antigen, usually an infectious disease agent.
Vibriosis	The revised name is Campylobacterosis, derived from the infective agent's scientific genus name, *Campylobacter.* Infection of unvaccinated naïve females usually results in marked reduction in pregnancy rate but there may also be an increase in abortion rate. No clinical disease in bulls.
Weaner	Calf permanently prevented from suckling its dam at the end of the reproductive cycle.
Weaner production	Lactation rate (retained cows) multiplied by average weaner weight.
Weaning rate (mated cows)	Cows weaning a calf as a percentage of those mated the previous year. Usually difficult to calculate as herd restructures and culling during pregnancy often prevents accurate information being available. Can be derived from multiplying annual pregnancy rate by (1-foetal and calf loss rate).

Weaning rate (retained cows)	Cows weaning a calf as a percentage of closing numbers within a group.
Weight	Measure of body mass. Can be very precise, but weight recorded will vary with different weighing protocols, especially diet and time since eating and drinking.
Wet cow	Lactating cow or cow suckling a calf.
Wet-dry round	A breeding herd muster when lactation status of cows, but not foetal age, is determined. Usually the first muster of the year for branding and or weaning.
Year group	Cohort of cattle. In tropical Australia where calving peaks at the end of the year, the year group is the year in the second half of the financial year as it coincides with most branding; eg, calves born in 2012-13 are called the 2013 year group.

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1 Background

1.1 Lower than expected reproductive performance in beef breeding herds in Northern Australia

It has been suggested[1] that a realistic target weaning rate for tropically adapted cattle in northern Australia in average or better rainfall years is 80 calves weaned for each 100 cows mated and retained (80%). This may be as high as 90% in extremely good seasons with excellent management. However, a minimum weaning rate (per cow mated and retained) should be 70% across a range of years. Industry surveys[2] suggest that the majority of beef breeding herds in northern Australia would fall below this mark, as the reported overall annual branding percentage is 63%, ranging from 48% in the Gulf of Carpentaria region to 73% in inland central and southern Queensland. Analysis of data on the reproductive performance of breeding mobs (n=45) in northern Australia published between 1990 and 2010 highlights the continuing marked variation in performance[3]. The interquartile range in annual pregnancy rate for heifers, first-lactation cows and mature cows was 74-87%, 6-54% and 78-90%, respectively. Similar marked variation was observed in the percentage of losses between pregnancy diagnosis and weaning, with an overall interquartile range of 9-25%.

Recent economic modelling[4] has demonstrated that in a typical northern Australian beef breeding herd of ~8,000 Adult Equivalents (AE), a 5% increase in the weaning rates of heifers, first-lactation cows, and mature cows will result in an extra $0.62, $1.09 and $ 3.65 per AE, respectively. A study of a sample of commercial and research station herds in Northern Australia[5] found that the established pregnancy rates per cycle ranged from 40 to 70%, indicating some herds are achieving physiological targets of performance. However, the economic benefits of improved pregnancy rates can only be realised if there are minimal losses between confirmed pregnancy and weaning. Foetal/calf losses of 15% to 20% in heifer mobs and 5% to 10% in cow mobs are not uncommon[6].

It is important to note that even where appropriate, good quality foetal or calf and maternal samples have been submitted for comprehensive pathological and microbiological investigation a definitive diagnosis of the cause of foetal/calf loss can only be obtained in about 30 to 50% of cases[7]. Wikse[8] reported that a specific diagnosis of the cause of abortion could only be made in about one third of laboratory submissions. In commercial beef breeding herds foetal/calf losses are usually simply defined as the difference between the proportion of females diagnosed pregnant and the proportion that wean a calf. However, studies involving the intensive monitoring of calving females have demonstrated that the period of greatest calf loss is around the time of calving[9]. A study of pregnant Brahman heifers (n=207) on a pastoral

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[1] McGowan and Holroyd (2008)
[2] O'Rourke *et al* (1992)
[3] McCosker *et al* (2011)
[4] Holmes (2010)
[5] Fordyce *et al* (2005)
[6] Burns *et al* (2010)
[7] McGowan *pers comm*
[8] Wikse (2002)
[9] Holroyd (1987)

company property on the Barkly Tableland found that only 79.2% successfully raised a calf, with 63% of the losses being perinatal loss, primarily dystocia, mismothering, and unknown causes[10].Many factors can affect calf viability in the first couple of weeks after birth. Dystocia is a well-recognised cause of neonatal loss and although calves maybe born alive they may be slow to suckle or fail to suckle due to cerebral anoxia, which occurs during prolonged parturition. Although the prevalence of dystocia in *B. indicus* cattle is generally lower than in *B.taurus* cattle[11], there are reports of significant losses in tropically adapted cattle due to dystocia e.g. in a mob of maiden Brahman heifers mated to Charbray bulls the prevalence of dystocia was 4%[12]. Another study reported a mortality rate of 5-10% due to dystocia in Brahman-cross females calving at two years of age[13].

The causes of poor reproductive performance in beef breeding herds are multifactorial and have been comprehensively reviewed[14]. Although in some cases the causes of these losses have been determined, the relative contribution of each to the risk of heifers or cows failing to become pregnant and pregnant females failing to rear a calf ***has not*** been defined at an industry level. Such information is critical to enable producers to focus management changes and investment on those factors that have been shown to be contributing most to herd reproductive outcomes. This information is also needed to guide investment by research funding agencies. For example, if most of the difference between mobs/herds can be explained by known factors then investment should target technology transfer or development of improved approaches to managing these factors; if little of the difference can be explained then investment should target further research to define the causes and factors associated with sub-optimal performance.

There has been no population-based study of the reproductive performance of commercial breeding herds in northern Australia, or of the major factors affecting performance in these herds. However, there have been a series of detailed studies of the performance of research station herds in northern Australia and the factors affecting lifetime productivity and mortality in these herds[15].

Major challenges to studying the reproductive performance of extensively managed breeding herds include the fact that breeding females are often only mustered twice a year, ‘mothering-up’ of calves is rarely done, and herds are either continuously mated or employ long joining periods. The use of foetal ageing at the time of annual pregnancy diagnosis allows month of conception and calving to be estimated. This enables assessment of the impacts of environmental, nutritional, management, animal, and infectious disease factors on the following:

1. how efficiently cows become pregnant,
2. the likelihood of pregnant cows rearing a calf, and
3. the likelihood of cows going missing (i.e., dead, lost ID tag, moved paddocks).

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[10] Brown *et al* (2003)
[11] Rowan (1990)
[12] Brown *et al* (2003)
[13] Fordyce *et al*. (2009)
[14] Burns *et al* (2010)
[15] O’Rourke *et al* (1995a) and (1995b)

1.2 Development of the CashCow project

During 2005, as part of MLA's Northern Beef Programme strategy development, a series of workshops were held with regional industry stakeholders—including producers, researchers, veterinarians, and beef cattle advisors—to establish research priorities. Reproduction was ranked equal third in the order of priority issues. It was recognised that there was a serious lack of data on achievable levels of breeding mob performance by broad geographic region, and on the variation in mob or herd performance that could be explained by known risk factors.

In April 2006, MLA's Northern Beef Programme held a forum on calf wastage with selected beef cattle veterinarians, industry representatives, and researchers to discuss the logistics of conducting a large scale research project to define and quantify the factors affecting breeding herd performance. A project development team (which later became the Cash Cow project team) was established in June 2006, and with funding support from MLA (B.NBP.0372 - Northern Australian Beef Fertility Project – Wean-a-Calf) an epidemiological study of factors affecting the reproductive performance of commercial breeding mobs was developed. After consultation and review of the proposed research with Northern Australian Beef Research regional committees and/or their chairpersons, a full funding application was submitted to MLA in April 2007.

A large longitudinal epidemiological project (Incalf) was conducted by Dairy Australia in the mid to late '90s to identify and quantify factors affecting the reproductive performance of dairy herds and cattle in Australia. The Incalf project provided a very useful template for designing the CashCow project, and it was very fortunate that Dr John Morton who led the Incalf project was an original member of the CashCow project team.

In addition, the findings of the following MLA funded projects were reviewed as part of development of the Cash Cow project:

- North Australia Beef Producer survey 1990[16]
- Minimising pregnancy failure and calf loss [17]
- Improved diagnosis of reproductive disease in cattle[18]
- Impact of infectious disease on beef cattle reproduction[19]

Finally, it was recognised that the CashCow project was likely to have significant linkages with relevant Beef CRC III projects (e.g., the Lifetime Female Reproductive Performance project) and other related MLA funded projects, including the "Study of causes of variation in post weaning liveweight gain (NBP.0390)".

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[16] O'Rourke *et al* (1992)
[17] Fordyce *et al* (2005)
[18] Lew *et al* (2006)
[19] Kirkland *et al* (2012)

2 Project objectives

1. Define reproductive performance in a selected population of northern Australian commercial properties (study population) over 3 consecutive years using a range of measures. The primary level of selection was at the property, and the main unit of analysis was the ‘mob’.

2. Establish outcome measures for monitoring and comparing the reproductive performance of breeding mobs and properties in northern Australia.

3. Define typical and achievable performance using (2) in the study population.

4. a) Estimate variation in reproductive performance at animal-, mob-, property- and region-level.

   b) Identify causes of variation in reproductive performance between animals, mobs, properties, and regions.

   c) Quantify the proportion of variation explained by identified risk factors.

   d) Identify those risk factors that explain the greatest amount of the variation between mobs, properties, and regions.

   e) Develop analytical tools to support mob-level decision making.

5. Develop cost benefit framework and analyse the economics of changing the major mob-level factors affecting reproductive performance.

6. Make recommendations on:

   a) A benefit cost study to assess the production and economic impact of changing well defined inputs and management practices that affect key risk factors.

   b) Extension priorities for changing well defined inputs and management practices that affect key risk factors.

   c) Research priorities for inputs and management practices (that affect key risk factors) for which the impacts are not well defined.

   d) The feasibility of establishing strategic ongoing reproductive performance monitoring ‘systems’ to enable the longitudinal evaluation of the impact of implemented changes in management practices and inputs.

3 Methodology

3.1 Design and management of the project

The CashCow project was designed to answer two fundamental questions:

1. Why do some breeding mobs have good reproductive performance, and others significantly poorer performance?
2. Why do some breeding females readily conceive and wean a calf, while others either take significantly longer to conceive and/or fail to wean a calf?

To address these questions, a four year prospective epidemiological study of region-, property-, mob-, and animal-level factors affecting the reproductive performance of a selected population of commercial breeding mobs was developed. Northern Australia was initially divided into the following regions for the purposes of selecting co-operator properties: Southern Queensland, Central Queensland, Western Queensland, Northern Queensland, North-West Queensland, Barkly Tableland, and Top End/Kimberley. It was considered that these regions represented the major beef breeding regions of northern Australia.

A regional co-ordinator from the project team was assigned to each region. A list of potential co-operating cattle veterinarians was then compiled by the project team and their interest in participating in the project determined. The regional co-ordinators worked with selected co-operating veterinarians (all were required to be accredited by the National Cattle Pregnancy Diagnosis Scheme administered by the Australian Cattle Veterinarians) to develop a short list of potential co-operating producers (details of selection criteria used to recruit study properties are presented in Section 3.2). Typically, each veterinarian had 1 to 3 properties to service during the project. A letter of agreement was created by the project team, which outlined what was expected of co-operating producers and veterinarians, and what the project would provide to them in return for their support and compliance with collection of all required data.

A critical component of the design of the CashCow project was the use of crush-side electronic data capture to enable rapid, accurate collection of all animal data and systematic evaluation of the reproductive performance of females over consecutive years. The majority of commercially available electronic data capture systems were evaluated by members of the project team and the AgInfoLink system operated by Outcross was selected. Subsequently, Outcross was contracted to conduct all the electronic crush-side data collection in Queensland; however, in the Northern Territory, Kimberley and Pilbara regions most of the data collection was conducted by the NTD&R staff using the same equipment and system as Outcross.

A comprehensive reference manual (see attached) was written by the CashCow project team covering all aspects of property and mob selection, identification of enrolled females, and methodology for collection of all breeding female, weaner, pasture, property, and infectious disease data. For each variable measured or assessed, the ‘best practice’ method of collection and recording of the data was described. Manuals were supplied to all Outcross Performance Pty Ltd (Outcross) data collectors, and co-operating producers and their veterinarians at the commencement of the project.

A pilot study was initially conducted in 2007-08 to guide the design and management of the main population-based study, which was conducted in 2009-11. Heifer mobs from two properties from each of the seven regions described above were enrolled (n= 14) in the pilot study. This enabled evaluation of the electronic and template data capture systems, and establishment of the CashCow project database. Prior to the commencement of the pilot study, a workshop was held at The University of Queensland's Pinjarra Hills beef farm to demonstrate and agree on the methodology for all data collection procedures, and to standardise among producers (n=14) and cattle veterinarians (n=21) all data collection procedures. At this workshop the degree of variation in individual veterinarian's estimates of the foetal age of pregnant females was determined (**Appendix I**), and scoring systems for condition and lactation were standardised. Further, after careful review and consultation with the producers and veterinarians at the workshop, several major changes were made to the design of the main study, including:

1. The potential impact of bull fertility on the reproductive performance of breeding mobs would be determined by assessing the property's replacement bull selection and management policy and their annual bull management and culling policy, rather than conducting bull breeding soundness examinations on the bulls mated to each breeding mob. This change was made because, particularly in the continuously mated mobs, co-ordinating veterinary availability with bull accessibility was predicted to be problematic. Also, it was considered that the continuing use of relatively high bull percentages (≥3%) could mask the effects of individual bull subfertility.
2. The reproductive performance of breeding females would be strategically determined once a year by pregnancy diagnosis and foetal ageing rather than pregnancy diagnosis on two consecutive occasions. However, it was agreed that the major factors affecting reproductive performance of cows (lactation status and body condition score) would be monitored twice a year: once at the main annual branding/weaning muster and then at the time of the annual pregnancy diagnosis muster.

After review of the pilot study it was recognised that there was a critical need to appoint a person (Mrs Di Joyner) to the project team with the responsibility of liaising with producers, Outcross data collectors, regional co-ordinators, and Dr Nancy Phillips (responsible for receiving, storing and co-ordinating submissions for testing of all dung, blood, and vaginal mucus samples). This position ensured that dung samples were collected, wet/dry and pregnancy diagnosis musters were scheduled and performed on time, and data capture templates were completed and submitted. It also provided administrative support for co-operating producers and the project leader, and organised and ran the annual CashCow meetings. The management structure of the project is presented in **Figure 1** and the roles of each member of the project team are outlined in **Appendix II.**

Also, to standardise data collection across the different properties and throughout the course of the project, a training workshop for all Outcross data collectors was conducted prior to commencement of the main study. Subsequently, several follow-up workshops were conducted, usually in conjunction with the annual project meeting and included assessment of variation between data collectors for key measurements e.g., body condition score (**Appendix III**).

In this project each co-operating property and their staff and veterinarian were effectively a 'research station'. To sustain interest in the project and support compliance with data collection, a project communication strategy was established. This involved producing a thrice or twice yearly project newsletter (**Appendix IV**), and holding an annual project meeting, workshop, and dinner.

Several major data analysis issues related to the study design constraint of only being able to examine females twice a year and relying on foetal ageing at the annual pregnancy diagnosis muster to determine likely month of calving were recognised at the beginning of the project and included:

1. Marked variation between properties across northern Australia in their mating strategies, ranging from continuous mating without segregation through to controlled mating for three months.

2. Well recognised cycle, particularly in continuously mated herds, of females calving and subsequently failing to become pregnant in that year but then becoming pregnant the following year. Thus the 'true' reproductive performance of a herd cannot be defined by performance in a single year.

3. The fact that the reproductive cycle of a breeding female (conception, calving, weaning and re-conception) often extends over a period of greater than 12months.

4. In most commercial breeding herds across northern Australia, calvings are not observed and 'mothering-up' of calves is not practiced. Therefore, the primary method of determining whether a pregnant female has reared a calf is assessment of her lactation status at the time of each round of weaning.

To gain a better understanding of whether a study design involving examination of females at the first annual branding or weaning round and then again at the annual pregnancy diagnosis muster could reliably define the reproductive performance of females in the CashCow project, a small study of reproductive performance data from several Beef CRC III herds and from a large pastoral company herd was conducted (**Appendix V**). This study particularly focussed on defining the major possible reproductive pathways, and the outcome of each pathway. Because of the intensive monitoring conducted in the Beef CRC III herds, very accurate reproductive outcome data were available for analysis. Analysis of these data focused on estimating the probability of an observed pregnancy/lactation combination at two successive annual musters conditional on an observed calf fate. The study indicated that in 97% of all pregnant/dry to pregnant/wet transitions, the predominant pathway observed in the Beef CRC III herds (represented 44% of all defined pathways), resulted in the weaning of a calf. However, 14% of reproductive pathways were from pregnant/dry to pregnant/dry. This pathway was of particular interest and further analysis showed that 50% (n=124) of females that had this reproductive pathway experienced perinatal loss, 21% (n=52) experienced postnatal loss, 16% (n=39) aborted, 8% (n=20) lost a calf just before weaning, and 5% (n=11) reconceived and lost the calf. To further investigate this pathway, foetal/calf loss from pregnancy diagnosis to weaning was determined using survival-time analysis. The results of this analysis demonstrated that the majority of losses from pregnancy diagnosis to weaning occur during the first month after calving.

A further major task undertaken at the commencement of the project was to critically review the measures used to define the reproductive performance of breeding mobs and females. Ideal measures of mob reproductive performance would be:

- Linked to mob profitability under at least some circumstances
- Conceptually transparent to managers and advisers
- Easily calculated with readily available data

In addition, for effective and widespread adoption, it is desirable that only a small number of key measures of performance are used. A set of draft measures of reproductive performance was developed by the project team and reviewed by co-operating producers and veterinarians at the annual CashCow project meeting in 2010. Particular emphasis was placed on ensuring clear definition of the denominator and numerator used to calculate each measure. The final measures of performance selected for use in the project are described in detail in **Section 3.5.1**

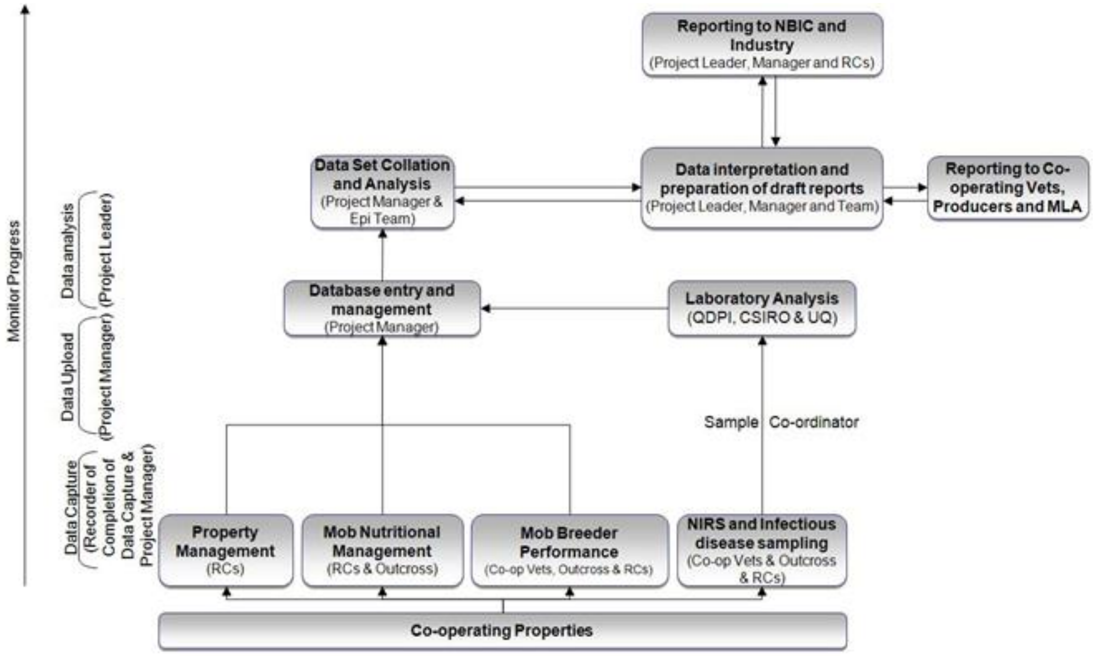

Figure 1: Outline of management structure of the Cash Cow project

3.2 Property and mob selection for the main study

To determine the number of properties, mobs and animals required to enable the factors significantly affecting reproductive performance to be identified, a power analysis was conducted using the following two outcome variables:

a) the proportion of lactating cows at either the first round muster or branding muster which are likely to have conceived in the first two to three months after the bulls were put with the females, or after a break in the season sufficient to enable a significant number of females to commence cycling, and

b) the proportion of replacement heifers that are likely to become pregnant in the first two to three months after bulls are added to the mob.

These measures were selected as they were very likely to be measures that would be assessed in the project.

A standard deviation (SD) of 0.11 (i.e., 11%) for lactating cow pregnancy rate was assumed, based on industry estimates provided by G Fordyce. The number of breeding mobs required to have 80% power (generally accepted level of power for this type of epidemiological study) to detect as significantly different ($P < 0.05$) mean differences ranging from 2.5% to 10% for the above outcome variable are shown in **Table 1**.

Table 1: The number of mobs required to detect significant differences between means ranging from 2.5% to 10% with 80% power.

Difference between means (%)	mobs exposed %	No. mobs required
2.5	10	1700
2.5	50	610
5	10	430
5	50	154
10	10	110
10	50	42

Using the above findings, enrolment of 154 mobs into the main longitudinal study would enable small effects (around 5% differences) of factors common to these mobs (50% of mobs exposed) to be detected. However power to detect less common (around 10% of mobs exposed) mob-level factors would be lower.

The number of female cattle required if the study was to have 80% power to detect significant differences ($P < 0.05$) between cattle either exposed or not exposed to a factor and where the actual proportions of cattle pregnant varied between 52.5% and 90% are shown in **Table 2**.

Table 2: The numbers of females needed to detect significant differences between breeding females with differing levels of exposure to a factor.

Cows/heifers exposed %	Proportion exposed %	Pregnant not exposed %	Total no. cows/heifers required
10	-	52.5	34840
50	-	52.5	12550
10	50	55	8670
50	50	55	3130
10	50	60	2130
50	50	60	776
10	80	85	4840
50	80	85	1812
10	80	90	990
50	80	90	398
10	80	85	20890
50	80	82.5	7652

On the basis of these power analyses it was decided that for the main CashCow study two mobs from each of 77 properties would be enrolled —36 from southern and central Queensland (primarily control mated herds) and 41 from north, north-west and western Queensland, the Northern Territory and northern Western Australia (primarily continuously mated herds) (**Table 3**). While this design was considered to provide adequate power to investigate common property level exposures such as mating practices, it would only provide moderate power to detect region–level effects. Wherever possible a mob of heifers and a mob of cows were initially enrolled on each property. These mobs were then monitored over the course of the project.

However, on a small number of properties new mobs of heifers were enrolled in 2010 and 2011.

The following criteria were then used to select co-operating producers and mobs:

- They were current or potential clients of selected project veterinarians
- They were keen to participate and support the project and collect and record all required data for the entire duration of the project and were prepared to sign a letter of agreement covering this commitment to the project
- They were prepared to maintain the mobs initially enrolled on the property (other than females culled as part of normal property culling policy) for the duration of the study. Fencing needed to be in good repair and mustering techniques adequate such that at least 90% of each selected mob could be mustered twice yearly
- They were prepared to ensure that initially all enrolled females were National Livestock Identification Scheme (NLIS) tagged, and any added females in Years two and three of the study were also NLIS tagged.
- The owner/manager was prepared to attend a one-day “Stocktake” workshop funded by the CashCow project
- The property was typical of commercial cattle properties in the region, in particular with respect to size, cow numbers, pastures, herd management (including breed, mating regime) and performance. For mixed properties, income from the breeder herd had to be a significant proportion of the total income for the property
- Pregnancy testing facilities in reasonable working condition were available, and the owner/manager was prepared to ensure that cattle in each enrolled mob (up to the maximum of 500 head per mob) were pregnancy-tested by a project veterinarian once a year either at least six weeks after the bulls were withdrawn or at the August-September muster
- Weighing facilities, for weaners at least, were available and the owner/manager was prepared to record weaner weights and associated information for each enrolled mob, and send to Outcross Pty Ltd after each round of weaning.

Table 3: Number of properties initially enrolled in each geographical region.

Region	Planned number of properties for main study	Actual number of properties enrolled in the main study (2008-2010)
Barkly Tableland	5	4
Central Queensland	20	14
Northern Queensland	8	16
North-West Queensland	10	7
Southern Queensland	16	19
Top End/Kimberley	8	12
Western Queensland	10	6
Total	**77**	**78**

On co-operating properties with mobs of 100 to 500 females, all females were enrolled in the study. However, in mobs of greater than 500 females a strategic sampling design was used in some cases to select a cross-sectional subset of 300 females from the mob at the first data collection visit in the first year of observations. This was done to ensure that all data collection from these large mobs could be completed in a single day. To determine which females were enrolled, the total number of females in the mob was divided by 300 and then every n^{th} (5^{th}, 6^{th} etc) female was selected as they presented at the crush during the first data collection muster. In addition, as one of the major objectives of the project was to define the annual kilograms of beef produced from each enrolled breeding mob the weight of either all the calves weaned or a representative samples of calves weaned at each weaning round was required. A sampling ready-reckoner for weaners (**Table 4**) was developed for use in large breeding mobs. These guidelines for enrolment of breeding females and selection of weaners to weigh at each weaning round were developed by the project's epidemiologists and were provided to the regional co-ordinators and data collectors.

Table 4: Sampling ready-reckoner* for selection of weaners for weighing.

Assumed precision	Assumed size of weaner mob				
(±kg)	200	300	500	700	1000
0.5	198	295	485	670	940
1	191	279	444	594	796
3	138	179	233	269	303
5	89	104	121	129	137
7	59	65	71	74	76
10	35	37	39	40	40

*Sample size requirements for weaner mobs assuming a fixed standard deviation of 47 kg around the mean weaner weight (148 kg), estimated from 5,408 weaner weights from a property in Northern Queensland.

3.2.1 Location of enrolled co-operating properties

Over the course of the project 78 properties located in each of the major beef production regions of northern Australia (**Figure 2**) were enrolled in the main study and the reproductive performance of 142 mobs (management groups) involving a total of 71,000 females was monitored. Six properties withdrew from the project (one in southern Queensland, three in central Queensland, one in northern Queensland and one in the Top End/Kimberley); they withdrew for a variety of reasons associated with their ability to provide and support the required data collection, through to property viability and sale of the property.

For the data analysis, various approaches were investigated to regionalise the enrolled properties to facilitate analysis and extension of findings. Initially, properties were allocated according to geographical regions (**Figure 2**). However, after review by the project team and discussion with co-operating producers the approach that was used was to assign each property to one of four country types (**Figure 3**) based on the country's production potential. Properties were categorised by subjectively assessing the land's production potential, and cross referencing with the producer's pasture description of the paddocks used. Properties with forested land types and fertile soils in the central and south-east regions were differentiated into those outside (Southern Forest) and within the Brigalow belt (Central Forest). In northern areas, land types predominated by tree-less black soil downs (Northern Downs) were separated from forested land types with low-fertility soils (Northern Forest). The number of mobs enrolled in each country type is shown in **Table 5**.

Table 5: Number of mobs enrolled in each country type by cow age class/cohort of female.

Country type	2008 Heifers	2009 Heifers	2010 Heifers	2011 Heifers	2009 Cows
Southern Forest	3	13	1	1	22
Central Forest	3	8	1	0	13
Northern Downs	4	8	2	1	13
Northern Forest	3	14	5	0	27
Total	13	43*	9	2	75**
	142				

*Processed as 47 management groups at time of induction
**Processed as 104 management groups at time of induction to project.

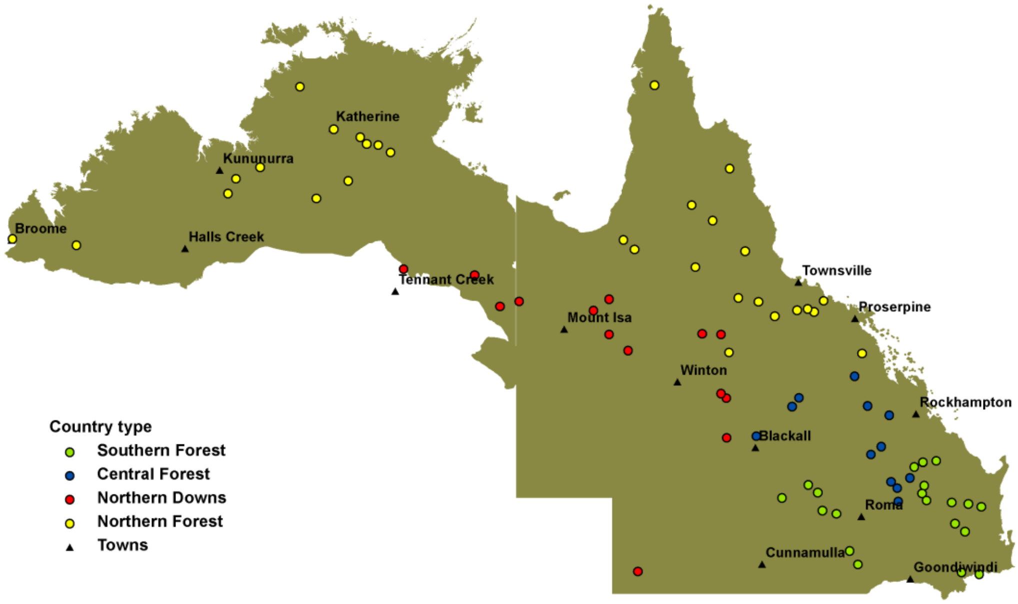

Figure 2: Map of enrolled properties by country type.

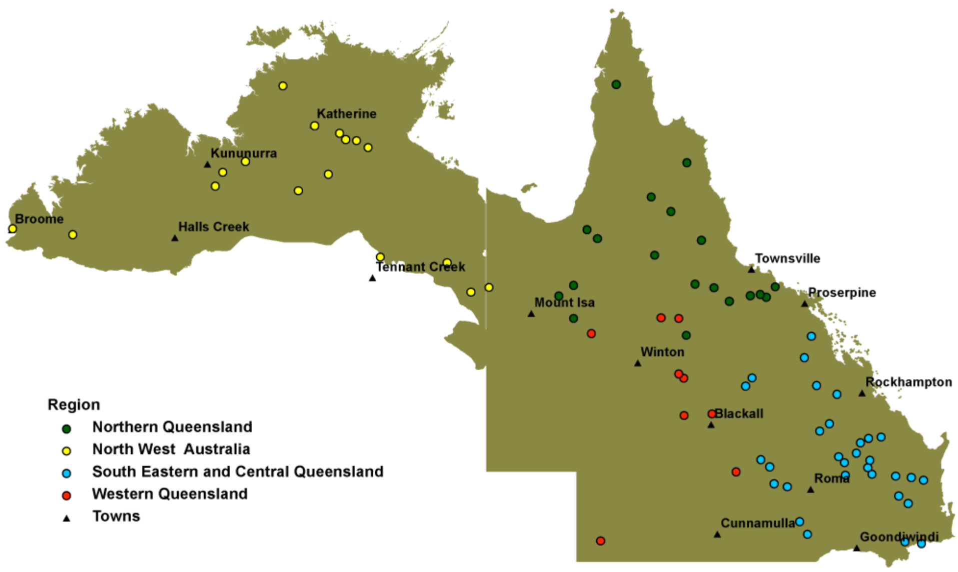

Figure 3: Map of enrolled properties by region.

3.3 Data collection

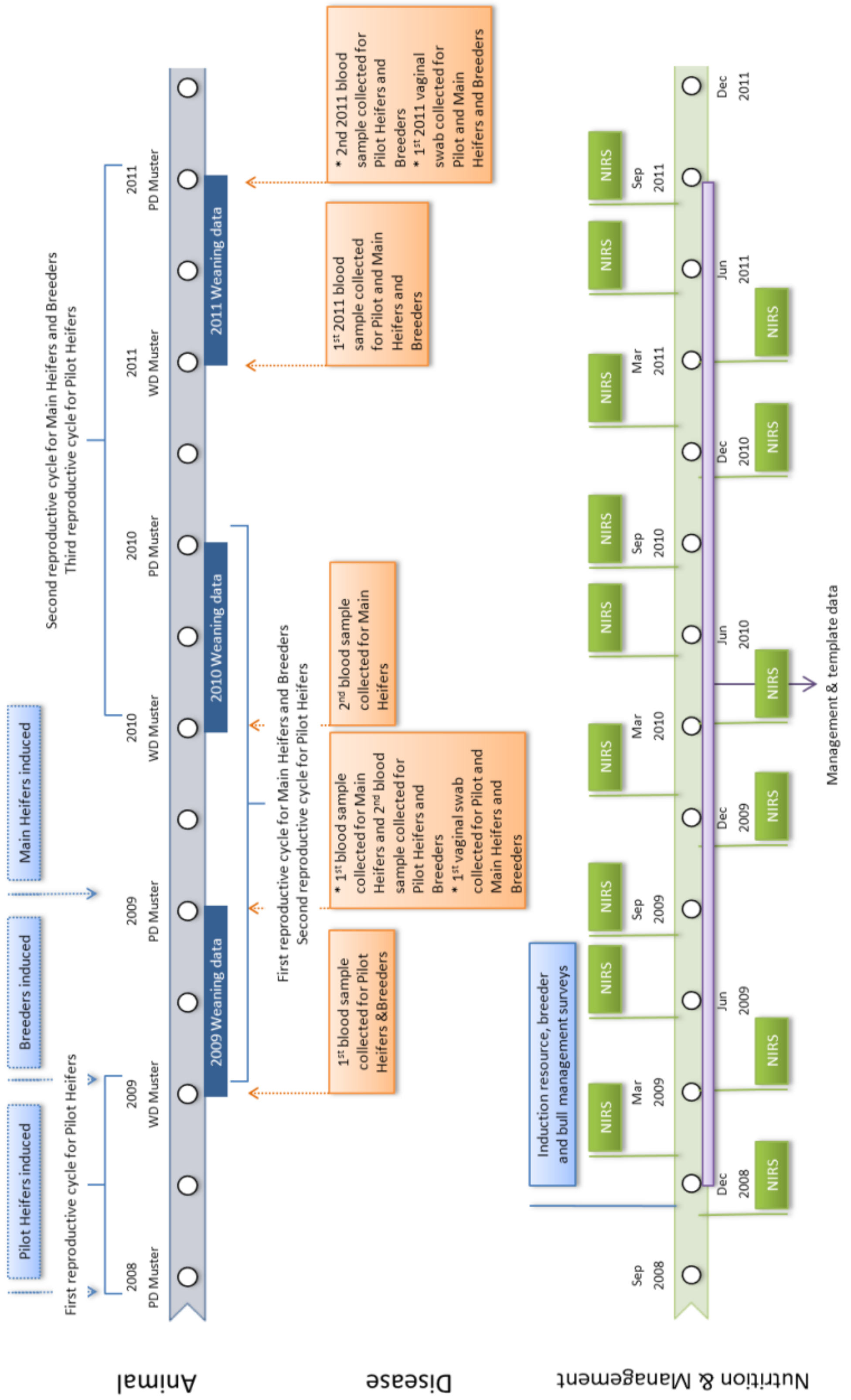

Figure 4: Summary of data collection throughout the project (note two heifer mobs were inducted in each year—2010 and 2011).

An outline of collection of all animal and property data and faecal/blood/vaginal mucus samples during the course of the project is provided in **Figure 4**.

3.3.1 Crush-side data collection: Breeding females and weaners

3.3.1.1 Electronic data capture

All crush-side animal data were collected using the AgInfoLink software system (**Figure 5**) for all properties except for a few where the collaborators existing data collection system was utilised.

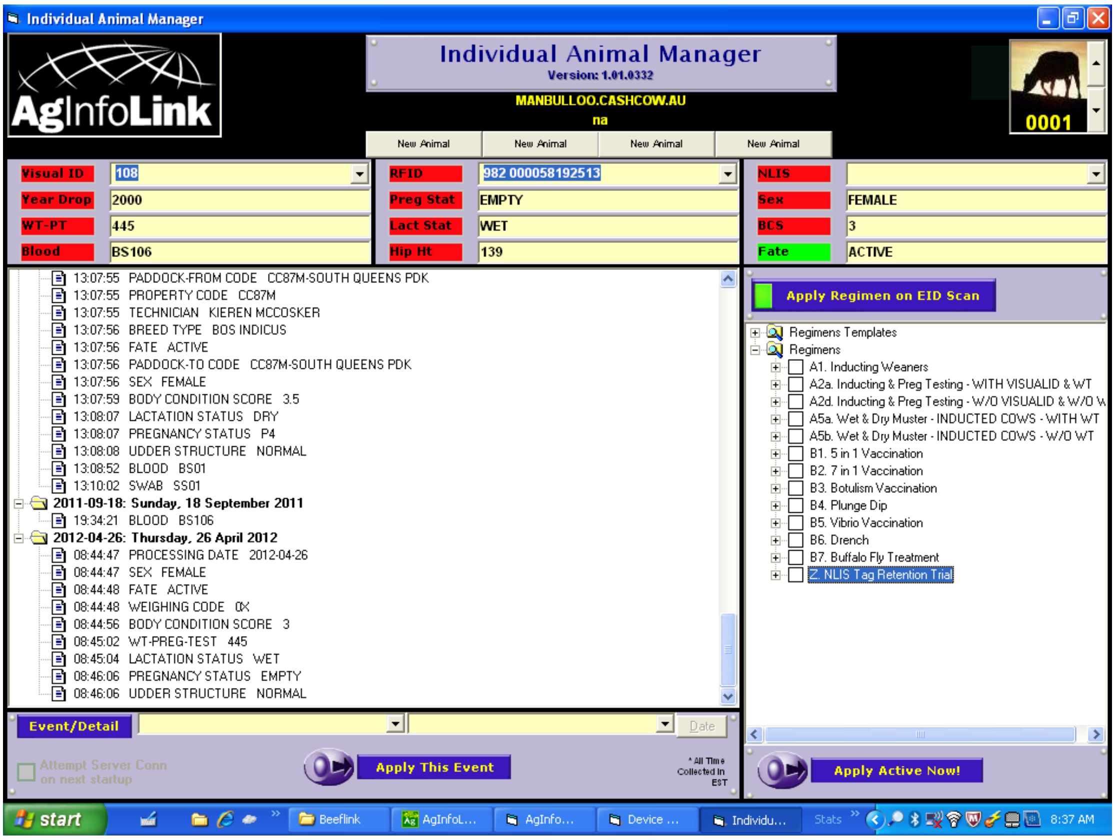

Figure 5: A screenshot of the AgInfoLink user interface, showing the data capture screen.

The AgInfoLink software was interfaced to NLIS technology including NLIS readers (wand and panel readers) and liveweight scales. A customised external keyboard (Enterpad; **Figure 6**) was used to ensure that the data could be entered quickly and accurately. The software ran on either Opentec Rugged laptops or Panasonic Toughbooks. All hardware that required external power (NLIS Panel Reader and Rugged Laptop) was powered by a 12volt system. Each data collection unit included two 12volt dry cell batteries, which would provide approximately 35Amp hours each when fully charged. Other hardware was either powered by an internal battery (NLIS wand and Liveweight scales) or powered by the computer (Enterpad).The hardware and software setup was the same when recording cows or weaners although the recording of weaner information was sometimes collected by the collaborator if the weaning occurred outside of the times Outcross was present.

The animal's identity was automatically collected from the NLIS panel reader as it entered the crush. The RFID (radio frequency identification device) number (microchip within the NLIS device) was then transmitted via a cable to the rugged laptop running the AgInfoLink software. The RFID number would trigger the software to begin recording, and depending on whether it was an animal with data already recorded (an "enrolled" cow) or a new animal (non-enrolled cow or weaner) would determine whether historic information would be presented on the screen. The mob level data that would be recorded for every animal included Processing Date, Property Code, Mob ID, Class (Cow or Weaner), Technician (Veterinarian's name), Operator (data collector's name), Paddock-From Code, Paddock-To Code and Breed Type (genotype of mob).

Once the standard information was recorded for each animal, which didn't require user input after setup, the variable information was recorded. For the cows, each animal would have Pregnancy Status and Foetal Age (once per year), Lactation Status (twice per year), Body Condition Score (twice per year) and Weight recorded where scales were available. If the animal hadn't previously been recorded certain "induction" information would be recorded including Sex, Year Brand (Age Brand) and Visual-ID (management tag number) if present. Other information that would be recorded included the vaginal swab and blood sample numbers, if a cow had an abnormal Udder Structure, and if an animal was being culled.

The weaner data recorded included Weight, Sex (male or female), Horn Status (dehorned or horned) and Processed (previously branded – yes or no).

The speed of processing was dependent on a number of factors, including the yard setup, number of property staff available, speed of the veterinarian, speed and/or experience of the data collector, and temperament of the cattle. The speed of collecting data at the annual pregnancy testing muster varied from approximately 40 to 150 heifers/cows per hour. The wet/dry round (first round) was normally slightly quicker. The maximum speed to record weaners was about 180 heifers/cows per hour.

After each animal was processed, the next RFID number would be read, which triggered the software to save the previous record and begin recording the next animal. Once all animals in the mob were processed the AgInfoLink data collection software (Beef Link) was shut down and a report could be generated showing the results of the days processing on the screen.

All cows were required to be identified with an NLIS tag by the first data recording session. There was, however, no requirement for weaners to be NLIS identified, in which case a random ID number was generated. If a cow lost its NLIS tag a new one would be inserted or the animal could be identified by the management tag number, if present. Towards the end of the project, if a cow didn't have a management tag and had lost its NLIS tag, a random number would be generated in order to record the current information.

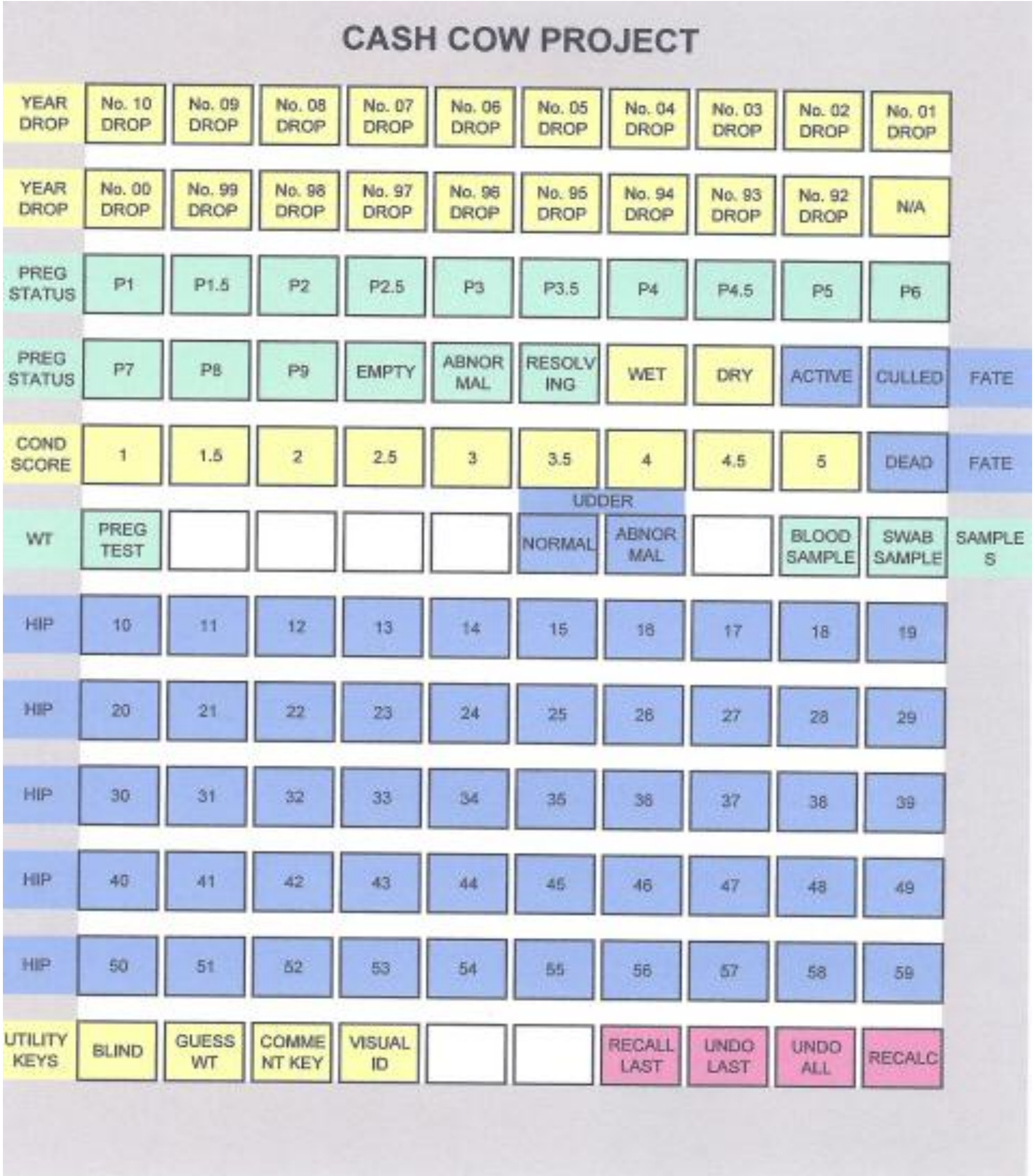

Figure 6: Image of the customised Enterpad used for crush-side data capture.

3.3.1.2 Age

The year brand for all females was recorded at the time of enrolment. Although there was some variation in year brand policy by property, generally the approach was to use financial year i.e., a No.13 branded female is an animal born in 2012-13.

3.3.1.3 Breed

The possible breed categories used were as follows:

- *Bos indicus*: e.g. Brahman
- *Bos indicus*-derived <25% British: This applies to herds that have <25% British breeds (e.g. Hereford, Angus, Shorthorn) and >75% Brahman Examples include cows born from Brangus bulls across Brahman cows or Brahman bulls across Santa Gertrudis cows

- *Bos indicus*-derived 25–50% British: A breed example here is the Santa Gertrudis, which have 3/8 or 37.5% Shorthorn (British)
- *Bos indicus*-derived ≥50% British: Any crossbred that has ≥50% British, most likely to be seen in herds in non-tick areas, e.g. cows resulting from Angus bulls across Brahman or crossbred cows
- *Bos indicus*-derived <25% Euro: This category includes herds that have <25% European breeds (Charolais, Limousin, Simmental, Salers etc.) and >75% Brahman. An example would be females derived from Charbray bulls across Brahman cows
- *Bos indicus*-derived with 25–50% Euro
- *Bos indicus*-derived ≥50% Euro: e.g. Charbray (cows born from Charolais bulls across Brahman or Charbray cows)
- British: e.g. Hereford, Angus, Shorthorn, Murray Grey, Devon, Wagyu
- European: e.g. Charolais, Limousin, Simmental, Salers
- British x European: e.g. Angus X Charolais
- Composite or crossbred: Any breeder herd where there is a combination of more than two breed categories, e.g. British, European and *Bos indicus;* OR British, Adapted *Bos Taurus,* and *Bos indicus*. Many of the NAPCO and AACo breeder herds are examples of this
- Adapted *Bos taurus* derived from African breeds: e.g. Senepol, Tuli, Belmont Red, Bonsmara

To investigate the impact of breed on performance these were subsequently collapsed to three categories according to estimated *Bos indicus* content:

- Females estimated to be less than 50% *Bos indicus*
- Females estimated to be 50-75% *Bos indicus*
- Females estimated to be >75% *Bos indicus*

3.3.1.4 Body condition score (BCS)

There are many body condition scoring systems used throughout Australia and the world. The reasons for different systems are complex, but most have been developed for a specific purpose rather than broad use. The trend is now for consolidation of these systems into a 5-point scale. Five-point scales work well because they fit with a typical framework of thinking, i.e., very bad (1), ordinary (2), average (3), good (4) and very good (5). In the CashCow project, the 1 to 5 BCS system was used and data collectors were provided with high quality side on photos of cows in different BCS (**Appendix III**). Females were scored in increments of 0.5 BCS.

3.3.1.5 Lactation status and udder structure

Lactation status was recorded as 'wet' or 'dry'. If there was any doubt about a female's lactation status, expressing milk from a quarter was attempted. Udder structure was scored as either normal (includes a large range of udder conformation not considered likely to adversely affect a calf's ability to suckle), or abnormal (very likely to affect a calf's ability to suckle from all 4 teats; **Figure 7**).

Figure 7: Abnormal udder structure.

3.3.1.6 Liveweight

Liveweight of cattle is a critical mob production parameter. Although it can be measured precisely, the accuracy may be low if diet and weighing protocol are not carefully managed. Therefore, if cattle are weighed, variables that may affect weight, such as the weighing protocol, should also be reported so that weight may be adjusted for these if appropriate.

A code made up of a number followed by a letter was used to label weights to denote days since removal from normal grazing (the code number), and whether feed and or water curfews of 12 hours or more have been applied (the code letter). The curfew code was:

- P: No curfews applied
- W: On water and off feed
- D: Off feed and water
- F: On feed and off water
- X: Variable or unknown

An example code was 1D: Mustered and held in yards overnight off feed and water before weighing.

3.3.1.7 Hip height

Experience has shown that if height is measured at the peak of the sacrum, height measurements are highly repeatable[20].

All hip height measurements were taken by setting a tape measure on top of a crush which is a known distance to the floor of the crush (= A), then measuring the distance down to the peak of the sacrum (= B), and finally subtracting B from A.

[20] Fordyce *et al* (2013a)

3.3.1.8 Pregnancy status

For the CashCow project, heifers and cows with a normal non-pregnant reproductive tract were recorded under 'Pregnancy status' on the Enterpad as 'E' (empty). Females that had recently calved or aborted (mid to late term) and had palpable signs of an involuting uterus (cervix enlarged, one or both horns markedly enlarged, uterine wall palpably thickened, tract hanging over the pubis) were recorded as 'R' (resolving). Females with palpable abnormalities of the reproductive tract (foetal mummification or maceration, pyometra, endometritis or metritis, adhesions or abscesses, cystic ovarian disease) were recorded as 'A' (abnormal). For pregnant females, the stage of gestation was estimated using the Australian Cattle Veterinarians guidelines. For females up to five months pregnant, stage of gestation was estimated in increments of 0.5 months and for those greater than five months pregnant, one month increments were used. **Figure 8** shows the frequency distribution of the interval between pregnancy diagnosis and predicted calving by country type.

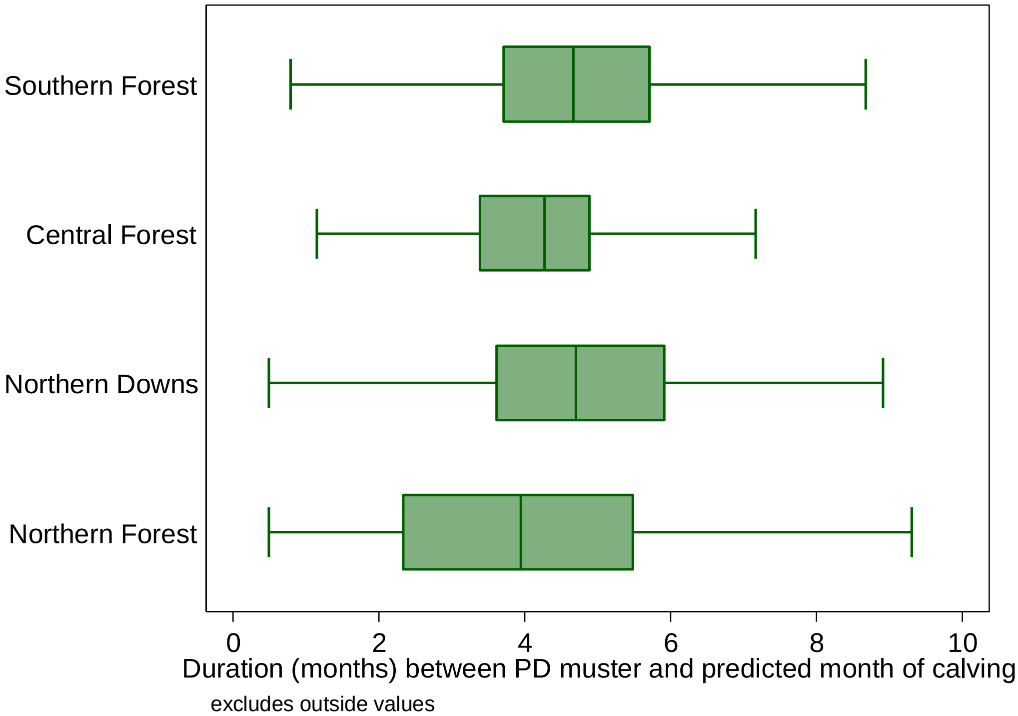

Figure 8: Duration (months) between the pregnancy diagnosis muster and predicted month of calving.

3.3.2 Nutrition

3.3.2.1 Stocktake training

To establish a link between reproductive performance and nutritional/environmental influences, a way of monitoring key measures across all properties was required. The location of properties across northern Australia precluded project staff carrying out these measurements, which meant the co-operating property managers and their staff were trained to do this.

To ensure consistency of all nutritional/environmental monitoring, CashCow producers and their key staff were required to attend training days to develop the necessary skills for measuring and reporting nutritional and environmental parameters. The *Stocktake* program[21] team delivered the training, with a CashCow coordinator at each workshop.

Stocktake is a paddock-scale land condition and monitoring package for grazing land managers to assess the condition of their resource. It is a one day workshop covering technical concepts of land management and demonstrates field techniques to record and monitor pasture and land condition.

The *Stocktake* training package was an off the shelf product which could be used immediately to train CashCow producers in collecting the relevant project information. Twelve workshops across northern Australia were held at the beginning of the project (**Figure 9**).

Figure 9: Map of Stocktake workshops for CashCow producers.

Nutritional data collected by the cooperating properties included faecal samples for estimates of diet quality using Near Infrared Reflectance Spectroscopy (NIRS), estimates of pasture quantity, and records of supplementation. The sampling protocols were based on MLA project B.NBP.0303[22]. Information was stored on an Access database and regular reports (**Appendix VI**) for each property were generated using a program developed by Evan Sergeant from the AusVet team.

[21] Aisthorpe *et al* (2004)
[22] Jackson *et al* (2009)

3.3.2.2 Diet quality

Diet quality was estimated by collecting fresh faecal samples and analysing them using faecal NIRS (F.NIRS) for dry matter digestibility (DMD) and crude protein content (CP)[23]. The ratio of CP to DMD was used to estimate the risk of protein deficiency adversely affecting performance. A calculation of diet metabolisable energy (ME, which is the energy extracted from pasture by cattle and used for maintenance and production – expressed as megajoules per kg of dry matter eaten) was made from F.NIRS estimates of dietary DMD.

Faecal phosphorous (P) was determined using wet chemistry techniques[24]. The concentration of phosphorous in submitted faecal samples was determined using a method based on that described by Zarcinas *et al*[25]. Briefly, approximately 0.3 g of sample was digested with 6 mL nitric acid and 2 mL perchloric acid and then made up to 20 mL with RO water. The digested samples were analysed using an inductively coupled plasma spectrometer[26]. The ratio of P to ME was used to estimate the risk of P deficiency adversely affecting performance. This ratio is based on fundamentals of nutrition: because the P required will be closely related to the ME intake it can be expected that the ratio will be a more generalized measure, at least within a class of animal. It is comparable to expression of diet nitrogen requirements on a diet concentration basis, although most if not all feeding standards would express them in relation to the ME concentration of the diet. Also, from a management recommendations aspect, the FP:ME ratio changes much less than does FP as liveweight gain of the animal increases from nil to a high liveweight gain; therefore a recommendation is less dependent on estimating the level of productivity of the animals in the specific situation.

Fresh dung samples were collected from the paddock where each CashCow mob was located in January, March, May, August and November. If these sampling months coincided with an animal recording date, dung samples may have been extracted per rectum. If, for logistical or other reasons, a sample was not collected in the scheduled collection month every effort was made to ensure a sample was collected in the month following. Supplements were not withdrawn prior to any sampling.

The faecal sample collection protocols were the same for both phosphorous and NIRS analysis. The protocol was as follows:

1. Fresh faeces were required and were usually collected at watering points, supplement stations or cattle camps.
2. Care was taken to avoid contamination with soil or plant material or dung beetles.
3. Samples from approximately 10-15 different animals were combined to make a composite sample. The composite sample was placed in an appropriate, labelled container, such as a zip-lock plastic bag for storage and despatch. The sample was frozen as soon as possible after collection.
4. As fresh faecal samples cannot be sent via post, the samples were sun dried as follows:

[23] Coates, (2004)
[24] Dixon *et al* (2007)
[25] Zarcinas *et al* (1987)
[26] Optima 7300 DV, PerkinElmer; Waltham, MA, USA

- The faecal sample to be dried was placed on a piece of clean, flat galvanized iron or other non-absorbent material
- The sample was spread out like a pancake to a thickness of 10mm or less
- After about 4 hours in the sun, the sample was turned over in one piece, if possible
- After another 4 hours, the sample was dry, depending on the weather. Once dry, samples were broken up and placed in a labelled brown paper bag and posted to the University of Queensland

3.3.2.3 Pasture quantity

At the time of faecal sampling, pasture quantity was determined by using photo standards[27] supplied in the CashCow manual. Co-operators could choose from twelve pasture communities typical of northern Australia to match to their monitor paddocks. They then visually estimated the average pasture quantity in the paddock as shown in **Figure 10**.

Estimated Pasture Yield						
Tick one box	<500 kg/ha	500-1000 kg/ha	1000-2000 kg/ha	2000-3000 kg/ha	3000-4000 kg/ha	>4000 kg/ha
	☐	☐	☐	☐	☐	☐

Figure 10: Extract from the CashCow NIRS field sheet (**Appendix VII**).

3.3.2.4 Supplementation

Co-operators were asked to keep records of any supplements fed. Amount fed, type, and dates fed were recorded both on the NIRS field sheet and separately on a supplementation template. Calculations of supplement intakes were based on these records.

3.3.2.5 Mob-level assessment of body condition score

At the time dungs samples were collected, co-operators were asked to estimate and record the percentage of lactating and non-lactating females in each body condition score (1 to 5; **Appendix III**). Co-operators also recorded whether they considered females were losing, holding, or gaining body condition.

3.3.2.6 Stocking rate

Where carrying capacity is exceeded by excessive stocking rates, pasture becomes limiting and breeder production falls. The link between stocking rate and reproduction can be defined as follows:

Reproduction is a function of (f) *BCS*

BCS (f) Nutrition

[27] Anon. (2004)

Nutrition (f) Quality & quantity (pasture)

Quality & quantity (f) Stocking rate

Several alternatives were considered to measure stocking rates including attempts to assign regional stocking rates, long term carrying capacities, and GRASP modelling. To attempt any of these with limited resources, across 547 paddocks, a range of grazing management, and fluctuating animal numbers was not possible.

Considering these complexities, the focus was on quality and quantity of pasture, a direct result of stocking rate. Our simple risk factor question was 'Is pasture quantity limiting and affecting breeder production?'

Cooperating properties estimated pasture yields 6 times a year with the aid of photo standards. At the same time faecal samples were collected and submitted for NIRS and Phosphorous analysis. Pasture yield at the end of the growing season (May sample) was a key determinant of whether quantity would become limiting before the seasonal break.

3.3.3 Environmental data collection

3.3.3.1 Land condition

Land condition can be defined as the capacity of grazing land to respond to rain and produce useful forage. A desktop land condition assessment of the paddocks grazed by enrolled mobs was conducted by co-operators with project coordinators following the Stocktake program training and recorded onto a data capture template.

The ‘ABCD’ land condition framework[28] is the northern beef industry standard used in MLA’s *EDGE Network Grazing Land Management* and *FutureBeef Stocktake* education packages.

This framework describes land condition in four categories, from good (A) to very poor (D).

‘A’ CONDITION

In general, ‘good’ or ‘A’ condition has all the following features:

- Good coverage of perennial grasses dominated by those species considered to be 3P grasses for that land type; little bare ground (<30%)
- Few weeds and no significant infestations
- Good soil condition, no erosion and good surface condition
- No sign or only early signs of woodland thickening

‘B’ CONDITION

Generally ‘fair’ or ‘B’ condition has at least one or more of the following features, otherwise similar to ‘A’ condition:

- Some decline in 3P grasses, increase in other species (less favoured grasses and weeds) and/or bare ground (>30% but <60%)

[28] Chilcott *et al* (2003)

- Some decline in soil condition, some signs of previous erosion and/or current susceptibility to erosion is a concern
- Some thickening in density of woody plants

'C' CONDITION

In general, 'poor' or 'C' condition has one or more of the following features, otherwise is similar to 'B' condition:

- General decline in 3P grasses, large amounts of less favoured species and/or bare ground (>60%)
- Obvious signs of past erosion and/or susceptibility currently high
- General thickening in density of woody plants

'D' CONDITION

Generally, 'very poor' or 'D' condition has one or more of the following features:

- General lack of any perennial grasses or forbs
- Severe erosion or scalding, resulting in hostile environment for plant growth
- Thickets of woody plants cover most of area

Using a specifically designed data capture template, paddocks were listed and described in broad land types (as described by the co-operator). The proportion of the paddock within these land types was estimated, and the percentages of ABCD land conditions were estimated for each land type.

3.3.3.2 Distance to water

Five hundred and thirty two (532) paddocks were digitised from either paper based maps, satellite maps, existing digital maps, or GPS points. Information from 314 maps contributed to the data. The additional 218 maps did not contribute as they were not used by the monitor mobs. Ninety six (96) paddocks that contributed data were not mapped due to information either not available or not forthcoming. Where short time duration (Cell) grazing using small paddocks occurred, those paddocks were classified as one paddock. Where paddocks were subdivided but the gates left open, or paddocks judged as insecure (poor fences), these were classified as one paddock.

Paddock areas were calculated using the ArcMap GIS program. To describe how evenly paddocks were utilised, particularly during the dry season, permanent water points were considered more important than ephemeral water and added to the digitised maps. AgData's Phoenix mapping software was used to calculate areas within 1.5, 2.5, >2.5 km from water points.

3.3.4 Property management

Property management data were collected in two stages of the project.

Stage 1: Initially, each cooperating property was visited by a regional coordinator to discuss project details and collect information on the property's resources and cow/heifer management using survey templates (see attached CashCow manual). This was only updated if there were significant changes during the course of the project. Key information in the resource survey included an overview of property location, rainfall, value, pests and known disease, herd size, and fence security. The cow/heifer survey included mustering technique, supplementary feeding, vaccination programs, and selection, joining, weaning, culling and genetic improvement policies.

A comprehensive bull selection and management survey was later developed and managed electronically via email (see attached CashCow manual).

Stage 2: Standardised templates were filled out by the co-operator to record day to day management for stocking history and mobs changing paddocks and submitted annually, or were completed during the annual visit by the regional coordinator, referring to the property's diary/book records.

3.3.5 Infectious disease monitoring

Monitoring for infectious causes of reproductive loss was conducted in 2009 and 2011, although a small number of properties that were not monitored in 2009 for logistical reasons or were enrolled later were monitored in 2010. A different sample of females was monitored in 2009 and 2011. A cross-sectional sampling method was used to collect between 10 to 30 blood samples from each enrolled mob at the time of the wet/dry muster and then again from the same females at the pregnancy diagnosis muster. Most heifer mobs were only sampled once at the pregnancy diagnosis muster. Also, at the pregnancy diagnosis muster vaginal mucus samples were collected from the same females selected for blood sampling. The following sampling guideline was used:

- For mobs of < 100 heifers/cows: 10-15 samples i.e., every 10th female, regardless of pregnancy or lactation status, presenting at the crush was sampled
- For mobs of 100-200 heifers/cows 15-20 samples were collected
- For mobs of 200-300 heifers/cows 20-30 samples were collected
- For mobs of > 300 30 samples were collected

All data collectors were trained in blood sample collection by coccygeal venepuncture and decanting of sera, and collection and processing of vaginal swab samples. Serum samples were decanted approximately 24hours after collection and then either frozen or shipped chilled to The University of Queensland where they were stored frozen in the 'CashCow serum bank' until all samples for the year were collected. All serological testing was conducted at the New South Wales Department of Primary Industries Elizabeth Macarthur Agricultural Institute. Vaginal swab samples were only collected at the time of pregnancy diagnosis. The cotton head of each swab was cut off and placed in a transport tube containing 4.5mL Tween 20 phosphate buffered saline. These samples were shipped chilled to The University of Queensland and were then frozen until assaying. ELISA testing for antibodies to *Campylobacter fetus venerealis* was conducted at the Queensland Government's diagnostic veterinary laboratory at Toowoomba.

Although the serological sampling strategy used could have enabled determination of the rate of seroconversion for specific diseases, the laboratory testing strategy ultimately used was based on what would be commonly done by a veterinarian investigating a lower than expected reproductive performance problem i.e., samples for laboratory testing would be collected from females either at the time of pregnancy diagnosis or at the wet/dry muster. Wherever possible, the serological tests used were those that provided some indication of whether exposure to a specific infectious agent was recent or not. The criteria used to estimate the prevalence of recent infections in each mob are provided below under details for each infectious agent monitored.

The number of females sampled from each mob was based on recommendations provided by Dr John Morton and are summarised in **Table 6**, which shows the 90% confidence intervals for various numbers of animals tested and for the various percentages that test negative[29]. For example, from the table, if 20 animals were tested and 10 (50%) were seronegative, the percentage of seronegative animals in the herd/group could be expected to be between 30% and 70%. Alternatively, if 30 animals were tested and 15 (50%) tested negative, the percentage of seronegative animals in the herd/group could be expected to be between 34% and 66%.

Table 6: Determining the precision of the serological profile with different numbers of animals tested.

% of animals tested that were seronegative	**Likely % of animals in herd/group that are seronegative**		
	10 animals sampled	20 animals sampled	30 animals sampled
0 (i.e., all tested positive)	0-26	0-14	0-10
30	9-61	14-51	17-47
50	22-78	30-70	34-66
70	39-91	49-86	53-83
100 (i.e., all tested negative)	74-100	86-100	90-100

Overall seroprevalence of each disease by class of animal and mob was determined from the counts of animals with a positive serological test result, which were then analysed using a negative binomial regression clustered for property, offset for number of animals sampled. Except for leptospirosis, estimates of overall seroprevalence included data from both vaccinated and unvaccinated mobs. A similar approach was used to determine the prevalence of recent infection using the counts of animals with serological test results indicative of recent infection, although only mobs in which females were not vaccinated for each specific disease were included in this analysis. Categories of seroprevalence and prevalence of recent infection were established after inspection of the distribution of data or according to published recommendations.

3.3.5.1 Testing to determine the association between vibriosis and reproductive performance

Vibriosis is a venereal disease caused by infection with *C. fetus subsp. venerealis*. It can cause transient infertility, early embryonic death, and sporadic abortion in cattle[30]. Typically, the earliest indication that an outbreak of vibriosis has occurred in a mob is the finding of a lower than expected pregnancy rate. This is when testing for the presence of this disease is most often conducted. The vaginal mucus samples collected from the enrolled mobs were tested for antibodies to *C. fetus subsp. venerealis* using an IgA enzyme-linked immunosorbent assay (ELISA[31]) which has a reported specificity of 98.5%. ELISA results are reported as positive, inconclusive or suspect (low positive result), and negative. The estimated prevalence of positive

[29] Anon. (2008)
[30] Hum *et al* (1994)
[31] Hum *et al* (1994)

reactors for heifer and cow mobs was determined. The prevalence of positive reactors provides a useful estimate of the prevalence of *C. fetus subsp. venerealis* infection, which in turn provides an estimate of the risk of vibriosis affecting mob performance. The mob prevalence risk categories were Nil: 0%; Moderate: >0 to <30%, and High: ≥30% ELISA test positive. All animals from a mob were assigned the same risk category based on the serological findings for the sample of animals tested.

3.3.5.2 Testing to determine the association between bovine pestivirus infection and reproductive performance

Bovine pestivirus or bovine viral diarrhoea virus (BVDV) infection of naïve cattle around the time of mating and during the first four to five months of pregnancy can result in a wide range of losses, including lower than expected pregnancy rates and/or weaning rates and reduced turn-off of young cattle[32]. Sera from heifers sampled at the time of pregnancy diagnosis and from cows bled at the time of the wet/dry muster were tested for BVDV antibodies using an Agar Gel Immunodiffusion (AGID) test, conducted at the Elizabeth Macarthur Agriculture Institute, New South Wales. The sensitivity and specificity of this test have previously been estimated in unvaccinated cattle at 89% and 98%, respectively. The AGID test results were reported as follows based on previous findings[33]:

0 – animal is seronegative

1 or 2 – seropositive (timing of infection cannot be determined)

≥3 – seropositive and indicative that the animal has been exposed to pestivirus recently (i.e., in the past 1-9months)

Vaccination of cattle with the Pestiguard vaccine generally does not induce an antibody response detected by the AGID test. In vaccinated cattle, an AGID test result of ≥3 indicates recent exposure to pestivirus and in only a small proportion of cattle does it indicate systemic infection.

The estimated prevalence of seropositive females and prevalence of females with an AGID test result of ≥3 in heifer and cow mobs was determined, and prevalences for each variable were collated into quartiles. The mob prevalence of seropositives and AGID test results ≥3 was used to determine whether pestivirus was likely to be associated with lower than expected reproductive performance. The mob seroprevalence risk categories were Low: <20%, Moderate: 20-80%, and High: >80% seropositive, and the mob risk categories of recent BVDV infection were Low: <10%, Moderate: 10-30%, and High: >30% AGID test results ≥3. All animals from a mob were assigned the same risk category based on the serological findings for the sample of animals tested.

3.3.5.3 Testing to determine the association between leptospirosis and reproductive performance

Leptospirosis has been associated with abortions, stillbirths, and birth of weak calves in beef cattle herds[34]. Sera from females bled at the time of pregnancy diagnosis were tested for antibodies to *Leptospira borgpetersenii* serovar *hardo* type Hardjobovis (*L. hardjo*) and *Leptospira interrogans* serovar *pomona* (*L. pomona*). These generally have been identified as being the most common leptospiral

[32] McGowan & Kirland (1995)
[33] McGowan *et al* (1993)
[34] McGowan (2003)

infections in beef cattle[35] in northern Australia, and are also the serovars that have been associated with reproductive loss and are present in commercially available vaccines. Samples collected at the time of the annual pregnancy diagnosis muster in 2009 and 2011 were tested for antibodies to *L. hardjo and L. pomona* using the Microscopic Agglutination Test (MAT). Samples with a MAT titre of >100 for each serovar were considered positive and samples with an MAT of ≥800 were considered indicative of recent infection[36].

The estimated prevalence of seropositive females and prevalence of females with a MAT titre of ≥200 in heifer and cow mobs was determined. Vaccination of cattle with commercially available leptospirosis vaccines does induce MAT titres of ≥200 for periods of approximately six months after vaccination[37], and thus the seroprevalence for each serovar was only determined for mobs which did not report that females were vaccinated for leptospirosis. Also it is well recognised that following infection MAT titres rise and fall quite quickly (often within several months), with abortions often occurring when titres have decreased to low values. The interpretation of MAT titres of ≤400 can be problematic as they may be associated with recent infection or they may simply indicate past exposure. MAT titres of ≥800 generally indicate that infection is relatively recent in unvaccinated herds, and thus enables a more direct association between reproductive loss and infection to be established. The prevalence of recent infection risk categories were Low: <10%, Moderate: 10-30%, and High: >30%. All animals from a mob were assigned the same risk category based on the serological findings for the sample of animals tested.

3.3.5.4 Testing to determine the association between Neospora caninum infection and reproductive performance

Neosporosis is recognised worldwide as one of the most important infectious causes of abortion in cattle[38]. The primary sources of *Neospora caninum* are wild and domestic dogs and other canids, such as foxes. Abortions due to *N.caninum* have been reported in beef cattle in Australia. However, the results of a recent MLA funded study in northern Australia[39] found that although infection was widespread in some herds, evidence of significant foetal/calf loss was only occasionally observed. Samples collected at the time of annual pregnancy diagnosis in 2009 and 2011 were tested for antibodies to *N.caninum* using an indirect ELISA developed at EMAI[40]. The ELISA had been previously validated against panels of sera tested by both indirect fluorescent antibody technique and western blotting, and was shown to have a sensitivity of 100% and specificity of 99%[41].The prevalence of seropositives was used to determine whether *N.caninum* infection was associated with lower than expected reproductive performance. The mob seroprevalence risk categories were Nil: 0%, Low: 0-20%, Moderate to High: ≥20%. All animals from a mob were assigned the same risk category based on the serological findings for the sample of animals tested.

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[35] Black *et al* (2001)
[36] Smith *et al* (1994)
[37] Smith *et al* (1994)
[38] Dubey *et al* (2007)
[39] Kirkland *et al* (2012)
[40] Bjorkman *et al* (1997)
[41] Kirkland, unpublished data

3.3.5.5 Testing to determine the association between Bovine Ephemeral Fever (BEF) virus infection and reproductive performance

BEF virus infections occur commonly in cattle across northern Australia, particularly during the summer-autumn period. Infection of naïve pregnant females has been reported to result in increased rates of abortion. In 2011, samples from females bled at the time of the annual pregnancy diagnosis muster were tested using a virus neutralisation test (VNT) for antibodies to BEF virus[42]. Samples with a VNT titre of >40 were considered positive and those with a titre of >640 indicative of recent infection. The prevalence of seropositives and recent infections was used to determine whether BEF virus infection was associated with lower than expected reproductive performance. The mob seroprevalence risk categories were Low: <20%, Moderate: 20-80%, and High: >80% seropositive, and the mob prevalence of recent infection risk categories were Low: <10%, Moderate: 10-30%, and High: >30% BEF VNT titres ≥640. All animals from a mob were assigned the same risk category based on the serological findings for the sample of animals tested.

3.3.5.6 Testing to determine the association between Coxiella burnetti infection and reproductive performance of breeder herds in Queensland

Coxiella burnetti infection is the cause of Q-fever and has been associated with sporadic abortion in cattle. As part of a study conducted by researchers at James Cook University[43], sera collected from 46 Queensland breeder mobs at the time of pregnancy diagnosis in 2009 were tested by ELISA for both phase II and phase I antigens of the organism using an Australian isolate. The ratio of the sample optical density to the positive control optical density was calculated for each sample and expressed as a percentage (S/P%). Samples with an S/P% of >50% to either or both Phase II and Phase 1 antigens were considered to be positive. As testing for *C. burnetti* was only performed in Queensland, analysis of the impact of infection on reproductive performance was not possible, due to significant missing data.

3.4 Data Collation and management

Data were managed using four main databases established in Microsoft® Access. Data management and flow is summarised in **Figure 11**.

[42] Cybinski (1987)
[43] Cooper *et al* (2011)

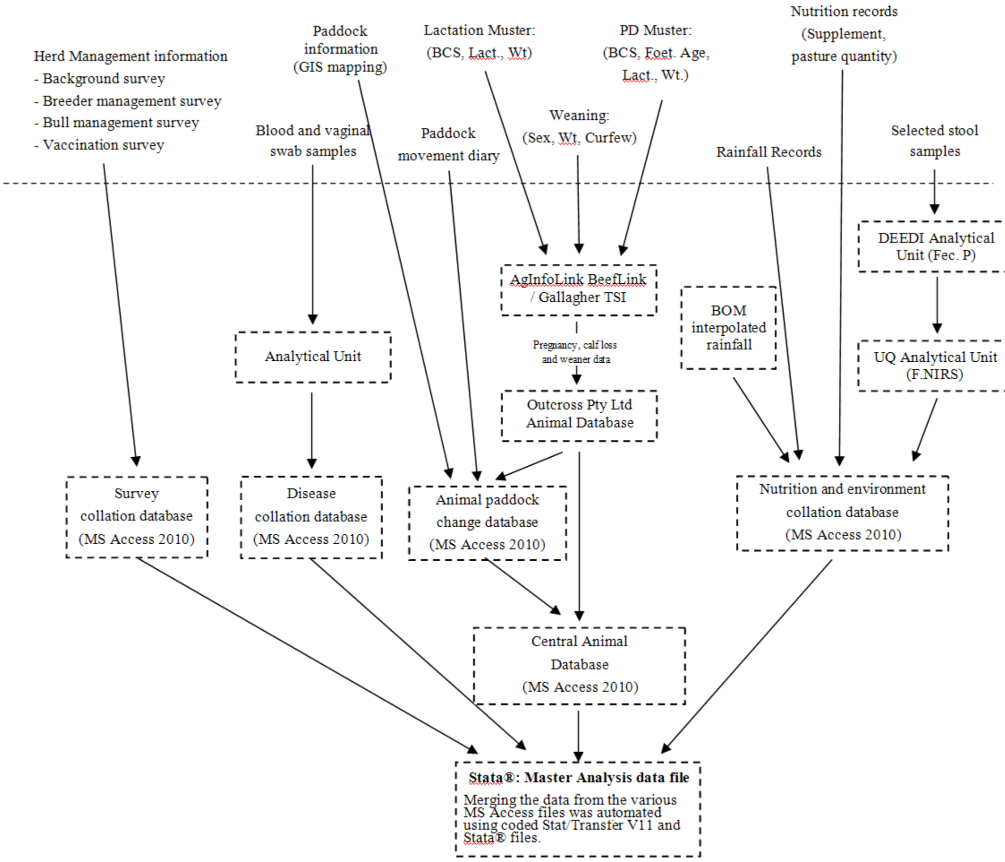

Figure 11: Schematic of overall data collation and management.

3.4.1 Collation and cleaning of animal data

Data collected on animals at the crush were stored locally on a laptop and then sent via FTP to a central server managed by Outcross. Multiple backup copies of all data files were generated within Outcross for data security. Individuals responsible for data collection at each site also submitted a separate Processing Report to Outcross.

Rules-based processes were used within the Outcross system to check and clean data and remove duplicate or erroneous records. Duplicate data could include things such as the data collector recording for example Lactation Status = Dry and then changing it to Wet; the initial recorded Lactation Status would be removed. Erroneous data could include things such as weights that were obviously outside a normal range.

Cleansed data were stored by Outcross as redundant copies of a Master database and increments from this database were then forwarded to the CashCow Project Manager on a monthly or bi-monthly basis for inclusion in the project database. Also, at this stage summary reports (either a Pregnancy Test Report, a Wet & Dry Report or a Weaning Report – **Appendix VIII**) were generated and sent to the co-operating producers. The Pregnancy Test and Wet & Dry Reports included historical data to build a picture of cow performance.

As an additional check that all data had been accounted for, a Data Collection Log was kept. This file incorporated such information as the start and end dates for each lot of property data collection, the property code and Mob ID, whether it was a pregnancy testing or wet/dry round, the number of cows processed, the name of the data collector, whether a report had been generated and forwarded to the collaborator, and any notes on the data collection. The Data Collection Log was forwarded to the CashCow Project Manager along with the ‘cleaned’ data file.

Data were extensively verified retrospectively using a number of different methods, which included a large number of queries written in Microsoft® Access and contingency tables using SAS® and Stata®. These approaches were used to identify and resolve duplicate records and situations where biologically implausible or illogical data entries indicated likely data entry errors. Where possible, these issues were resolved such that valid data were retained. In addition, a master file was maintained of animal identification records (incorporating RFID and visual tag details) that allowed traceability of records in cases where one or the other identification was not recorded on any occasion or where an animal had a RFID tag replaced.

3.5 Data analysis

The following section details the derivation of animal, nutritional, and property variables used in final statistical analyses. A more comprehensive list of candidate risk factor variables is provided as **Appendix IX**.

3.5.1 Measures of reproductive performance

All measures of performance (outcome variables) were derived from individual animal data. Most were generated for an annual production cycle (period between pregnancy testing muster in one year to the pregnancy testing muster the following year); those variables that did not relate to this period have been defined specifically. It is recognised that an annual production cycle was not exactly equal to one year on all occasions but this period fits in well with the annual management for most northern beef properties.

3.5.1.1 Annual lactation status

Lactation status at any one observation was recorded as ***wet*** or ***dry*** based on whether or not the animal was showing signs of being suckled at the time of each observation. Annual lactation status for each animal was based on aggregation of the lactation status records from each mustering occasion during the annual period. Animals that were recorded as ***wet*** at either one or both mustering occasions during the annual period were given an annual lactation status of ***wet.***

A missing value was assigned if there was uncertainty as to whether the female had lactated or not. The most common situation for this was where a female previously recorded as being pregnant failed to be mustered at the first muster the following year and was recorded as dry at the subsequent muster.

3.5.1.2 Annual pregnancy status

Annual pregnancy status was defined as a single record for each annual period and each female that was enrolled in the study and exposed to mating in a given year. The variable was given the value ***1*** if the animal was determined to be ***pregnant*** with conception occurring after September 1 in the previous year and prior to September 1 in that year, and ***0*** otherwise. The first day of September was defined as the start of the joining period as that allowed the resulting progeny to be weaned the following year in continuously mated herds. Animals coded as ***0*** included those that were not pregnant (***empty***) in the defined time period or that conceived after September 1 in the current year.

Pregnancy status of animals was generally determined by pregnancy diagnosis and foetal ageing. If foetal ageing was conducted late in the year, conceptions occurring after September 1 were attributed to the next annual production cycle. Alternatively, advanced pregnancies detected early in the following year (weaning/branding muster) were attributed to the current annual production cycle.

There were occasions where annual pregnancy status for animals was dependent on data checking procedures. For example, an animal that was recorded as empty or was not recorded at the pregnancy testing muster in one year and subsequently presented as lactating the following year was retrospectively assigned an annual pregnancy status of ***1*** (pregnant) for the previous annual period, but such females were not assigned a predicted month of calving.

3.5.1.3 Pregnant within four months of calving (P4M)

Pregnant within four months of calving (P4M) was defined as a binary variable with 0=failed to be pregnant within four months of calving and 1=pregnant within four months of calving. P4M was only determined for those cattle that were lactating at the time of conception (i.e., reared their calf).

Foetal ageing in the previous and current production cycles were used to predict dates of calving and re-conception, which were then used to generate P4M. The predicted month of calving was calculated using estimated foetal age at the date of the pregnancy test muster and projected forward using an assumed gestation length of 287 days. As foetal age was recorded in months, it was multiplied by 30.4 days per month to estimate foetal age in days. The predicted date of conception was then estimated using the foetal age data from the pregnancy test muster in the current year. Females that had an inter-calving interval of ≤13 months (or 108 days/3.5 months since predicted calving) were defined for the purpose of this report as pregnant within four months of calving.

Animals were not eligible for classification under P4M if they were recorded as having been not-pregnant in the previous annual period or if they had failed to rear a calf. Females were recorded as successfully rearing a calf if they were diagnosed as being pregnant and were then recorded as wet after the expected calving date. Females were recorded as having failed to rear their pregnancy if they were recorded as being dry at the first muster after the expected calving date, provided this muster occurred greater than one month after the expected month of calving, and they were not subsequently recorded as lactating. P4M was recorded as missing for those animals that did not meet eligibility criteria.

Two categories of this variable were considered in preliminary analyses: pregnant within three months of calving (P3M) and P4M. There were pros and cons associated with the use of either category (**Figure 12**).

If a cow is to achieve a 12-month intercalving interval, and assuming a 9.5 month gestation, then she has to conceive within about 2.5 months of calving. Preliminary analyses of data obtained from the Beef CRC (including observed calving dates and detailed data on conception dates) indicated that very few cows (about 10%) maintain a 12-month intercalving interval over their breeding life.

To further investigate this issue, the intercalving intervals of cows in different country types and with different durations of mating were analysed (**Appendix X**). As would be expected, the duration of mating affected the pattern of intercalving intervals, but surprisingly, the pattern for mobs mated for ≤3 months was similar to mobs mated for

4 to 7 months. In most cases a distinct peak in calving interval was observed, except for the Northern Forest where there were typically two smaller peaks about three to five months apart, most likely reflecting the impact of weaning on conceptions. Also, examination of the pattern of intercalving intervals by cow age class and country type indicated that in reality the peak interval occurs between about 12 to 13 months, supporting the use of the measure P4M. Using the measure P3M would underestimate the population of cows described by the observed peak in calving pattern.

Many producers in extensive beef producing areas use foetal ageing to assign pregnant cows to a three month calving window (for example, expected to calve between Oct to Dec). Management strategies may be different depending on what calving window a cow may be assigned to, and also properties may attempt to have cows calve in the same three month window in consecutive years. Examination of Beef CRC records indicated that for those cows that calved in the same three month window in consecutive years, the percentage of cows conceiving within 2, 3, or 4 months of calving was 17%, 64% and 90%, respectively. This finding suggested that P4M was likely to provide the best estimate of the proportion of cows likely to wean a calf in consecutive years.

Preliminary analyses of CashCow data suggested that there was a significant risk that individual properties may have no animals conceiving in some age classes within three months of calving, which would present problems if P3M were to be used as an outcome variable in the multivariable analysis.

There were also concerns over the accuracy of foetal ageing (**Appendix I**). The estimate of time from calving to conception was based on two separate foetal ageing records, and depending on the stage of gestation when the cow was examined the foetal age may either have been overestimated or underestimated by approximately 0.5 months. However, the direction of the errors in foetal ageing are not consistent and thus the estimated intercalving interval for a cow with an actual intercalving of 12 months could range between 11 and 13 months.

After reviewing all of this information a decision was made to proceed with P4M.

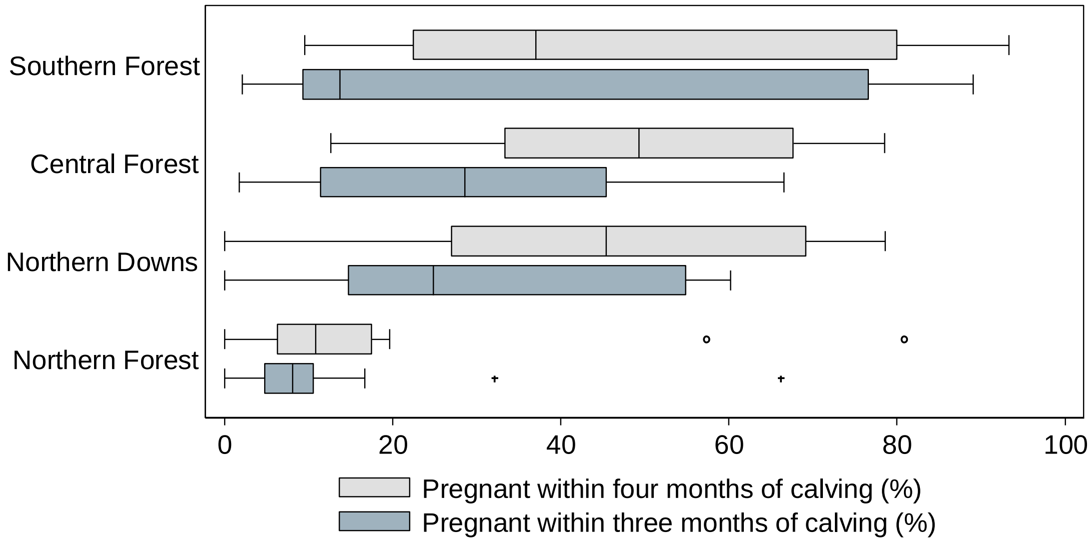

Figure 12: Box and whisker diagram summarising P3M and P4M by country type for first-lactation and second-lactation females.

3.5.1.4 Estimated Month of Calving

The predicted month of calving was calculated using estimated foetal age at the date of the pregnancy test muster and projected forward using an assumed gestation length of 287 days. As foetal age was recorded in months it was multiplied by 30.4 (365/12) days per month to estimate foetal age in days.

In instances where a foetus had been aged twice, recorded foetal ages less than five months were considered to have a higher degree of accuracy than ≥ 5 months (**Appendix I**).

3.5.1.5 Foetal/Calf loss

Females were recorded as successfully rearing a calf if they were diagnosed as being pregnant and were recorded as lactating (wet) at an observation after the expected calving date.

Females were recorded as having experienced foetal/calf loss if they were recorded as being pregnant in the previous year and were then recorded as not lactating (dry) at the first muster after the expected calving date, if this muster occurred more than one month after expected month of calving and they were not subsequently recorded as lactating (for example, at the pregnancy diagnosis muster for that year).

3.5.1.6 Contributed a weaner

Contributing a weaner was defined as a binary variable coding for whether or not a female was recorded as having weaned a calf in the current year. This was used to generate aggregated animal-level data summaries such as a weaning rate estimate for properties by years.

Females were recorded as having successfully weaned a calf if they were diagnosed as being pregnant in the previous year and were recorded as lactating (wet) at an observation after the expected calving date.

Females were recorded as having failed to wean a calf if they failed to become pregnant in the previous year or were recorded as having experienced foetal/calf loss in the current year.

3.5.1.7 Liveweight of weaners

The mean liveweight of weaners was determined using a simple arithmetic mean (total of all weaner liveweights divided by number of weaners weighed). Properties that submitted data from less than 30 animals were excluded from the analysis for that year.

Due to a subset of liveweights being recorded for larger mobs and weaning being conducted at different times throughout the year in continuously mated properties, adjusting the average weaner liveweight according to the proportion of weaners weaned at different times of the year was explored. The percentage of those cows that presented as lactating at the weaning/branding muster and that presented as non-lactating at the pregnancy-muster was used as an indicator of the proportion of progeny that were weaned at the first muster. Cows that were predicted to have calved by the pregnancy testing muster were removed from the calculation. As there was good agreement between the adjusted and un-adjusted average liveweight of weaners, the unadjusted average weaner weight was used.

3.5.1.8 Missing pregnant cows (mortality)

Annual percentage of pregnant cows missing was defined as the percentage of cows that had been enrolled in the study and diagnosed pregnant, but without any record of being ***culled***, did not contribute any further data at any of the subsequent musters.

Any animal that was not present at one or more musters and that then turned up at any subsequent muster right through to the end of the project was classified as ***absent*** for the earlier musters when it had not been present. An absent animal was therefore any animal that failed to be yarded for an observation period but that was known to be alive because it subsequently turned up at a later mustering period.

An animal could therefore only be classified as missing once the study had concluded and all possible observation periods could be reviewed to ensure that animals were not classified as missing if they had appeared at any subsequent mustering period.

Animals that were known to have died were classified as missing from when they were known to have died.

Pregnant cows classified as missing were considered to provide an indirect record of mortality, given that many extensive beef properties are not able to observe cattle in order to accurately determine mortalities.

The outcome, percentage of pregnant cows missing, is likely to be an over-estimate of mortality as it includes cows that lost their lifetime traceability due to loss of NLIS tag, or were un-reportedly relocated within the property and not sold before the end of the project.

During the data cleaning process some properties were identified with a higher than expected number of animals meeting the missing criteria. A possible explanation for this was that some of the ‘missing’ females might have been culled and not recorded as culled. In this situation the count of missing animals may have been unnecessarily biased as an indicator of mortality.

An attempt was then made to check project records by contacting participating properties to seek information on any animals that may have been transported off the property during the course of the project. Individual electronic identification (EID) records were obtained from the national NLIS database for all transfers off the property from 63 of the participating properties. Two properties provided assurances that no breeding females were sold off the property and five properties were not able to provide the data for various reasons. NLIS transfers were not requested from eight properties as all enrolled cows had been accounted for in the data.

The NLIS transfer files were manually collated producing a data file pertaining to 402,962 individual animal transfers. This data file contained data relating to the EID of the animal, the date the transfer occurred, and the property identification code the animal was being transferred to. Cross-referencing the NLIS transaction file against the CashCow data resulted in identification of 4,693 animals that had been recorded as ***missing,*** identified 27.7% (4,693/16,943) of breeding females suspected of potentially dying that actually had been culled from the property i.e., 27.7% (4,693/16,943) of breeding females suspected of potentially dying had actually been culled from the property. These animals were recoded so they were not recorded as missing in the dataset.

3.5.2 Estimating annual incidence of NLIS tag replacement (tag loss)

The National Livestock Identification System (NLIS) provides whole-of-life traceability for cattle in Australia and all animals must have an NLIS compliant, radio frequency (RF) device (typically an ear tag) inserted before they are moved from their property of birth to any other property. If an NLIS device is lost or becomes unreadable for any reason then under Australian legislation it must be replaced with a workable device.

When animals enrolled in the CashCow project were processed as part of the project, their NLIS devices were scanned as the primary means of animal identification. This provided an opportunity to assess tag loss rates in the enrolled population of cattle.

The dataset used in this analysis was restricted to those properties that recorded cattle identity using both NLIS and visual tags, and that recorded details of replacement of NLIS tags. The dataset included data on 8,565 NLIS devices recorded across 30 individual properties during the study period. Of these, 4,131 NLIS devices across 26 properties were believed to have been applied to the animals within the 12 months previous to the animal being first recorded. Records from animals that were lost to follow up (missing and dead animals) were excluded from this analysis.

The starting dataset was structured such that one row of data represented one NLIS device with a binary outcome defined as 0=NLIS device not replaced and 1=NLIS device replaced during the study period. The period at risk of losing a tag was used as an offset in the analysis and was defined as the duration (months) from being first recorded until the animal's involvement in the study ceased or, for NLIS devices that were lost, the mid-point between the date of last scanning and the date the tag was replaced.

Two forms of censoring (right and interval) need acknowledging for this dataset. Censoring is defined as the occurrence or possible occurrence of a failure when the animal is not under observation[44]. As most properties mustered animals biannually, interval censoring is likely as tag loss could only be assessed periodically at these musters. Therefore, the precise time a tag was lost was not known and the mid-point between the date of last scanning and the date the tag was replaced was assumed. Right censoring occurred due to the animal's involvement in the study stopping (either due to being culled or study ended) before the tag loss occurred. Some left truncation of the data also exists as animals were tagged prior to the study and no information regarding tag loss was captured.

Animal records were clustered within property and property was incorporated as a random effect in Poisson models used to estimate incidence rates for tag replacement. Clustering at the property level ensured that the statistical output was adjusted for possible unmeasured effects at the property level, including factors such as variation in application technique, using tags from a particular manufacturer, level of woody vegetation on the property, and management practices such as plunge dipping.

Microchips within NLIS devices are encoded with a number that is unique and unalterable. Microchip numbers, when read electronically with a suitable reader, are generally 16 characters in length, where the first three identify the manufacturer. This manufacturer's code was used to identify the brand of tag in the following analysis. The manufacturer codes used were as follows: 900 – Gallagher/Drover's Ay-One; 951 – Leader/AnimalLife ID/Duo Tags; 964 – Datamars; 982 – AllFlex.

Two separate analyses were conducted. A survival analysis was performed and a Kaplan-Meier estimate of the survivor (failure) function completed using a restricted dataset that included only those animals which were believed to have been tagged within the 12 months prior to being first recorded for the purposes of the CashCow project. This dataset included all heifers on properties that were considered to have accurately recorded tag replacements and breeder mobs that were known to have been tagged for the purpose of being involved in the CashCow project. The survival analysis model was not adjusted for clustering due to property level effects. The survival analysis model analysed the time from tag insertion to tag failure or loss.

A second analysis involved Poisson regression to model the incidence rate of replacement tags as a measure of tag loss per unit of animal-time. The dataset used to model the incidence rate of tag replacement was conducted using a larger dataset, which included all animals on those properties where there was evidence of conscientious replacement of lost tags. Whether or not the NLIS tag was reported to have been applied in the previous 12 months prior to the start of the CashCow project was included as a predictor in the incidence rate model.

3.5.3 Data inclusion and exclusion rules

The inclusion of individual animal data for risk factor analyses was determined by animals providing information on either rearing a calf or re-conception (including those animals that were previously non-pregnant) for at least one reproductive cycle. Therefore, heifers that were culled at pregnancy testing (induction) were excluded from the dataset and cows that were either culled at their first wet/dry muster or pregnancy diagnosis muster were also excluded from the analysis dataset. Animals that were culled at their first muster have not been included in the analysis file as

[44] Dohoo *et al* (2009)

they lack explanatory data that can be used to investigate risk factors associated with maiden heifers becoming pregnant.

The inclusion of individual animal data for descriptive analyses was determined by animals providing information on either pregnancy, rearing a calf, or going missing.

For those mobs where a muster took place but the data were not captured, all animal records for that management group were excluded from all analyses for that reproductive cycle.

3.5.4 Derived nutritional and environmental variables

The following section details how some of the reported nutritional and environmental variables have been derived. For simplicity and consistency with other publications (e.g., Phosphorous management of beef cattle in northern Australia), the ratios CP:DMD and FP:ME are referred to in this report as whole values, i.e., an FP:ME ratio of >500:1 is expressed as >500.

3.5.4.1 Ratio of crude protein to dry matter digestibility (CP:DMD)

The ratio, CP:DMD, provides a measure of the availability of rumen degradable nitrogen to metabolisable energy in the diet. A liveweight response to supplementary rumen degradable nitrogen can be expected in cattle grazing tropical pastures when the DMD:CP ratio exceeds 8–10[45] (CP:DMD less than 0.1-0.125).

The average ratio CP:DMD was derived for both the wet (November 1 – April 30) and dry (May 1 – October 31) seasons for each year. Faecal samples were required to be collected during the months November, January, March, May, and August in all paddocks occupied by project cattle. The CP:DMD ratio was calculated per submitted sample and averaged across all samples collected within the time period of interest for each property.

Deriving the ratio of CP:DMD for each analytical mob was explored by relating all animal-paddock transfers to NIRS results. However, due to not all paddocks having faecal samples submitted and results varying relatively little between paddocks, property averages were used to maximise the animal data contributing to the analyses. The reasons for faecal samples not being submitted were varied; examples were major flooding and paddock access during the wet season.

3.5.4.2 Ratio of faecal phosphorous to metabolisable energy (FP:ME)

Since the amount of phosphorous needed depends on the amount of energy the animal is consuming, the need for phosphorous can be estimated from the ratio of the phosphorous concentration in faeces and the level of dietary energy[46].

The average ratio FP:ME was derived for the wet season (November 1 – April 30) each year. Faecal samples were required to be collected during the months November, January, and March in all paddocks occupied by project cattle. The FP:ME ratio was calculated per submitted sample and averaged across all samples collected during November 1 – April 30 for each property.

Deriving the ratio of FP:ME for each analytical mob was explored by relating all animal-paddock transfers to NIRS results. However, due to not all paddocks having

[45] Dixon and Coates (2005)
[46] Jackson *et al* (2012)

faecal samples submitted and results within properties varying relatively little across paddocks, property averages were used to maximise the animal data contributing to the analyses. The reasons for faecal samples not being submitted were varied and examples were major flooding and paddock access during the wet season.

Faecal phosphorous was determined using wet chemistry techniques. It should be noted that at various times some properties provided supplemental phosphorous at varying intakes. Although it is best practice to remove animals from supplemental phosphorous one to two weeks prior to dung sample collection, it is likely that the faecal phosphorous results have been derived on some animals that were consuming supplemental phosphorous.

The metabolisable energy (ME) level of the diet was calculated from the dry matter digestibility (DMD) as estimated from faecal near infrared spectroscopy (F.NIRS) using the equation $ME = 0.172\ x\ DMD - 1.707$.

3.5.4.3 Onset of wet season

The wet season onset was derived using interpolated daily rainfall information that was downloaded from the Australian Bureau of Meteorology (BOM) using the GPS location for the paddock or homestead. The wet season onset was defined as the date at which an accumulation of 50 mm of rainfall was reached in 14 days or fewer, starting from any day after September 1 (but before March 31).

3.5.4.4 Days after wet season onset to follow up rain

Using interpolated daily rainfall information for the GPS location of a paddock or homestead from the Australian Bureau of Meteorology (BOM), the number of days following the wet season onset until another major rainfall event was derived. A major rainfall event was defined as an accumulation of 50 mm of rainfall in 14 days or fewer. Therefore, the number of days to follow up rain after wet season onset was calculated by determining the number of days between the first two sequential rainfall events.

3.5.4.5 Temperature humidity index (THI)

An index combining temperature and humidity (THI) has previously been used to investigate the effects of extreme climatic variables on livestock performance and welfare[47]. THI is an indicator of the heat stress in cattle. More elegant heat stress models are available and recommended, but these models require additional parameters, such as wind speed, which were not able to be interpolated and therefore have not been used.

Using interpolated temperature and humidity information for the GPS location of either a paddock or homestead from the Australian Bureau of Meteorology (BOM) the THI was estimated for each day using the equation:

$$THI = 0.8\ x\ Ambient\ temperature + \left\{\left(\frac{Relative\ humidity}{100}\ x\ (Ambient\ temperature - 14.4)\right) + 46.4\right\}$$

[47] Hahn *et al* (2009)

3.5.5 Multivariable analyses

The dataset was structured such that one row of data represented one annual production cycle for each animal. An annual production cycle was defined as beginning after the pregnancy test round of the previous year and ending with the pregnancy test round of the current year.

Separate multivariable models were built using logistic regression for the following outcomes, each of which was coded using a binary notation (0,1):

- Pregnant within four months of calving (P4M): 0=no, 1=yes
- Annual pregnancy status: 0=not pregnant or conceived after September 1 in the current year, 1= pregnant with conception occurring between September 1 of the previous year to September 1 of the current year
- Failed to rear – lower (FTR): 0=successfully reared a calf, 1=failed to rear a calf

An additional multivariable model using Poisson regression was used to analyse the percentage of pregnant cows missing (an indicator of mortality), where individual animal records were coded as zero (not missing) or one (missing) in each annual production cycle. The mortality analysis was restricted to pregnant cows because there was a high likelihood that non-pregnant cows in any one year may be culled as part of routine commercial management decisions and culled animals were then lost from follow-up.

Multivariable models were built using a manual stepwise approach[48]. 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 mob 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 mob level variables.

In some cases starting models did not converge, probably because of the large number of explanatory variables. In these cases a forwards step-wise model building process was used, starting with the most significant animal-level explanatory variable from the screening process and then adding all other candidate variables one at a time and retaining the variable with the lowest significant p-value. This process was continued until a final animal-level model was produced and then mob-level variables were added in the same way to produce a final main effects model. All omitted variables were then re-screened in the candidate main effects model, and retained if significant, to generate the final main effects model.

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

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[48] Dohoo *et al* (2009)

assessment of marginal means and plots of effects. Country type was forced into all models and two-way interactions considered between country type and other explanatory factors in the model, because of specific interest in the effects of region that were being represented by country type.

All logistic regression models incorporated a random effect coding for property identity to adjust for correlations between cows within the same property. Model checking involved generation of summary measures of goodness-of-fit and identifying any specific observations that did not fit the model, or were having undue influence on the model[49].

The Hosmer-Lemeshow goodness–of–fit (GOF) test compares the observed number of cases (outcome=1) to the expected number as determined from the statistical model, using groups based on deciles of estimated probabilities. A lack of fit was found in some models using the GOF test even though inspection of GOF output indicated that there was less than 2% difference between the observed and expected probabilities in each of the 10 deciles. The lack of fit based on the GOF test was considered likely to have been influenced by the large sample size, as previously described[50], and the close agreement between observed and expected deciles was interpreted as supporting model fit.

Variance partitioning was explored by considering intercept-only models with up to three nested random effects represented by observations within animals (level 1), within properties (level 2), within country-type (level 3), to produce starting estimates of variance at each of the three hierarchical levels in the datasets. An attempt was made to run final models with the same three random effects in order to be able to assess the effect of explanatory variables in the final model on variance remaining at each of the clustering levels. In some cases, full models did not converge with the additional random effects.

A similar model building approach was used for the multivariable Poisson regression model analysing mortality risk. The model incorporated a random effect coding for property to adjust for clustering of animals within each property and also an offset measuring the number of months each animal contributed to the time at risk during each annual production cycle.

When each multivariable model was built, a number of individual animal records were dropped from the dataset contributing to the final model for each outcome because they were missing data on one or more variables that were included in the final analysis. In a number of cases, this meant that some properties were also dropped where all animal records from some properties may have been missing data on one or more variables in the final model. Variables that were missing a large proportion of measurements (>40% missing data) were not considered for inclusion in the model but many variables were missing some data. This meant that the dataset that contributed to each final multivariable model was a subset of the starting dataset.

The multivariable modelling approach produced a final model that included only those explanatory variables (factors) that were both significantly associated with the outcome and where a biologically plausible explanation was considered to be consistent with the statistical association. The exception was country type which was forced into all models.

[49] Dohoo *et al* (2009)
[50] Paul *et al* (2013)

It is important to note that the marginal means derived for each variable were dependent on the other variables included in the final model. The purpose of the multivariable modelling process was to identify the major drivers for each outcome and to explain the effect each variable had on the outcome after adjustment for all other variables in the model.

The model building process meant that a number of candidate explanatory variables that were considered for inclusion in each multivariable model were not retained in the final model because they were not significantly associated with the outcome, or in some cases where the association was not biologically plausible. In other cases some explanatory variables were not considered for the multivariable model because of the level of missing data in the variables. It was recognised that there may be interest amongst stakeholders in having the impacts of these discarded explanatory variables described.

An attempt was made to explore the association between selected additional explanatory variables by back-fitting them one at a time to the final multivariable model. The term back-fitting is used to describe the practice of taking the final model and adding a selected explanatory variable to that final model, regardless of whether the added explanatory variable is significant or not. The resulting model output can then be used to generate estimates of predicted outcomes for the levels of the added variable of interest and these estimates are adjusted for the effects of all of the other terms in the final model. However, caution is urged to avoid over-interpreting the findings from back-fitting because it involves assessing the effects of variables that were either considered and not retained in the model building process, or were missing sufficiently large proportions of records that valid modelling may have been compromised.

All analyses were conducted in Stata, version 12 (www.stata.com).

4 Descriptive analyses and results

4.1 Evaluation of crush-side electronic data collection

Most heifers and cows were inducted at the initial wet/dry muster or pregnancy test muster in 2009. This included recording 20 different pieces of data per animal. Following the initial induction, each time a female was processed it would have between 12 and 14 records. Females could also have animal health treatments recorded, such as a Buffalo Fly treatment, which included the application date, type of treatment (e.g. dip) and the product brand.

In addition, blood and swab sample numbers would be recorded on those cows randomly selected for sampling. Therefore, during the main study a female could have up to 86 individual records; if the female was enrolled in the pilot study that increased the number of data records to close to 100. The amount of weaner data collected was significantly less due to it being collected only once, resulting in approximately 11 records per weaner. The estimated rates of processing females during the annual pregnancy test muster in 2010 are shown in **Figure 13**.

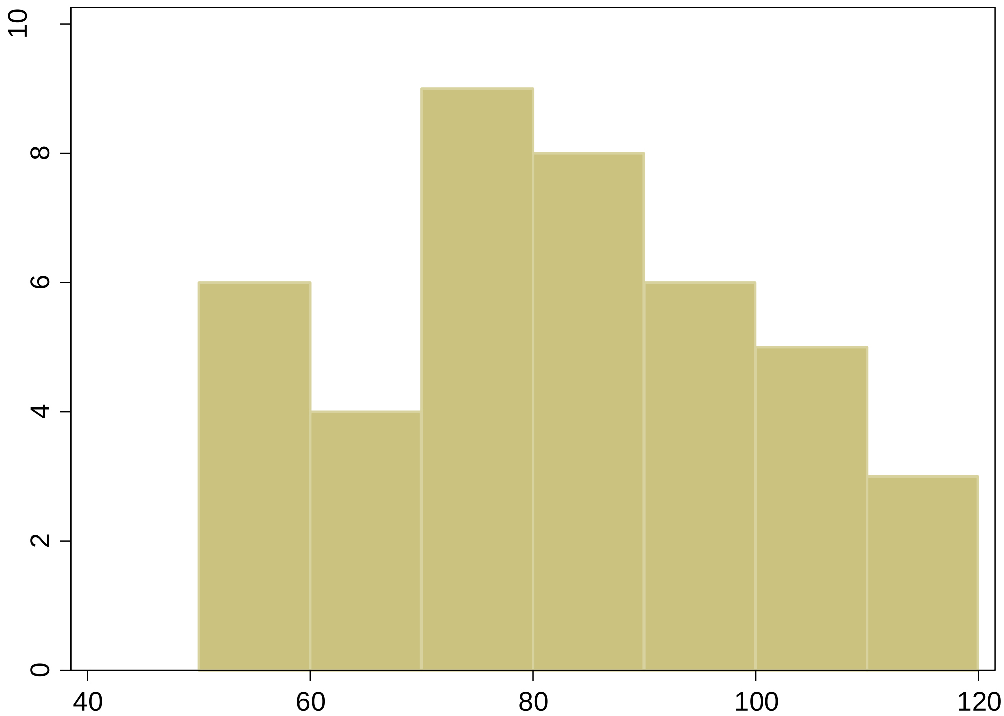

Figure 13: Histogram of average mob processing rates of enrolled females during 2010 pregnancy diagnoses musters (cows/hour).

Inevitably, when working in extreme environments and when collecting the amount of data required by the CashCow project, occasionally things went wrong. As with any technology system the experience of the operator was a big factor affecting the number of problems encountered. During the four years of the CashCow project (one year pilot project and three year main study), there were approximately 20 different data collectors utilised by the project.

At the outset it was very apparent to the management of Outcross that backups of hardware were required to minimise issues. For this reason each data collection unit contained two rugged laptops, three RFID reader options (one panel reader and two Bluetooth wands) and two external power sources (2 x 12 volt dry cell batteries). In addition, numerous cables were required including spare power leads and data cables for the panel readers, spare data cables to connect the liveweight scales to the computer and spare power cables for the computer.

Issues that occurred could be categorised as either minor—in which case data were still collected—or major, in which electronic data were not recorded.

Hardware problems encountered included:

- Computer's crashing due to hardware failures, which were overcome by using the backup computer. One failure resulted from working in very rainy conditions causing water ingression and the computer to crash. Another issue was caused by a motherboard failure.
- RFID Panel Reader failing due to knocks, kicks or even pulled off the cattle crush. Backup cables were essential to get around the problem of cables being pulled, stretched and stood on. If the panel reader failed to work the RFID wands were used.
- Reduced read range on RFID Panel Reader. On one particular brand of heavy duty cattle crush, the range of the antenna to read RFID tags was drastically reduced. Due to the gate configuration on the right hand side (offside) of the crush, opening this gate didn't substantially improve the read range. The Bluetooth wand had to be used on occasions to pick up the RFID number.
- Liveweight scales failed or produced inaccurate results on occasions and weights could not be collected.
- Lack of external power on long processing days. In most cases two 12volt batteries was sufficient but on occasions additional power was required from a vehicle battery.

Software problems encountered included:

- Difficulties interfacing the external hardware with the computer. This was especially apparent with setting up the Bluetooth connection from the RFID wand to the computer's Bluetooth adapter and to a lesser extent interfacing the different brands of liveweight scales to the computer to enable the weights to be imported automatically. The RFID panel reader was the main hardware unit for capturing the animal's identity, so unless it failed the inability to interface the Bluetooth wands was not an issue. If the data collector could not interface the scales, weights were manually typed in.
- Issues with retagging animals that had lost their initial RFID tag. The process of performing a retag within the software sometimes confused operators and led to software lockups. This could be corrected by shutting down the software and/or the computer and starting up again.
- Issues related to loss of power when writing backup information to the database. This resulted in the database being corrupted.

Data collection failures during visits to 13 pilot study properties in 2008 and twice yearly visits to 78 main and pilot study properties over three years (2009, 2010 and 2011) can be summarised as follows:

- May 2009 - Software Issue/Inexperienced Operator – the operator had an issue with recording a retag and could not get the software to continue so the day's data were recorded on paper by recording the management tag number.
- June 2010 - Hardware Failure/Inexperienced Operator – Operator could not get either the RFID panel reader or wand to work so the day's data were recorded on paper by recording the management tag number.
- August 2011 – Software Failure – The operator was installing the historic data for the property the night before processing but as the computer was not on power it ran out of battery power and crashed. The database became corrupted and the data that were collected the next day were not stored in the database. The data were able to be retrieved as the empty cows were still in the yards and were able to be rescanned the following day. From that the pregnant cows were able to be deduced, since numbers of cows had not changed from the wet/dry muster.

4.2 Compliance with data and sample collection protocols

Overall, the compliance with collection of data at the branding or wet/dry and pregnancy diagnosis musters was very high (**Table 7**) given the many challenges co-operating producers faced during the project. Note the total number of mobs by cow age class/cohort varies between musters and from what was initially enrolled because producers would regularly combine mobs for management reasons, such as calving, and then redraft mobs for mating. Three major flood events were experienced over the course of the project. In January 2009, 15 properties were affected over the NT, and north and north-western Queensland. In January through to March of 2010, seven properties in north, central, west and southern Queensland were affected by flooding. From November 2010 through to March 2011, 15 properties were affected throughout NT, north, central, and western Queensland. The severity of the floods influenced property recovery time and therefore their compliance. One property could not access their cattle for over three months.

Ensuring all required faecal samples were collected was one of the major challenges with regards to compliance. Regular reminder emails/phone calls and faxes prior to week of sample collection and again two or three weeks later ensured that the majority of required samples were collected. Some producers/managers went to extraordinary lengths to collect their dung samples, using helicopters to access mobs over flooded rivers, and devising ingenious methods to protect their samples from dung beetles. However, as a consequence of compliance problems, data from 9,024 females were deemed unsuitable for analysis and was archived (**Table 8**).

Other factors affecting compliance with data and sample collection included:

- misadventure causing sample loss
- miscommunication with Outcross data collectors and/or regional coordinators
- lag time in receiving the "sample receipt details" report
- annual holidays and off-farm commitments
- lack of available labour to help with mustering and dung collections
- threat of property loss to a mining company
- difficulty maintaining data collection over a long duration (three to four years)

Table 7: Percentage of required data collected at the pre-joining, pregnancy diagnosis (PD) and wet/dry musters.

Cow age class	Muster	No mobs	Mustered, data collected	Mustered, data not collected†	Not Mustered *	Attrition ‡
Pilot heifers	'07 pre-join§	6	100%	0%	0%	0%
	'08 PD	13	100%	0%	0%	0%
	'09 wet/dry	13	85%	15%	0%	0%
	'09 PD	13	85%	15%	0%	0%
	'10 wet/dry	13	85%	0%	8%	8%
	'10 PD	12	92%	0%	0%	8%
	'11 wet/dry	11	91%	0%	9%	0%
	'11 PD	11	100%	0%	0%	0%
Main study heifers#	'09 PD	43	100%	0%	0%	0%
	'10 wet/dry	43	86%	5%	2%	7%
	'10 PD	40	95%	3%	0%	3%
	'11 wet/dry	39	90%	3%	8%	0%
	'11 PD	39	90%	10%	0%	0%
Heifers#**	'10 PD	9	100%	0%	0%	0%
	'11 wet/dry	9	78%	0%	0%	22%
	'11 PD	7	100%	0%	0%	0%
Heifers#††	'11 PD	2	100%	0%	0%	0%
Main study cows/mixed	'09 Wet/Dry	75	85%	15%	0%	0%
	'09 PD	75	96%	3%	0%	1%
	'10 Wet/Dry	74	86%	7%	4%	3%
	'10 PD	72	94%	1%	0%	4%
	'11 Wet/Dry	71	83%	4%	13%	0%
	'11 PD	69	97%	3%	0%	0%

* Enrolled mob was not mustered. Most reproductive data were derived from their next muster.

† Enrolled mob was mustered without notifying project team of planned muster and individual animal data were not recorded on-property.

‡ Property ceased involvement in project.

§ A pre-mating muster was conducted at the discretion of property managers.

Heifer mobs initially enrolled in main study

#** To increase the number of heifer mobs, a second round of heifer mob enrolments was conducted in 2010.

#†† Heifers first processed in 2011 were enrolled, contributing maiden heifer pregnancy rate information.

Table 8: Summary of number of animals archived and reason for archiving.

Reason for Archiving	Cows/mixed	Heifers	Total
Lactating heifer at the time of induction*	0	51	51
Data recorded outside the study period	5,516	10	5,526
Insufficient data for inclusion in analyses[†]	2,674	82	7,794
No unique identification	685	6	691
TOTAL	8,875	149	9,024

* On properties where both heifer and cow mobs were enrolled, heifers lactating at the time of induction were re-categorised as cows.

[†] A further 5,038 cows and 5,805 heifers had insufficient data to be included in risk factor analyses. However, were included in either or both beef production or maiden heifer descriptive analyses. Of the animals with insufficient data for inclusion, 1,176 cows and 29 heifers were recorded on properties that prematurely terminated their involvement in the project.

4.3 Incidence of NLIS tag loss

During the course of the project 99,136 individual NLIS devices were scanned. The breakdown of the proportion of tags used from different manufacturers was: AllFlex – 80.2%, Leader/AnimalLife ID/Duo Tags – 10.7%; Gallagher/Drover's Ay-One – 7.8% and Datamars – 1.3%. The manufacturer of tags was not included in any of the analyses as a predictor for tags being replaced because some manufacturers were represented by low numbers of ear tags, and there were analytical limitations due to censoring and tag manufacturer being confounded with property.

NLIS tags were replaced if, at the time of data collection, the tag was missing from the ear, or was present but could not be read using either a wand or panel reader. Indications of significant risk of tag loss included marked deterioration of either the tag 'male pin' or 'female part', the stamped NLIS number no longer able to be read, and marked necrosis of the ear around the tag.

Although only those properties considered to have captured the replacement of unreadable or lost tags were eligible for inclusion in tag loss analyses, the estimated replacement rates should be interpreted with some caution. The electronic system being used throughout the CashCow project had the alibility to record data using a visual tag and therefore the calculated replacement rates potentially are a slight underestimate, due to either the NLIS tag being actually replaced sometime after the recorded muster, or the tag not being replaced at all. However, the occurrence of these events was considered to be very low.

The Kaplan-Meier estimate of the probability of NLIS devices being replaced indicated that approximately 8.3% of tags were replaced within 3.5 years of when they were first scanned (**Figure 14**). Similar cumulative NLIS ear tag losses of 10.9%

by 3.5 years have previously been reported[51]. Relatively few losses were recorded up to approximately 18 months since application, which previously has been reported as a time of significant loss. Losses due to application technique are generally thought as occurring relatively soon after application. Application technique, such as dipping both tag and applicator in an antiseptic solution to prevent infection at the site of tag placement, has been previously associated with tag loss[52]. Possible explanations for this not being apparent in the current dataset (**Figure 14**) include increased producer awareness resulting in more care taken with the application of tags, or alternatively, as animals were tagged prior to the trial in many cases, early losses associated with tag placement had already occurred prior to the start of the study.

The estimated annual incidence of tags being replaced during the course of the CashCow project was 2.6% (1.5 - 3.7% 95% CI) per annum. However, the proportion of tags being replaced per annum appeared to be increasing over time with 1.5% of tags being replaced by 18 months, 2.7% being replaced in the subsequent 12 months and a further 4.1% being replaced in the following year (**Figure 14**). A similar finding was reported by Schatz[53] where 0.6% of tags were replaced within the first 18 months and a further 2.9% and 7.4% in the subsequent two years. These findings may indicate that incidence of tag loss is associated with the duration of NLIS tag insertion.

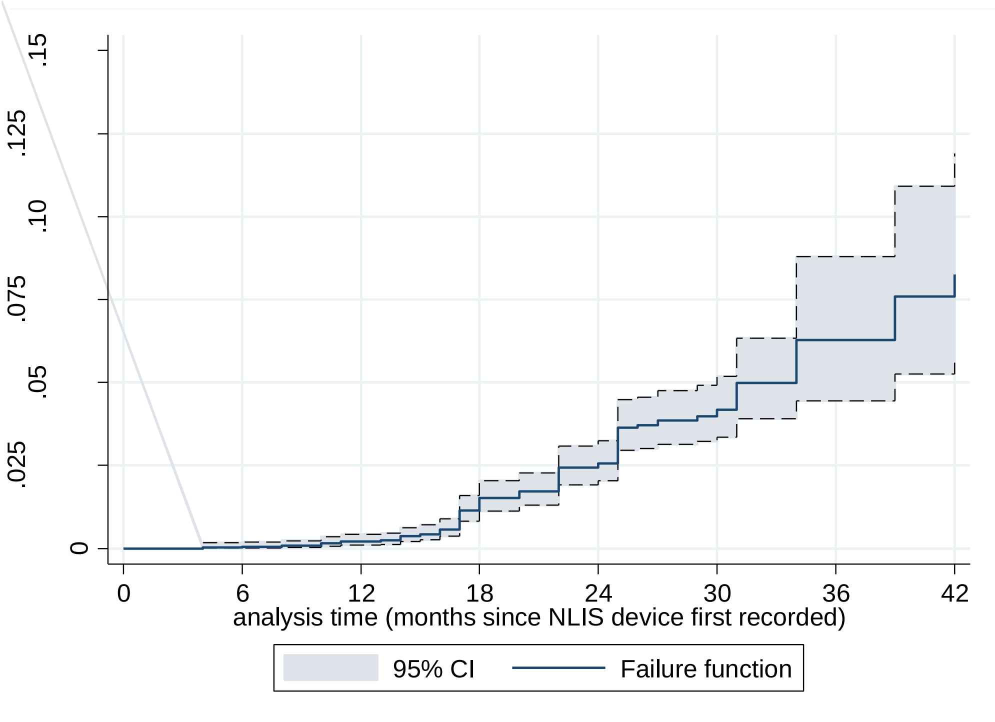

Figure 14: Kaplan-Meier estimate of the probability of NLIS ear tags being replaced over the entire course of the project, with 95% confidence intervals (CI).

51 Schatz (2011)
52 Schatz (2011)
53 Schatz (2011)

For those animals that were believed to have been tagged within 12 months prior to first being recorded, the incidence of tag loss across the study period was 1.3% (0.7-1.9% 95% CI) per annum compared with 3.8% (2.1-5.4% 95% CI) per annum for those animals where their approximate time of tag application was not known. As most of the animals with unknown times of tag insertion were cows, and therefore likely to have had tags inserted for extended lengths of time, the observed difference in incidence of tag replacement adds further support to the hypothesis that increasing time since tag insertion is associated with an increase in incidence rate of tag loss.

PIRSA[54] have stated that provided the NLIS devices have been applied in accordance with manufacturer instructions and by an appropriate applicator, loss rates of NLIS devices are less than 1% per annum. The incidence of tag replacement observed in the CashCow project is nearly three times as high as this estimate.

There was large variation in the incidence of tag replacement across properties (**Figure 15**). The median incidence of tag loss was 2.5% per annum. The 25th and 75th percentile incidence rates of tag replacement were 0.2% and 3.5% per annum, respectively. As previously noted, this variation across properties may be due to many different factors, such as variation in application technique including disinfection of tag applicator, time since tag insertion, tag manufacturer, level of woody vegetation on the property, and variations in management technique such as drafting through a head bail (increasing the chance of physical trauma to the NLIS device) versus drafting in a yard ('pound'). During the course of the CashCow project, a separate study was commissioned to investigate factors affecting NLIS tag loss.

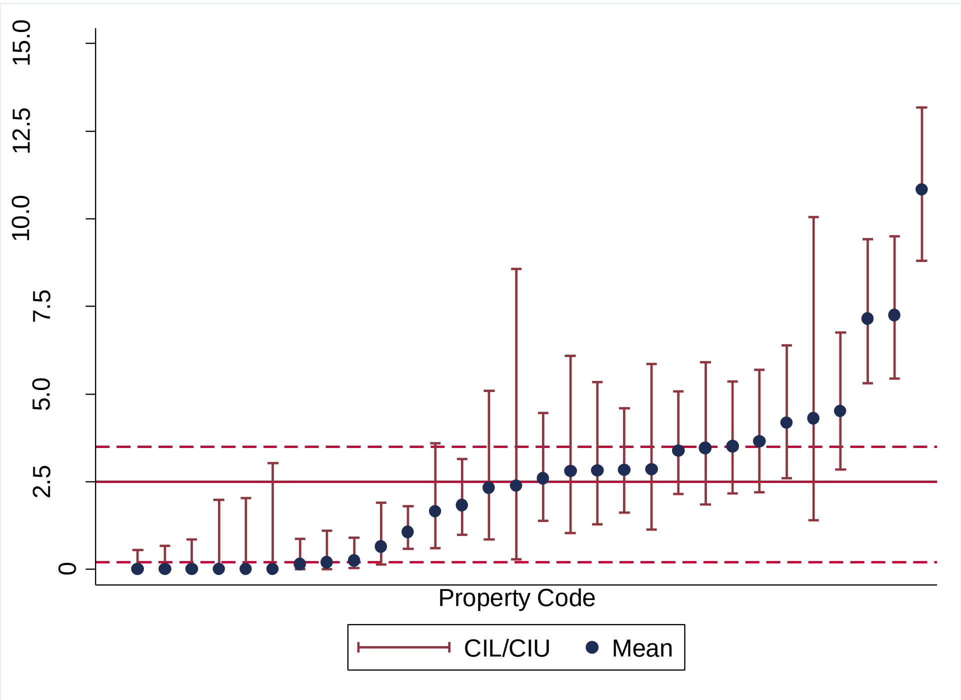

Figure 15: Overall and individual property incidence of tag replacement, with lower (CIL) and upper (CIU) 95% confidence intervals. The overall median (solid line: 2.5% p.a.) and the 25th and 75th percentile bands (dashed lines: 0.2% and 3.5% p.a.) are also shown (n=30).

54 PIRSA (2007)

4.4 Descriptive summary of property resource and management

4.4.1 Property and herd demographics

Table 9 and **Table 10** provide summaries derived from survey templates of CashCow property demographics and management, and breeding herd management of properties enrolled in the CashCow project. As expected, property size and paddock area were highest in the Northern Downs and Forest, but the proportion of the paddock within 2.5km of permanent water was also lowest in these country types compared to the Southern and Central Forest. (Please note that because the data for property and paddock size were not normally distributed there are marked differences between mean and median values for these parameters). Mustering by air was more commonly practised on the Northern Downs and Forest than elsewhere. The majority of properties were trying to maintain herd number, although 48% of properties in the Northern Forest reported that they aimed to increase herd size by at least 10%. The majority of properties mated for less than seven months in the Southern and Central Forest. Although 38% and 62% of properties in the Northern Downs and Forest respectively mated for greater than seven months, over half of the properties in the Northern Downs used some form of segregation system i.e., cows were drafted into different mobs according to lactation status and or foetal age. In the Southern and Central Forest most properties used ground mustering techniques, while most properties in the Northern Downs and Forest employed air mustering techniques.

Dry season supplementation was practised for most age classes in 87%, 31%, 46% and 55% of Northern Forest, Northern Downs, Central Forest and Southern Forest, respectively. Overall, 45% of properties provided wet season supplementation; 63%, 31%, 38% and 30% of herds were supplemented during the wet season in the Northern Forest, Northern Downs, Central Forest and Southern Forest, respectively. Properties that provided dry season supplement were three times more likely to also provide wet season supplement.

Table 9: Summary of property demographics and management by country type. Number in brackets is a count of the number of properties contributing data.

	Southern Forest	Central Forest	Northern Downs	Northern Forest	Overall
Management structure of property (%)					
No. responses	22	12	13	30	77
Owner/Manager	82	50	62	33	55
Employed Manager	5	33	0	20	14
Company-Manager	14	17	38	40	29
Leasee/Agistee	0	0	0	7	3
Property Size (km^2)					
No. responses	16	13	13	23	65
Mean	652	168	3,306	1,528	1,396

Median	60	162	364	1,250	240
Range	12–8,900	49–410	130–16,118	26–4,500	12–16,118
Paddock size (ha)					
No. paddocks	85	61	80	59	285
Mean	1,448	860	6,857	4,052	3,379
Median	419	714	2,153	2,611	943
Range	17-46,437	63-2,802	370-71,160	202-16,387	17-71,160
Proportion of paddock area within 2.5km grazing radius of permanent water					
No. paddocks	89	61	79	60	289
Mean	96%	95%	78%	79%	87%
Median	100%	100%	94%	96%	100%
Range	19-100%	23-100%	6-100%	12-100%	6-100%
Mustering technique					
No. responses	19	13	13	26	71
Ground	79%	62%	38%	15%	45%
Air	16%	38%	62%	77%	51%
Trapping	11%	8%	0%	31%	15%
Reported mustering efficiency					
No. responses	19	13	13	26	71
Mean	97%	97%	98%	89%	94%
Median	99%	98%	98%	90%	97%
Range	90-100%	90-100%	90-100%	70-100%	70-100%
Major sources of income: Sale of (more than one source could be identified)					
No. responses	16	13	13	25	67
Weaners	31%	31%	15%	56%	37%
Feeder cattle	44%	31%	62%	32%	40%
Cows/Bulls	44%	31%	38%	36%	37%
Bullocks	56%	62%	23%	16%	36%
Reported annual live weight gain of a yearling steer (kg)					
No. responses	12	6	5	17	40
Mean	195	179	168	116	156
Median	200	182	160	105	155
Range	140-250	140-220	150-200	75-220	75-250

Table 10: Summary of breeding herd management by country type.

	Southern Forest	Central Forest	Northern Downs	Northern Forest	Overall
			Current number of breeding females		
No. responses	18	13	13	23	67
Mean	972	1,192	8,737	4,614	3,772
Median	573	1,200	2,400	3,700	1,200
Range	280-8,056	350-3,000	550-44,000	220-15,097	220-44,000
Herd size management objective					
No. responses	22	13	13	27	75
↓≥10%	14	8	15	7	11
↓<10%	5	0	8	4	4
Maintain	55	69	69	30	51
↑<10%	0	0	0	11	4
↑≥10%	27	23	8	48	31
Size of mob (management group) (%)					
No. responses	21	15	13	33	82
<150	43	40	23	0	22
150-400	52	60	46	67	59
>400	5	0	31	33	20
Mating management and duration (%)					
No. responses	19	15	13	32	79
≤3m	42	47	38	3	27
4-7m	42	53	23	31	37
>7m	16	0	15	63	32
>7m with segregation	0	0	23	3	5
Females culled on age (%)					
No. responses	18	13	10	28	69
Yes	100	92	80	79	87
No	0	8	20	21	13

Age females routinely culled (years)					
No. responses	18	12	8	22	60
Mean	10.2	10.3	10.1	10.0	10.2
Median	10	10	10	10	10
Range	9-12	8-12	8-12	8-12	8-12
Weaning age (months)					
No. responses	16	10	7	23	56
Mean	7.4	5.6	6.4	5.6	6.2
Median	7	6	7	6	6
Range	4.5-11	4-7	5-8	3-8	3-11
Weaning varies with season (%)					
No. responses	17	11	11	24	63
Yes	76	82	45	6	67
No	24	18	55	94	33

4.4.2 Property disease control strategies

Across all country types, most properties did not practise BVDV vaccination. Only a few properties—primarily in the Southern Forest—either vaccinated their whole herd or the heifers only (**Table 11**). Approximately half of the properties in the Southern Forest and Central Forest vaccinated bulls only against BEF, but elsewhere vaccination was only rarely practised (**Table 12**). In the Southern and Central Forest, 53% and 67% respectively of properties vaccinated heifers and cows against leptospirosis, but elsewhere vaccination was rarely practised (**Table 13**). Except in the Southern Forest, across the remaining country types approximately two-thirds of properties vaccinated their bulls against vibriosis. Vaccination of heifers against vibriosis was rarely practised (**Table 14**).

With respect to vaccination to control infectious causes of mortality (tick fever and botulism), in Northern Forest and Downs approximately two thirds of properties vaccinated maiden heifers and cows for botulism, but only 44% vaccinated bulls routinely. By contrast, only 11% of properties in the Southern and Central Forest vaccinated females and bulls for botulism. However, vaccination to prevent tick fever in breeding females was practised by two thirds of properties in the Southern and Central Forest, but was only used on 14% of properties in the Northern Forest and Downs. Of concern was that only about one third of properties in the Southern and Central Forest vaccinated their bulls for tick fever.

Table 11: Vaccination for BVDV by country type.

Country-type	No. of properties	Vaccination Program		
		Nil	**Heifers Only**	**Entire Herd***
Southern Forest	19	15 (79%)	1 (5%)	3 (16%)

Central Forest	12	11 (92%)	0 (0%)	1 (8%)
Northern Downs	13	12 (92%)	1 (8%)	0 (0%)
Northern Forest	29	29 (100%)	0 (0%)	0 (0%)
Overall	*73*	*67 (92%)*	*2 (3%)*	*4 (6%)*

*****Inclusion of bulls in whole herd vaccination varied between properties

Table 12: Vaccination for BEF by country type.

Country-type	No. of properties	Vaccination Program		
		Nil	Bulls Only	Entire Herd
Southern Forest	19	9 (47%)	9 (47%)	1 (5%)
Central Forest	12	6 (50%)	6 (50%)	0 (0%)
Northern Downs	13	12 (92%)	1 (8%)	0 (0%)
Northern Forest	29	28 (97%)	1 (4%)	0 (0%)
Overall	73*	55 (75%)	17 (23%)	1 (1%)

*Includes data for several properties which subsequently withdrew from the project

Table 13: Vaccination for Leptospirosis by country type.

Country-type	No. of properties	Vaccination Program	
		Nil	Vaccinate females
Southern Forest	19	9 (47%)	10 (53%)
Central Forest	12	4 (33%)	8 (67%)
Northern Downs	13	13 (100%)	0 (0%)
Northern Forest	29	26 (90%)	3 (10%)
Overall	73	52 (71%)	21 (29%)

Table 14: Vaccination for Vibriosis by country type.

Country-type	No. of properties	Vaccination Program		
		Nil	Bulls (%)	Bulls & Heifers
Southern Forest	19	10 (53%)	8 (42%)	1 (5%)
Central Forest	12	3 (25%)	8 (67%)	1 (8%)
Northern Downs	13	2 (15%)	10 (77%)	1 (8%)
Northern Forest	29	8 (28%)	19 (66%)	2 (7%)
Overall	73	23 (32%)	45 (62%)	5 (7%)

4.4.3 Bull selection and management

In the pilot study, all bulls (n=97) used on six properties underwent a complete bull breeding soundness examination. Greater than 90% of bulls were considered physically sound and all had scrotal circumference measurements which met the recommendations of the Australian Cattle Veterinarians. However, the proportion of bulls on each property with greater than 70% morphologically normal sperm varied markedly (30 to 100%).

Bull mating percentages were similar across country types with the majority (~ 75%) using >2 to 4%. Only ~11% of properties used bull percentages of ≤2%, and only 16% used the current recommended 2.5 per 100 breeding females.

Of those properties using EBV's (n=26) for selection of replacement sires, 10/13 (76.9%), 2/3 (66.7%), 3/5 (60%) and 5/5 (100.0%) for Southern Forest, Central Forest, Northern Downs and Northern Forest respectively, used fertility EBVs. Only about a quarter of properties routinely used a breeding soundness examination including microscopic examination of semen to select replacement bulls, and the period of acclimatisation prior to first mating was often less than two months (**Table 15**). Further, most replacement bulls were introduced in the spring-summer period. Also, only about one third of properties annually conducted breeding soundness evaluations on their herd bulls. However, most producers managed their bulls to maintain them in satisfactory body condition.

Poor temperament was a key criteria used for culling bulls on 7/17 (41.2%), 7/11 (63.6%), 6/10 (60.0%) and 16/20 (80.0%) properties in the Southern Forest, Central Forest, Northern Downs and Northern Forest, respectively. Poor semen quality was used for culling bulls on 6/16 (37.5%), 7/11 (63.6%), 2/10 (20.0%) and 5/17 (29.4%) properties in Southern Forest, Central Forest, Northern Downs and Northern Forest, respectively. A total of 20/54 (37.0%) properties culled bulls for semen quality. Poor serving capacity was not used for culling bulls on any enrolled CashCow properties.

Table 15: Percentage of properties by region utilising specific bull selection and management practices.

Bull Selection & Management Practice	Region (see **Figure 2**) Southern Forest (n=18)	Central Forest (n=12)	Northern Downs (n=11)	Northern Forest (n=21)	TOTAL (n=62)
Bull to Female mating ratio					
≤ 2 :100	22%	0%	9%	10%	11%
>2 to 4 : 100	61%	92%	91%	71%	76%
> 4 : 100	17%	8%	0%	19%	13%
Selection of replacement bulls					
EBV data used	72%	25%	45%	35%	46%
Physical exam only by vet	17%	42%	18%	24%	24%
Physical exam & microscopic exam of semen by vet	29%	58%	45%	24%	37%
Management of replacement bulls					
Season of introduction to property Spring/Summer	83%	83%	70%	55%	72%
Autumn/Winter	17%	17%	30%	45%	28%
Duration of acclimatisation prior to 1st joining < 2 months	50%	18%	22%	70%	47%
2 to 4 months	50%	64%	44%	20%	41%
≥ 4 months	0%	18%	33%	10%	12%
Annual bull management					
Breeding soundness examination conducted annually	47%	58%	27%	24%	37%
Age bulls routinely culled < 6yrs	13%	0%	9%	0%	5%
6 to 9yrs	75%	73%	55%	85%	74%
>9yrs	13%	27%	36%	15%	21%
Bulls maintained in satisfactory body condition	94%	92%	82%	80%	88%
Bulls treated for external & internal parasites	50%	67%	18%	50%	47%

4.5 Summarising and defining achievable breeding performance of beef cattle in Northern Australia

This section presents descriptive summaries of the performance of heifers and cows and derives potential achievable levels.

It should be noted that the measures of performance summarised in this section are observed values for properties by and across cow age classes. These outcomes reflect actual performances monitored and may not directly correspond to the predicted means from multivariate statistical models presented in later sections of this report (**Section 5**).

The data in this section have been presented using two methods:

1. *Box plots* have been used to display the distribution of values recorded within each country type. The spacing between the different parts of the box helps indicate the degree of variation in performance. The central line in the box is the median (50th percentile or middle) performance value. The left edge of the box is the 25th percentile performance value (25% of values recorded were less than this value) and the right edge is the 75th percentile value (25% of values recorded were higher than this value). The extremities of the whiskers represent what could be considered as the typical range of performance values recorded. Values that are numerically quite different to the rest of the data recorded (outliers) have been represented with open circles.

2. *Summary tables* have also been used to present the numerical values of the box in the box and whisker plots and additionally present the number of property-year summaries contributing to the analysis.

For performance measures, such as annual pregnancy rate and P4M, the achievable level of performance was defined as the 75th percentile value. For measures such as foetal/calf loss and estimates of mortality, the achievable level of performance was defined as the 25th percentile value.

Data have been presented by country type, across all females, and by each cow age class (‘heifers’, ‘first-lactation’, ‘second lactation’ and ‘mature and aged’ cows). Outcome measures for different cow age classes have been derived by aggregating animal-level performance data by cow age class and year for each property and are presented by property-year. As heifers were consistently managed as a separate group, data is presented by mob-years.

This rules-based approach was used to overcome issues arising from the mixing of cattle between management groups across time and the mixing of cow age classes within management groups on the same property.

The number of property-years contributing data varied between outcome variables. For outcome variables that summarise information from two annual production cycles, such as foetal/calf loss and weaner production, the number of property-years contributing data were reduced because only two or three outcomes per property were able to be derived during the study period. Where outcome variables were based on one production cycle, such as annual pregnancy, three or four outcomes were derived per property.

4.5.1 Pregnant within four months of calving (P4M)

Determination of the percentage P4M was restricted to only those cows that reared their calf. This means that cows that did not rear their previous pregnancy were not included in performance analyses, nor included in the derived achievable levels of performance.

For those that failed to rear their previous pregnancy 66%, 71%, 55% and 55% were recorded as being pregnant within four months of calving for Southern Forest, Central Forest, Northern Downs and Northern Forest, respectively.

The cow age class, heifers, is not presented in this section, as a heifer has been defined as a female up to the end of their first mating. Females that were experiencing lactation for their first time have been defined as first-lactation cows.

4.5.1.1 Performance of first lactation cows

Individual first-lactation cow data (includes data from both yearling and two-year-old heifers that were mated and subsequently calved) from 48 properties were aggregated to property-years for the outcome P4M. Data were summarised and are presented in **Figure 16** and **Table 16**. The achievable levels of performance have been derived for each country type and are presented in **Table 16**.

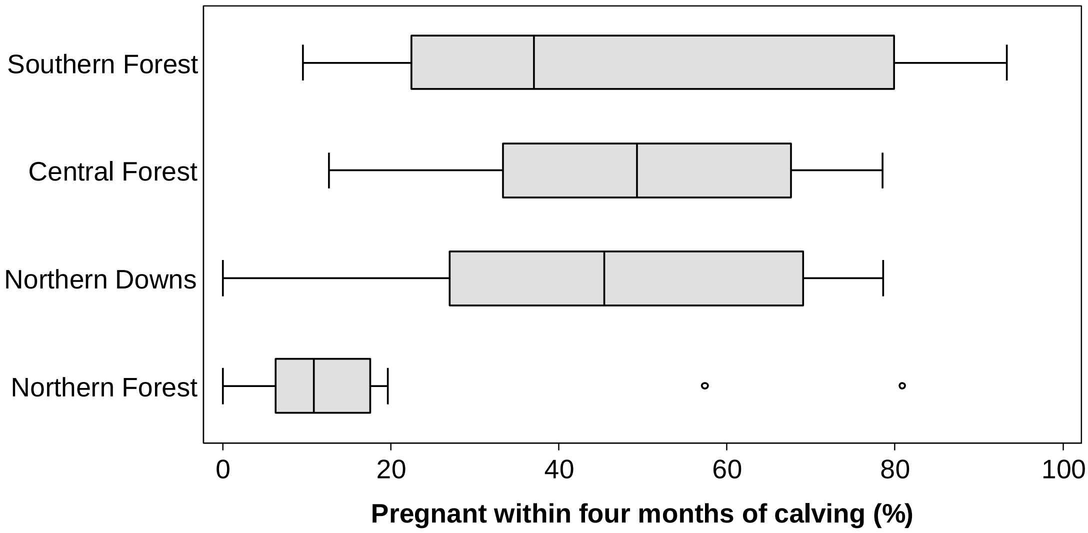

Figure 16: Box plot of property-year rates for P4M in first-lactation cows by country type. The vertical line within the box indicates the median, boundaries of the box indicate the 25th and 75th percentiles, and the whiskers indicate the typical range of performance values recorded. The “o” marked outside the whiskers identify extreme values.

Table 16: Property-year rates of P4M recorded for first lactation cows by country type. The shaded column indicates the derived achievable level of performance. Note that analysis was restricted to cows that were lactating at time of conception.

Country type	No. of property-years	Percentage P4M (%)		
		25th percentile	Median	75th Percentile (Achievable*)
Southern Forest	15	22	37	80
Central Forest	11	33	49	68
Northern Downs	12	27	45	69
Northern Forest	15	6	11	18
Overall	*53*	*16*	*35*	*62*

*Achievable performance was defined as the 75th percentile value.

The age at which heifers were first mated varied between properties. Data were recorded for first-lactation cows from 19 properties that were mated for the first time in the year that they were weaned i.e., yearling mated. The derived achievable rate for P4M of females that calved at approximately two years of age was determined as 76%, with a median value of 56% using data pooled across the Southern Forest, Central Forest and Northern Downs country types. One property in the Northern Forest conducted yearling mating and recorded 0.9% P4M.

4.5.1.1 Performance of second lactation cows

During the course of the project it became clear that in control mated herds in particular, the percentage P4M for second-lactation cows was lower than might be expected. Therefore, for this measure only the performance of second-lactation cows was determined. Individual data for second-lactation cows were aggregated to property-years from 38 properties for the outcome P4M and summarised (**Figure 17**, **Table 17**). The achievable levels of performance have been derived for each country type and are also presented in **Table 17**. Four properties that had enrolled second-lactation cows did not contribute to this analysis due to incomplete lactation data.

It should be noted that second-lactation cows have been defined as cows during the period when the majority of their cohort is experiencing their second lactation. This means that females that did not raise their first pregnancy or failed to become pregnant and were retained and re-mated were also classified as second-lactation cows. The number of these females contributing data to this analysis is very few as the majority were culled by property managers for low reproductive performance.

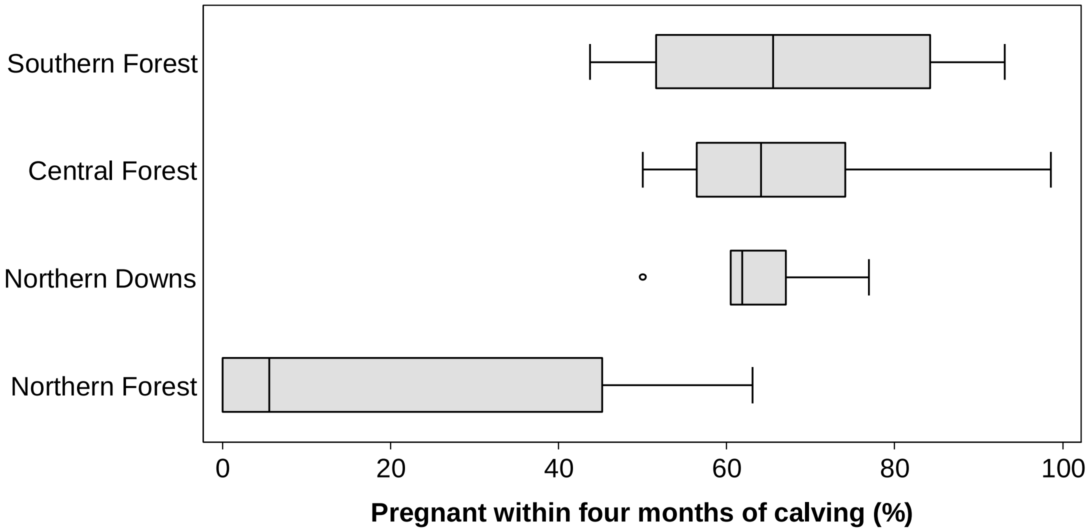

Figure 17: Box plot of property-year rates of P4M of second-lactation cows by country type. The vertical line within the box indicates the median, boundaries of the box indicate the 25th and 75th percentiles, and the whiskers indicate the typical range of performance values recorded. The “o” marked outside the whiskers identify extreme values.

Table 17: Property-year rates of P4M recorded for second-lactation cows by country type. The shaded column indicates the derived achievable level of performance. Note that analysis was restricted to cows that were lactating at time of conception.

Country type	No. of property-years	Percentage P4M (%)		
		25th percentile	Median	75th Percentile (Achievable*)
Southern Forest	12	52	66	84
Central Forest	10	56	64	74
Northern Downs	7	60	62	67
Northern Forest	11	0	6	45
Overall	*40*	*46*	*61*	*69*

* Achievable performance was defined as the 75th percentile value.

4.5.1.2 Performance of mature and aged cows

This analysis has been restricted to cows that were approximately four years of age or older, determined by their year brand. Cows were categorised as mature if they were estimated to be ≥4 ≤ 8years old. Aged cows were estimated to be >8 years old. Data for the outcome P4M were aggregated to the level of property-year. Data from 67 properties were summarised and are presented in **Figure 18** and **Table 18**. The achievable levels of performance have been derived for each country type and are also presented in **Table 18**.

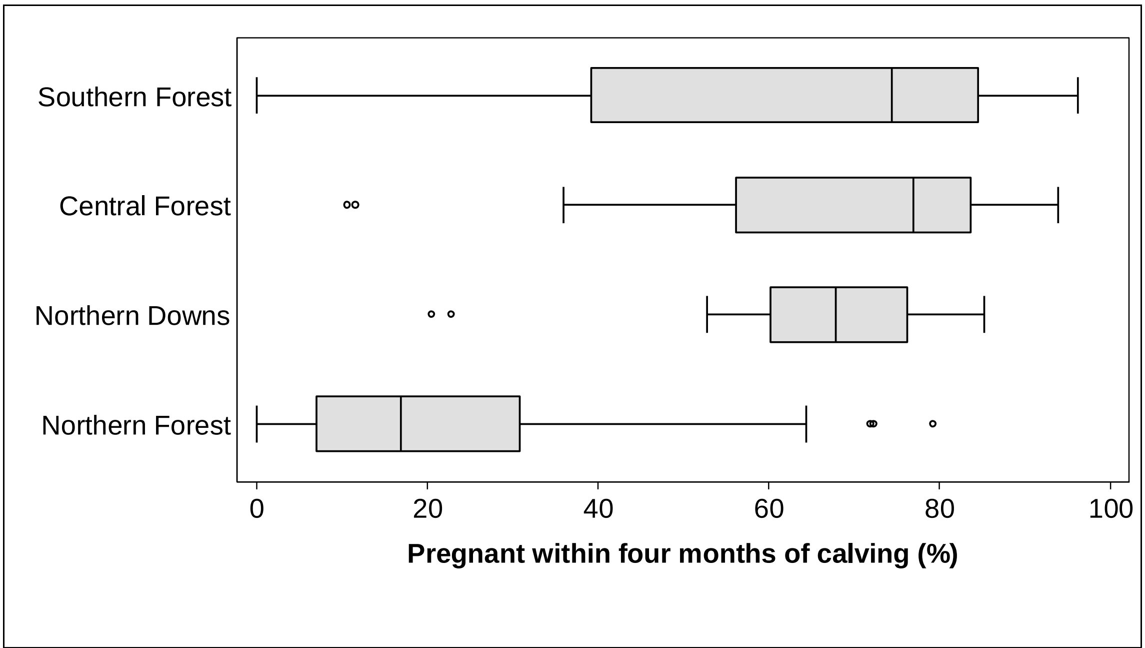

Figure 18: Box plot of property-year rates for P4M for mature and aged cows by country type. The vertical line within the box indicates the median, boundaries of the box indicate the 25th and 75th percentile and the whiskers indicate the typical range of performance values recorded. The “o” marked outside the whiskers identify extreme values.

Table 18: Property-year rates for P4M recorded for cows estimated to be ≥ four years old (i.e. mature and aged) by country type. The shaded column indicates the derived achievable level of performance. Note that analysis was restricted to cows that were lactating at time of conception.

Country type	No. of property-years	Percentage P4M (%)		
		25th percentile	Median	75th Percentile (Achievable*)
Southern Forest	36	39	74	85
Central Forest	22	56	77	84
Northern Downs	21	60	68	76
Northern Forest	44	7	17	31
Overall	*123*	*18*	*55*	*77*

*Achievable performance was defined as the 75th percentile value

The percentage P4M was compared for mature and aged cows and is presented below in **Figure 19** and **Table 19**.

Aged cows performed similarly to mature cows. The derived achievable performances for aged cows tended to be slightly higher for all country types with the exception of the Northern Forest.

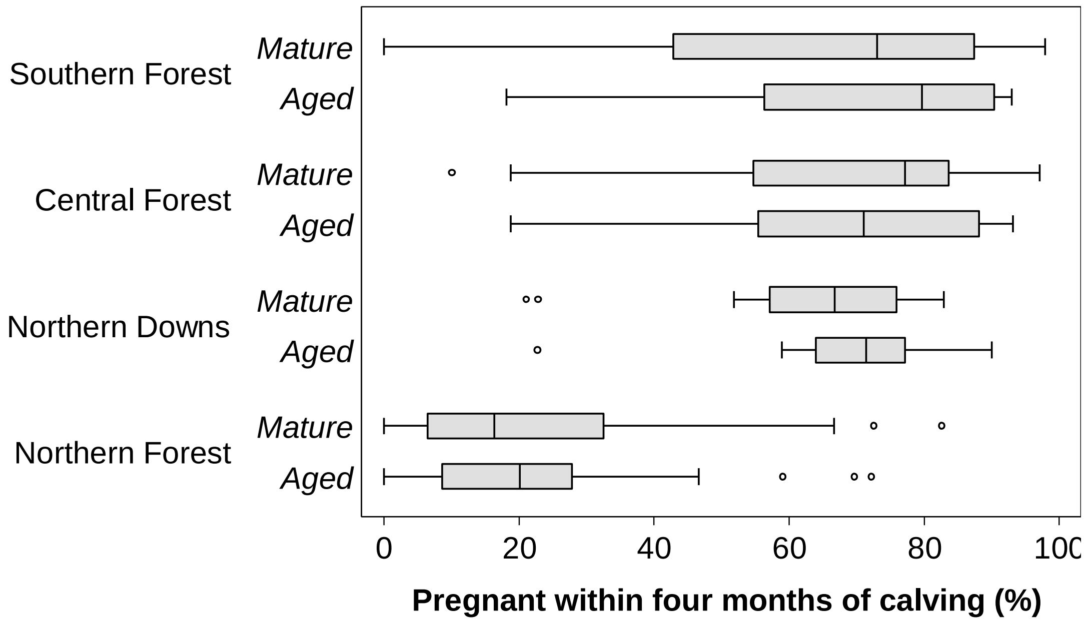

Figure 19: Box plot of property-year rates for P4M by mature cows and aged cows within country type. The vertical line within the box indicates the median, boundaries of the box indicate the 25th and 75th percentiles, and the whiskers indicate the typical range of performance values recorded. The “o” marked outside the whiskers identify extreme values.

Table 19: Property-year rates of P4M recorded for mature cows and aged cows by country type. The shaded column indicates the derived achievable level of performance. Note that analysis was restricted to cows that were lactating at time of conception.

Country type	Age Group	No. of property-years	Percentage P4M (%)		
			25th percentile	Median	75th percentile (Achievable*)
Southern Forest	Mature	33	43	76	88
	Aged	16	56	80	90
Central Forest	Mature	21	55	77	84
	Aged	12	55	71	88
Northern Downs	Mature	19	57	67	76
	Aged	12	64	71	77
Northern Forest	Mature	40	7	16	33
	Aged	28	9	20	28
Overall	*Mature*	*113*	*21*	*55*	*77*
	Aged	*68*	*21*	*58*	*77*

* Achievable performance was defined as the 75th percentile value

4.5.1.3 Performance of all females

Animal-level data were aggregated for properties by year to derive overall female rates for percentage P4M. These data were summarised and are presented in **Figure 20** and **Table 20**. The achievable levels of performance have been derived for each country type and are also presented in **Table 20**.

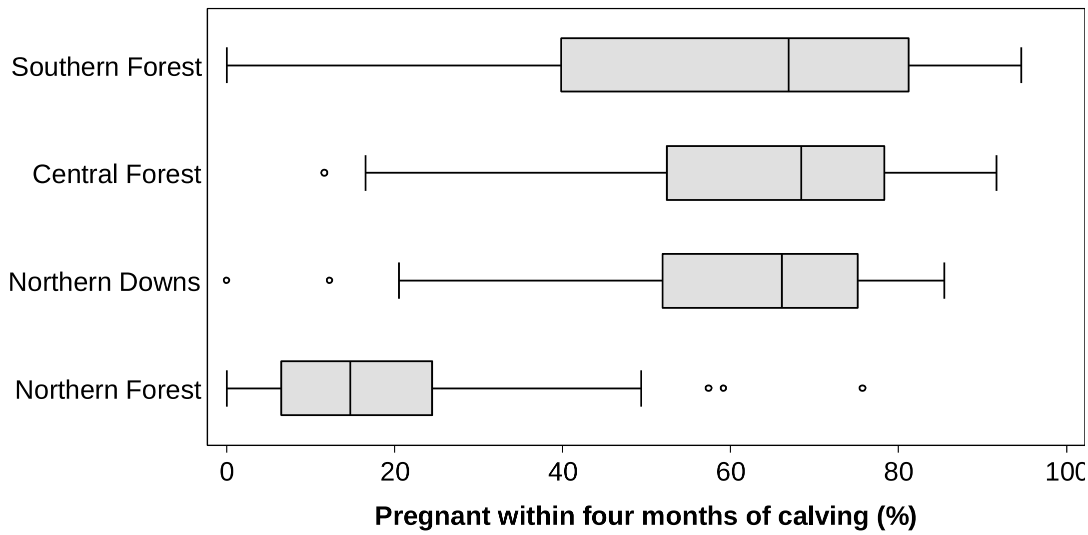

Figure 20: Box plot of P4M for all cow mobs in each country type. The vertical line within the box indicates the median, boundaries of the box indicate the 25th and 75th percentiles, and the whiskers indicate the typical range of performance values recorded. The "o" marked outside the whiskers identify extreme values.

Table 20: Recorded P4M across all females by country type. The shaded column indicates the derived achievable level of performance. Note that analysis was restricted to cows that were lactating at time of conception.

Country type	No. of Property-years	Percentage P4M (%)		
		25th percentile	Median	75th Percentile (Achievable*)
Southern Forest	39	40	67	81
Central Forest	32	52	68	78
Northern Downs	26	52	66	75
Northern Forest	53	7	15	25
Overall	*150*	*17*	*47*	*71*

* Achievable performance was defined as the 75th percentile value

4.5.2 Annual pregnancy

The results presented in this section relate to the descriptive analyses with property-year annual pregnancy rates as the outcome. The results from these analyses have been presented for each cow age class and overall. Animal-level data were aggregated to derive the outcome data.

Note that the outcome of annual pregnancy status used in this analysis refers to pregnancies where conception occurred in the 12 months ending September 1 of the current year. In addition, data checking procedures corrected current pregnancy status for subsequent lactation. This means that animals that were diagnosed as ***empty*** and subsequently recorded as lactating the following year were retrospectively assigned as being pregnant in the current year.

4.5.2.1 Performance of Heifers

The cow age class, 'heifer', has been defined as female cattle up to the end of their first mating. The outcome of annual pregnancy has been summarised for heifers from 53 properties in **Figure 21** and **Table 21**. The achievable levels of performance have been defined for each country type and are presented in **Table 21**. Data from five properties did not contribute to this analysis due to only pregnant heifers being enrolled into the project.

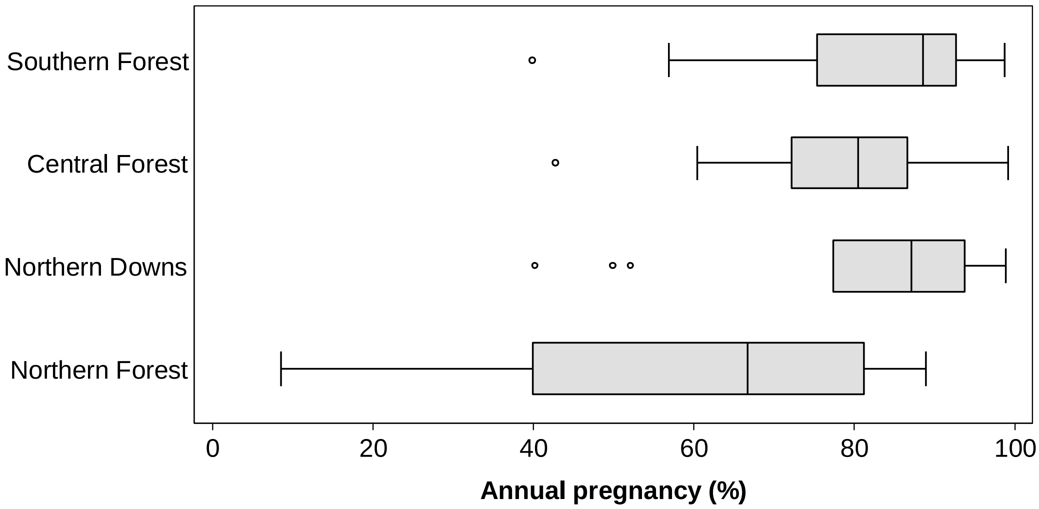

Figure 21: Box plot of mob-year rates for annual pregnancy rates for heifers in each country type. The vertical line within the box indicates the median, boundaries of the box indicate the 25th and 75th percentiles, and the whiskers indicate the typical range of performance values recorded. The "o" marked outside the whiskers identify extreme values. Note that for Northern Downs the lower whisker is not presented due to no values being observed between the lower whisker and the 25th percentile.

Table 21: Recorded mob-year rates for annual pregnancy rates for heifers by country type. The shaded column indicates the derived achievable level of performance. Note: Five enrolled mobs were excluded from analysis due to selection bias at time of induction.

Country type	No. of Mob-years	Annual pregnancy (%)		
		25th percentile	Median	75th Percentile (Achievable*)
Southern Forest	17	75	89	93
Central Forest	11	75	80	87
Northern Downs	14	77	87	94
Northern Forest	20	40	67	81
Overall	*62*	*65*	*80*	*90*

Note: Five enrolled mobs were excluded from analysis due to selection bias at time of induction.
* Achievable performance was defined as the 75th percentile value

The age at which heifers were first mated varied between properties. Data were recorded for 22 property-years of heifers across 20 properties that were mated for the first time in the year which they were weaned i.e., yearling mated. An achievable annual pregnancy rate for yearling mated heifers was determined as 81% and a median value of 75% using data pooled across the Southern Forest, Central Forest and Northern Downs country types. One property in the Northern Forest conducted yearling mating and recorded 32% annual pregnancy for that mob.

4.5.2.2 Performance of first-lactation cows

Property-year rates for annual pregnancy rates in first-lactation cows has been summarised from 48 properties and is presented below in **Figure 22** and **Table 22**. These results relate specifically to cows that were experiencing lactation for their first time. This means that heifers that conceived but failed to rear their pregnancy or heifers that failed to become pregnant during their first mating have been removed from this analysis. Data from four properties were removed from this analysis due to incomplete lactation data.

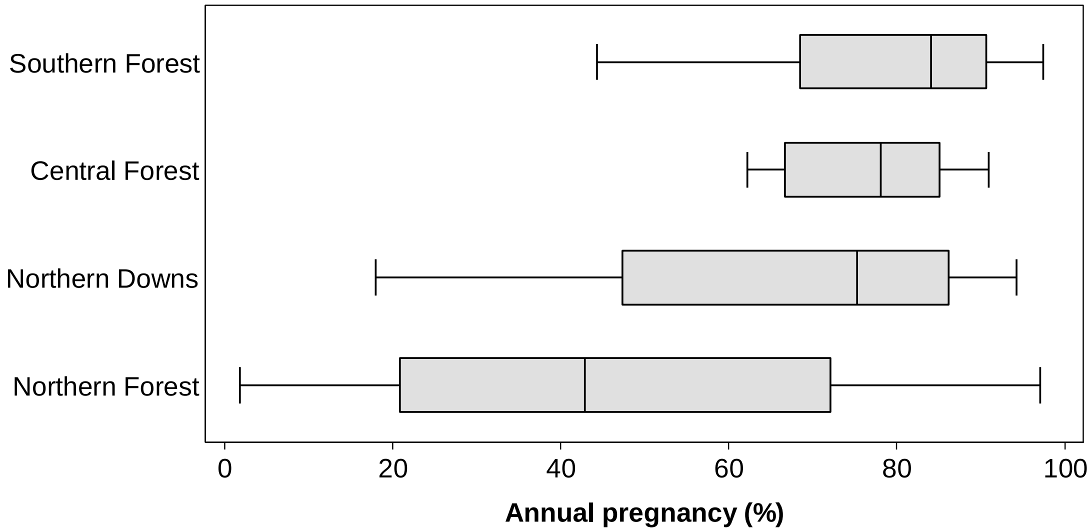

Figure 22: Box plot of property year-rates for annual pregnancy rates in first-lactation cows by each country type. The vertical line within the box indicates the median, boundaries of the box indicate the 25th and 75th percentiles, and the whiskers indicate the typical range of performance values recorded.

Table 22: Property-year annual pregnancy rates recorded for first-lactation cows by country type. The shaded column indicates the derived achievable level of performance. Note: four enrolled mobs were excluded from analysis due to incomplete lactation data

Country type	No. of Property-years	Annual pregnancy (%)		
		25th percentile	Median	75th Percentile (Achievable*)
Southern Forest	15	68	84	91
Central Forest	11	67	78	85
Northern Downs	12	47	75	86
Northern Forest	15	21	43	72
Overall	*53*	*48*	*77*	*86*

* Achievable performance was defined as the 75th percentile value

4.5.2.3 Performance of Mature and Aged Cows

This analysis has been restricted to cows that were approximately four years of age or older, determined by their year brand. Cows were categorised as mature if they were estimated to be ≥4 ≤ 8years old. Aged cows were estimated to be >8 years old. Property-year rates for annual pregnancy rates in mature and aged cows were summarised from 75 properties and are presented below in **Figure 23** and **Table 23**. Achievable levels of performance have also been derived and are presented in **Table 23**.

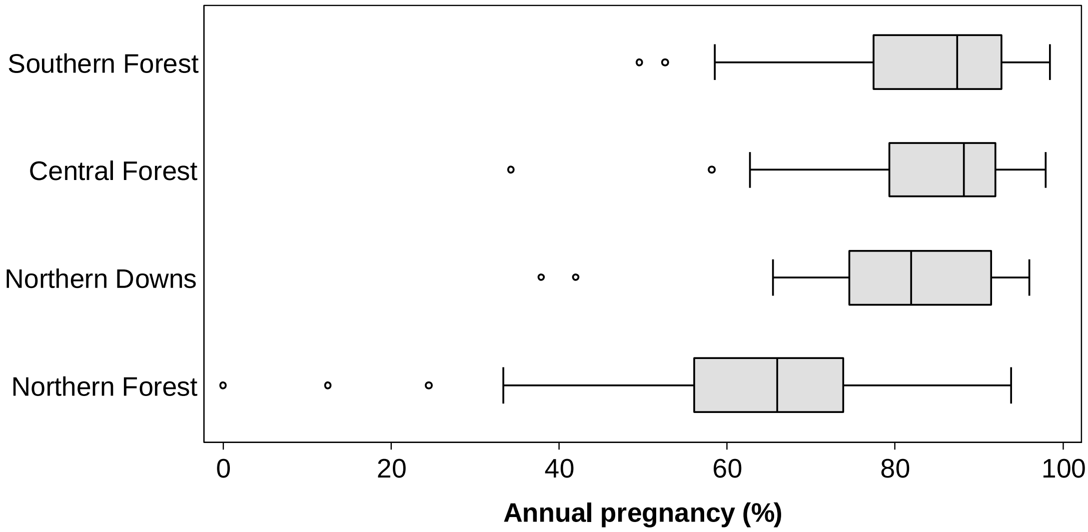

Figure 23: Box plot of property-year annual pregnancy rates for mature and aged cows by country type. The vertical line within the box indicates the median, boundaries of the box indicate the 25th and 75th percentiles, and the whiskers indicate the typical range of performance values recorded. The "o" marked outside the whiskers identify extreme values.

Table 23: Property-year annual pregnancy rates for mature and aged cows by country type. The shaded column indicates the derived achievable level of performance.

Country type	No. of property-years	Annual pregnancy (%)		
		25th percentile	Median	75th Percentile (Achievable*)
Southern Forest	57	77	87	93
Central Forest	37	79	88	92
Northern Downs	36	75	82	91
Northern Forest	76	56	66	74
Overall	*206*	*66*	*79*	*90*

* Achievable performance was defined as the 75th percentile value

The annual pregnancy rates of mature and aged cows were compared and are presented below in **Figure 24** and **Table 24**. Across all country types aged cows performed similarly to that of mature cows.

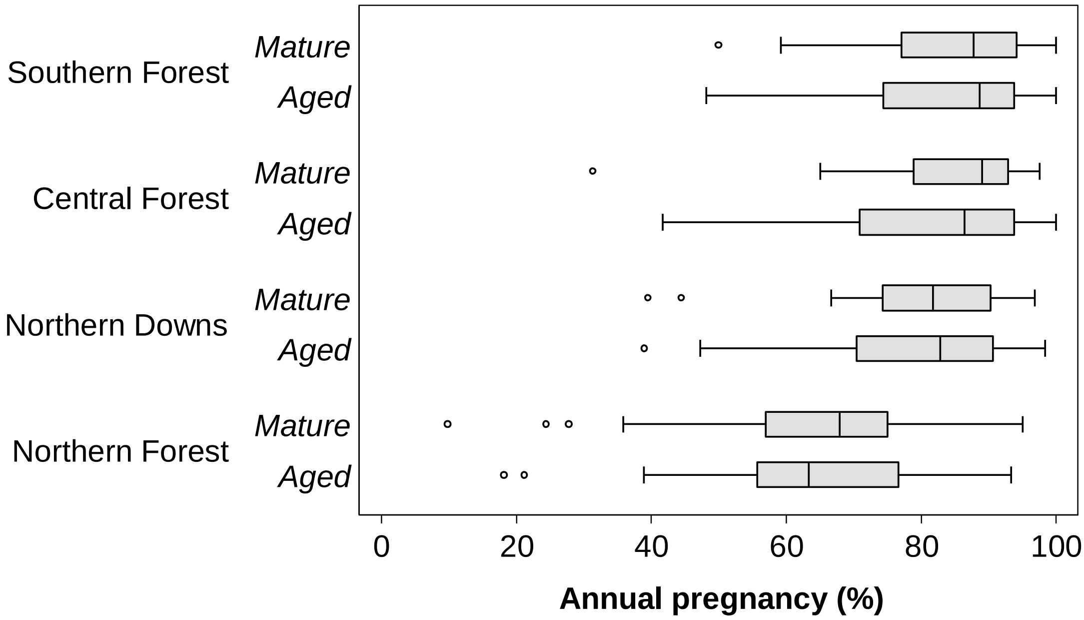

Figure 24: Box plot of property-year annual pregnancy rates by mature cows and aged cows within country type. The vertical line within the box indicates the median, boundaries of the box indicate the 25th and 75th percentiles, and the whiskers indicate the typical range of performance values recorded. The "o" marked outside the whiskers identify extreme values.

Table 24: Recorded annual pregnancy rates for mature cows and aged cows by country type. The shaded column indicates the derived achievable level of performance.

Country type	Age Group	No. of property-years	Annual pregnancy (%)		
			25th percentile	Median	75th percentile (Achievable*)
Southern Forest	Mature	57	77	88	94
	Aged	43	74	89	94
Central Forest	Mature	35	79	89	93
	Aged	27	71	86	94
Northern Downs	Mature	30	74	82	90
	Aged	25	70	83	91
Northern Forest	Mature	69	57	68	75
	Aged	54	56	63	77
Overall	*Mature*	*191*	*68*	*80*	*91*
	Aged	*149*	*63*	*81*	*90*

*Achievable performance was defined as the 75th percentile value

4.5.2.4 Performance of all females

Animal-level data were aggregated for properties by year to derive overall female annual pregnancy outcomes. These data were summarised and are presented below in **Figure 25** and **Table 25**.

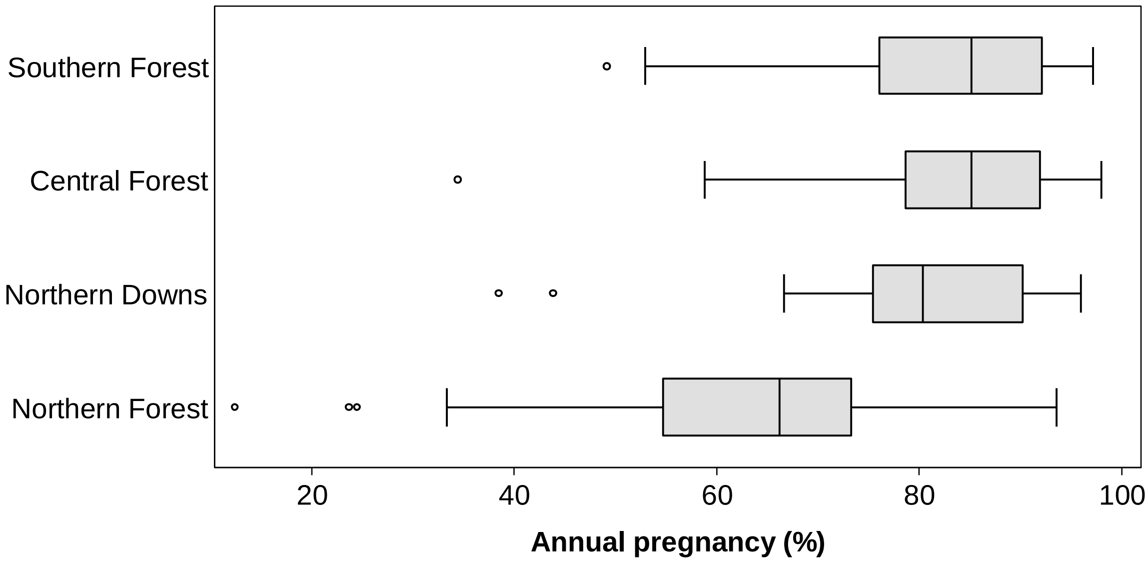

Figure 25: Box plot of annual pregnancy rates of all females by each country type. The vertical line within the box indicates the median, boundaries of the box indicate the 25th and 75th percentiles, and the whiskers indicate the typical range of performance values recorded. The "o" marked outside the whiskers identify extreme values.

Table 25: Recorded annual pregnancy rates across all females by country type. The shaded column indicates the derived achievable level of performance.

Country type	No. of properties	No. of property -years	Annual pregnancy (%)		
			25th percentile	Median	75th Percentile (Achievable*)
Southern Forest	20	57	76	85	92
Central Forest	15	41	79	85	92
Northern Downs	13	36	75	80	90
Northern Forest	28	78	55	66	73
Overall	*76*	*212*	*67*	*79*	*89*

* Achievable performance was defined as the 75th percentile value

4.5.3 Foetal/Calf loss

The results presented in this section relate to the descriptive analyses with property-year foetal/calf loss rates as the outcome. The results from these analyses have been presented for each cow age class and overall. Animal-level data were aggregated to derive the outcome data. The achievable level of performance was derived for each cow age class and overall, defined as the upper boundary of the lower quartile (25th percentile).

Foetal/Calf loss from a confirmed pregnancy was determined if a heifer or cow was diagnosed as pregnant in one year and were recorded as ***dry*** (non-lactating) at an observation at least one month after the expected calving month the following year.

Cows lactating during the following year were recorded as successfully rearing their pregnancy.

As the outcome, foetal/calf loss, combines information from two annual production cycles (pregnancy and survival) a reduced number of observations were able to contribute to this analysis compared to other derived outcome variables such as annual pregnancy.

4.5.3.1 Performance of Heifers

The cow age class, ‘heifer’, has been defined as female cattle up to the end of their first mating. The outcome foetal/calf loss has been summarised for heifers from 48 properties in **Figure 26** and **Table 26**. The achievable levels of performance have been defined for each country type and are also presented in **Table 26**. Data from 17 properties did not contribute to this analysis due to incomplete lactation data.

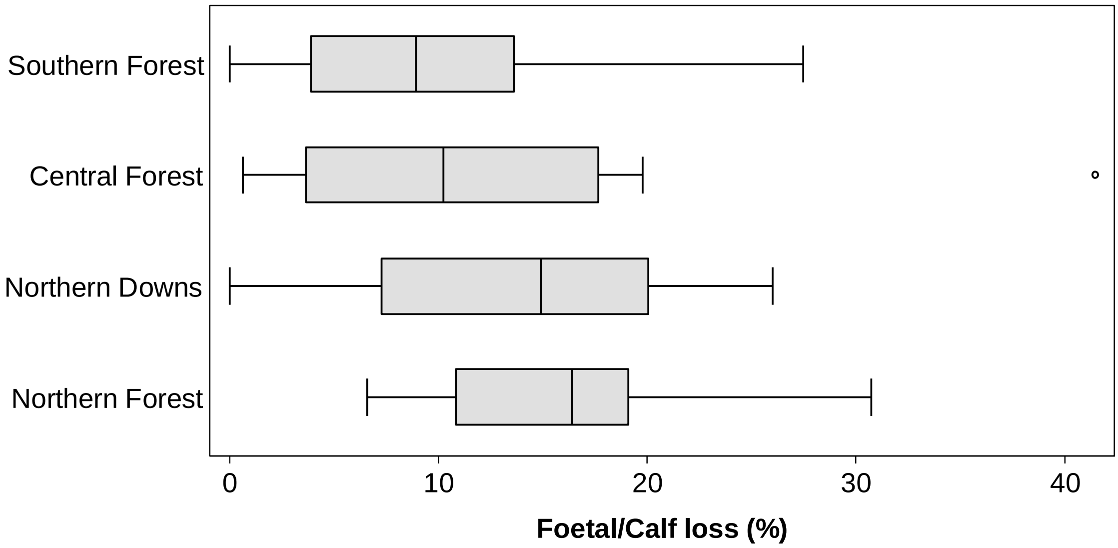

Figure 26: Box plot of mob-year rates for foetal/calf loss in heifers by country type. The vertical line within the box indicates the median, boundaries of the box indicate the 25th and 75th percentiles, and the whiskers indicate the typical range of performance values recorded. The “o” marked outside the whiskers identify extreme values.

Table 26: Mob-year foetal/calf loss rates recorded for heifers by country type. The shaded column indicates the derived achievable level of performance.

Country type	No. of mob-years	Foetal/calf loss (%)		
		25th percentile (Achievable*)	Median	75th Percentile
Southern Forest	14	3.9	8.9	13.6
Central Forest	11	3.7	10.2	17.7
Northern Downs	12	7.3	14.9	20.0
Northern Forest	14	10.8	16.4	19.1
Overall	*51*	*5.1*	*11.1*	*17.9*

* Achievable performance was defined as the 75th percentile value

4.5.3.2 Performance of first lactation cows

This section summarises results for foetal/calf loss rates for first-lactation cows (**Figure 27** and **Table 27**). Individual foetal/calf loss data were restricted to first-lactation cows (i.e., cows attempting to rear their second confirmed pregnancy) and aggregated for 35 properties by year and property. Four properties did not contribute data from enrolled first-lactation females due to incomplete lactation data. Some caution needs to be applied when comparing results of first lactation cows with mature cows, especially for the Northern Forest, due to the limited data available for analysis.

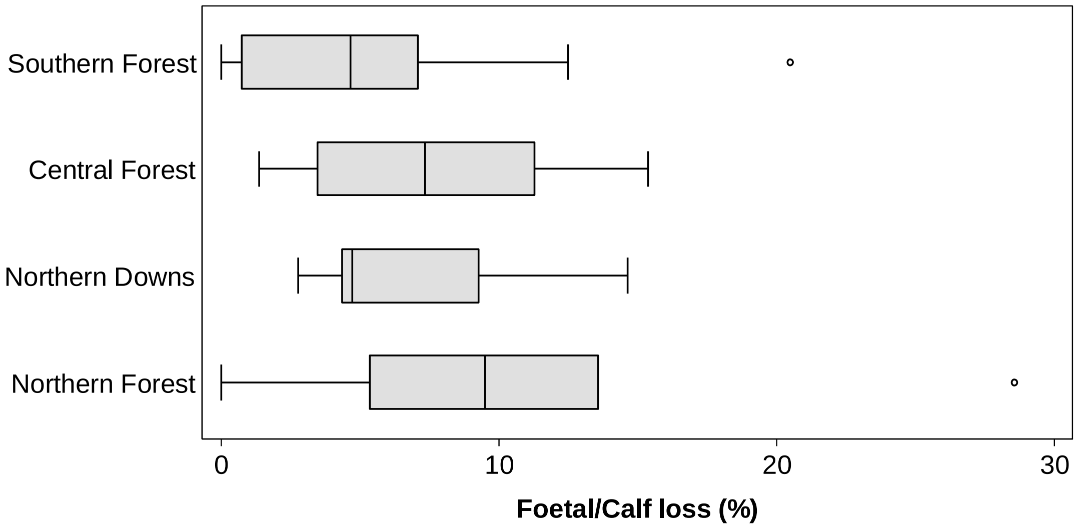

Figure 27: Box plot of property year-rates for foetal/calf loss in first-lactation cows for each country type. The vertical line within the box indicates the median, boundaries of the box indicate the 25th and 75th percentiles, and the whiskers indicate the typical range of performance values recorded. The “o” marked outside the whiskers identify extreme values.

Table 27: Property-year foetal/calf loss rates recorded for first lactation cows by country type. The shaded column indicates the derived achievable level of performance.

Country type	No. of property-years	Foetal/Calf Loss (%)		
		25th percentile (Achievable*)	Median	75th Percentile
Southern Forest	12	0.7	4.6	7.1
Central Forest	10	3.5	7.3	11.3
Northern Downs	9	4.3	4.7	9.3
Northern Forest	6	5.4	9.5	13.6
Overall	*37*	*3.3*	*6.5*	*10.5*

* Achievable performance was defined as the 25th percentile value

4.5.3.3 Performance of mature and aged cows

This analysis has been restricted to cows that were approximately four years of age or older, determined by their year brand. Cows were categorised as mature if they were estimated to be ≥4 ≤ 8years old. Aged cows were estimated to be >8 years old. Property-year rates for foetal/calf loss in mature and aged cows were summarised from 66 properties and are presented below in **Figure 28** and **Table 28**.

The extreme outliers should be noted. One property in Southern Forest was severely affected by flooding and one property in the Northern Forest experienced a major bushfire causing the study mob to be mustered and relocated to another paddock around the time of peak calving. These factors were considered as being contributory causes of the extreme values recorded.

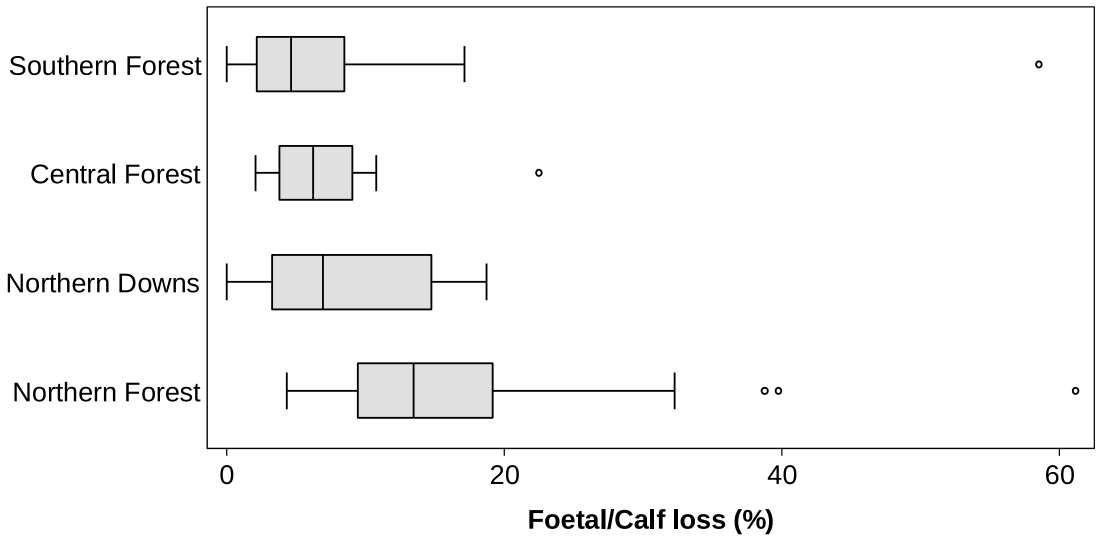

Figure 28: Box plot of property year-rates for foetal/calf loss in mature and aged cows by country type. The vertical line within the box indicates the median, boundaries of the box indicate the 25th and 75th percentiles, and the whiskers indicate the typical range of performance values recorded. The “o” marked outside the whiskers identify extreme values.

Table 28: Property-year foetal/calf loss rates recorded for mature and aged cows by country type. The shaded column indicates the derived achievable level of performance.

Country type	No. of property-years	Foetal/Calf Loss (%)		
		25th percentile (Achievable*)	Median	75th Percentile
Southern Forest	33	2.2	4.6	8.5
Central Forest	22	3.8	6.2	9.1
Northern Downs	22	3.3	6.9	14.7
Northern Forest	41	9.4	13.5	19.2
Overall	*118*	*4.1*	*8.1*	*14.3*

* Achievable performance was defined as the 25th percentile value

The foetal/calf loss rates for mature cows and aged cows were compared and are presented below in **Figure 29** and **Table 29**. Across all country types, property-year rates for aged cows were similar to mature cows.

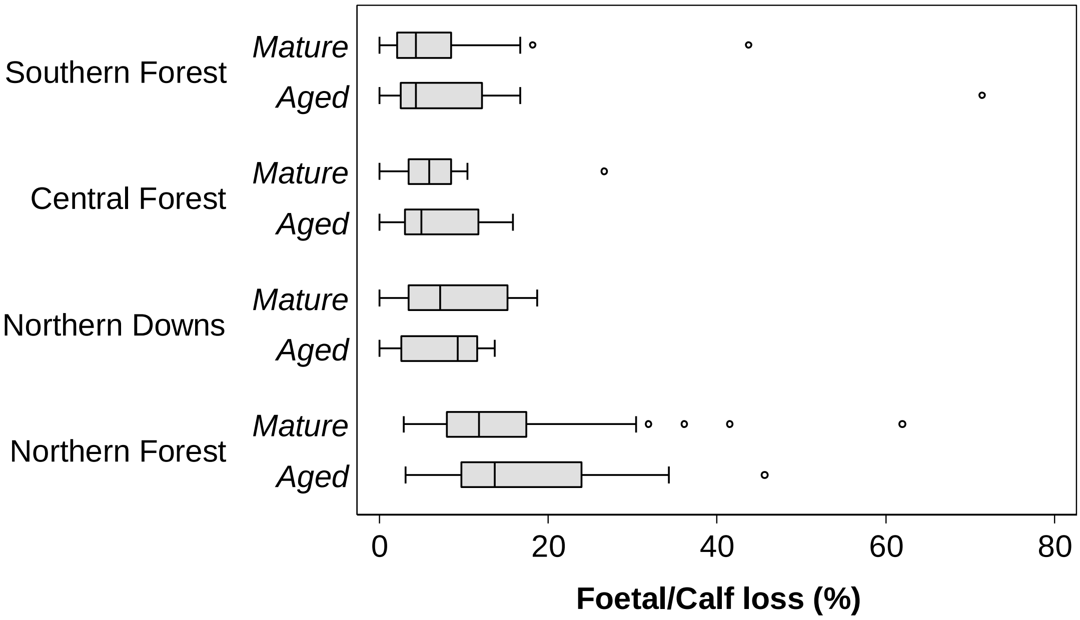

Figure 29: Box plot for property year-rates of foetal/calf loss in mature cows and aged cows by country type. The vertical line within the box indicates the median, boundaries of the box indicate the 25th and 75th percentiles, and the whiskers indicate the typical range of performance values recorded. The “o” marked outside the whiskers identify extreme values.

Table 29: Property-year foetal/calf loss rates recorded for mature cows and aged cows by country type. The shaded column indicates the derived achievable level of performance.

Country type	Age Group	No. of property-years	Foetal/Calf Loss (%)		
			25th percentile (Achievable*)	Median	75th percentile
Southern Forest	Mature	32	2.1	4.3	8.5
	Aged	19	2.6	4.3	12.2
Central Forest	Mature	21	3.4	5.9	8.5
	Aged	14	3.1	4.9	11.8
Northern Downs	Mature	20	3.5	7.2	15.3
	Aged	12	2.6	9.3	11.7
Northern Forest	Mature	40	8.0	11.8	17.4
	Aged	30	9.7	13.7	24.0
Overall	*Mature*	*113*	*4.0*	*7.6*	*14.3*
	Aged	*75*	*3.8*	*9.7*	*14.0*

* Achievable performance was defined as the 25th percentile value

4.5.3.4 Performance of all females

Animal-level data were aggregated for properties by year to derive overall female foetal/calf loss outcomes. These data were summarised and are presented below in **Figure 30** and **Table 30**.

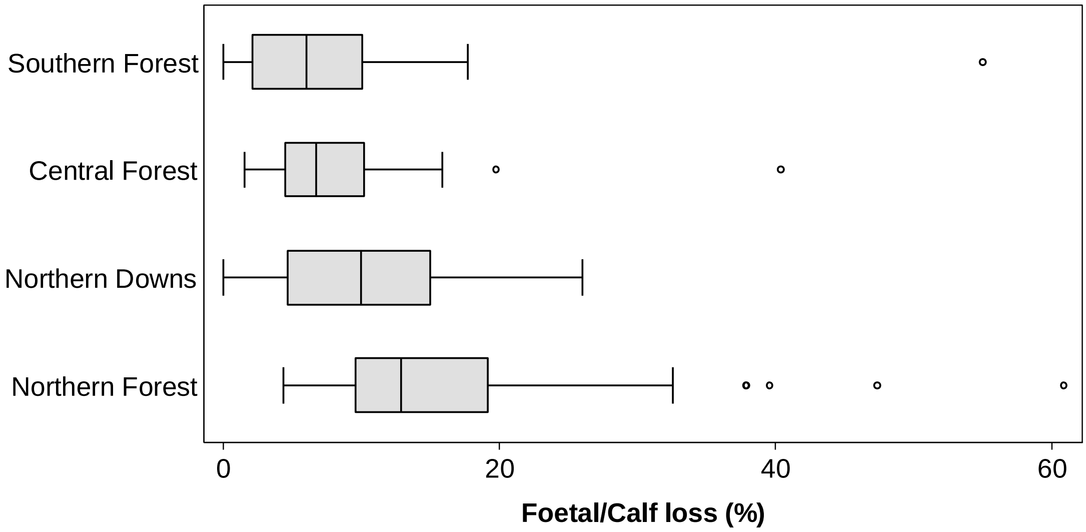

Figure 30: Box plot for property-year rates of foetal/calf loss across all females by country type. The vertical line within the box indicates the median, boundaries of the box indicate the 25th and 75th percentiles, and the whiskers indicate the typical range of performance values recorded. The "o" marked outside the whiskers identify extreme values.

Table 30: Recorded foetal/calf loss rates across all females by country type. The shaded column indicates the derived achievable level of performance.

Country type	No. of property-years	Foetal/Calf Loss (%)		
		25th percentile (Achievable*)	Median	75th Percentile
Southern Forest	35	2.1	6.0	10.1
Central Forest	32	4.5	6.7	10.2
Northern Downs	27	4.7	10.0	15.0
Northern Forest	52	9.6	12.9	19.2
Overall	*146*	*5.2*	*9.5*	*15.0*

* Achievable performance was defined as the 25th percentile value

4.5.4 Contributed a weaner

The results presented in this section relate to the descriptive analyses with property-year rates for females weaning a calf as the outcome. Females were recorded as having successfully weaned a calf if they were diagnosed as being ***pregnant*** in the previous year and were recorded as ***wet*** (lactating) at an observation after the expected calving date. Assessing lactation provided an indirect record of cattle successfully rearing their pregnancy as determining maternal parentage of progeny was generally not possible.

Animal-level data were aggregated to derive the outcome data. The results from these analyses have been presented for each cow age class and overall.

As the outcome, contributing a weaner, combines information from two annual production cycles (pregnancy and survival) a reduced number of observations were able to be derived when compared to other derived outcome variables such as annual pregnancy, which was dependant on information recorded within one production cycle.

A note of caution to readers: as the number of mobs/properties contributing data for each measure of performance was not the same, the measure 'weaning rate' cannot be determined by simply using the data for annual pregnancy rate and percentage foetal/calf loss.

4.5.4.1 Performance of Heifers

The outcome, contributing a weaner, has been summarised for heifers from 47 properties and is presented in **Figure 31** and **Table 31**. The achievable levels of performance have been derived for each country type and are presented in **Table 31**.

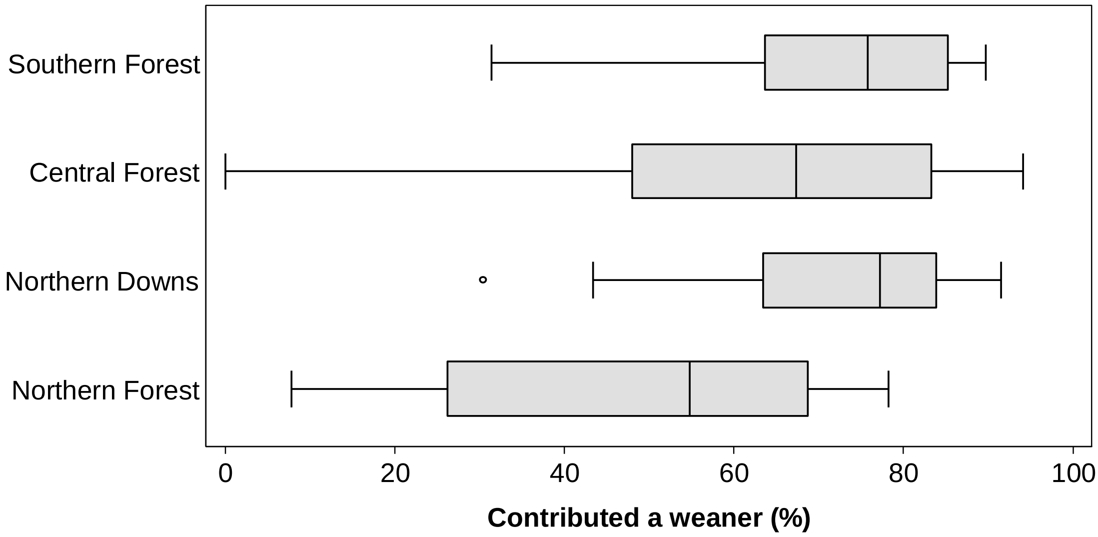

Figure 31: Box plot for mob-year rates of heifers contributing a weaner by country type. The vertical line within the box indicates the median, boundaries of the box indicate the 25th and 75th percentiles, and the whiskers indicate the typical range of performance values recorded. The "o" marked outside the whiskers identify extreme values.

Table 31: Recorded mob-year rates of heifers contributing a weaner by country type. The shaded column indicates the derived achievable level of performance.

Country type	No. of mob-years	Contributed a weaner (%)		
		25th percentile	Median	75th Percentile (Achievable*)
Southern Forest	14	63	76	85
Central Forest	11	48	67	83
Northern Downs	11	63	77	84
Northern Forest	16	26	55	69
Overall	*52*	*48*	*67*	*80*

* Achievable performance was defined as the 75th percentile value

Data were recorded for 20 mob-years of heifers across 20 properties that were mated for the first time in the year that they were weaned i.e., yearling mated. The derived achievable performance of yearling mated heifers was 76% and the median was 64% using data pooled across the Southern Forest, Central Forest and Northern Downs. Only one property in the Northern Forest yearling mated; 24% of heifers contributed a weaner in this mob.

4.5.4.2 Performance of first-lactation cows

Property-year rates for first-lactation cows contributing a weaner during the subsequent year have been summarised from 39 properties and are presented below in **Figure 32** and **Table 32**. Note the analysis was restricted to only those females recorded as lactating for their first time.

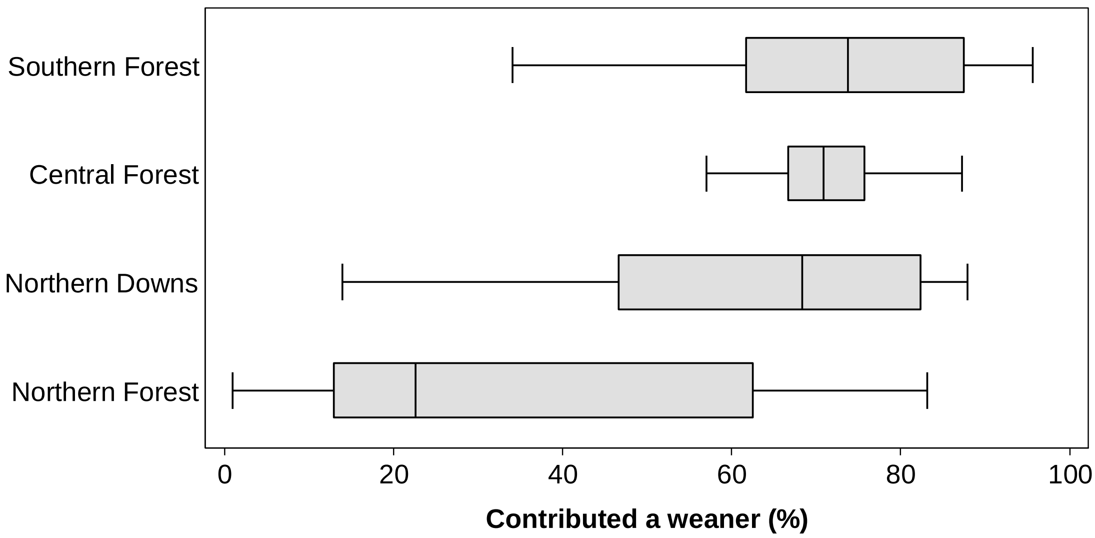

Figure 32: Box plot for property-year rates of first-lactation cows contributing a weaner during the subsequent year by country type. The vertical line within the box indicates the median, boundaries of the box indicate the 25th and 75th percentiles, and the whiskers indicate the typical range of performance values recorded.

Table 32: Recorded property-year rates of first-lactation cows contributing a weaner by country type. The shaded column indicates the derived achievable level of performance.

Country type	No. of Property-years	Contributed a weaner (%)		
		25th percentile	Median	75th Percentile (Achievable*)
Southern Forest	13	62	74	88
Central Forest	10	67	71	76
Northern Downs	9	47	68	82
Northern Forest	9	13	23	63
Overall	*41*	*47*	*67*	*82*

* Achievable performance was defined as the 75th percentile value

4.5.4.3 Performance of mature and aged cows

This analysis has been restricted to cows that were approximately four years of age or older, determined by their year brand. Cows were categorised as mature if they were estimated to be ≥4 ≤ 8years old. Aged cows were estimated to be >8 years old. The percentage of mature and aged cows contributing a weaner for properties by years has been summarised from 68 properties and is presented below in **Figure 33** and **Table 33**. The achievable levels of performance have been derived for each country type and are also presented in **Table 33**.

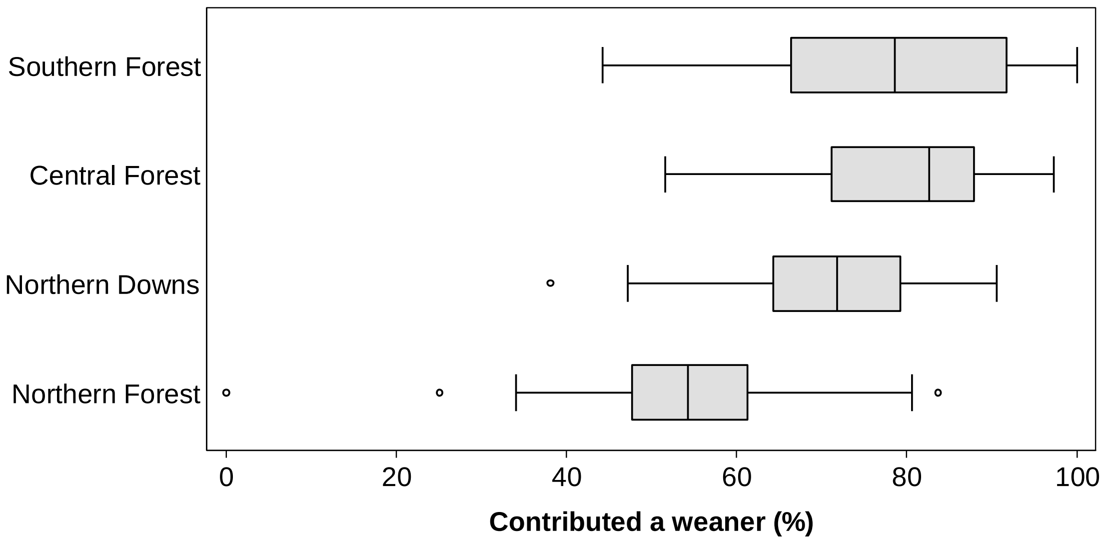

Figure 33: Box plot for property-year rates for mature and age cows contributing a weaner by country type. The vertical line within the box indicates the median, boundaries of the box indicate the 25th and 75th percentiles, and the whiskers indicate the typical range of performance values recorded. The “o” marked outside the whiskers identify extreme values.

Table 33: Recorded property-year rates of mature and aged cows contributing a weaner by country type. The shaded column indicates the derived achievable level of performance.

Country type	No. of Property-years	Contributed a weaner (%)		
		25th percentile	Median	75th Percentile (Achievable*)
Southern Forest	33	66	79	92
Central Forest	22	71	83	88
Northern Downs	22	64	72	79
Northern Forest	44	48	54	61
Overall	*121*	*54*	*68*	*83*

* Achievable performance was defined as the 75th percentile value

Property-year rates for mature and aged cows were compared for the outcome, contributed a weaner, and are presented in **Figure 34** and **Table 34**. Across all country types aged cow mobs performed very similarly to that of mature cow mobs for this outcome.

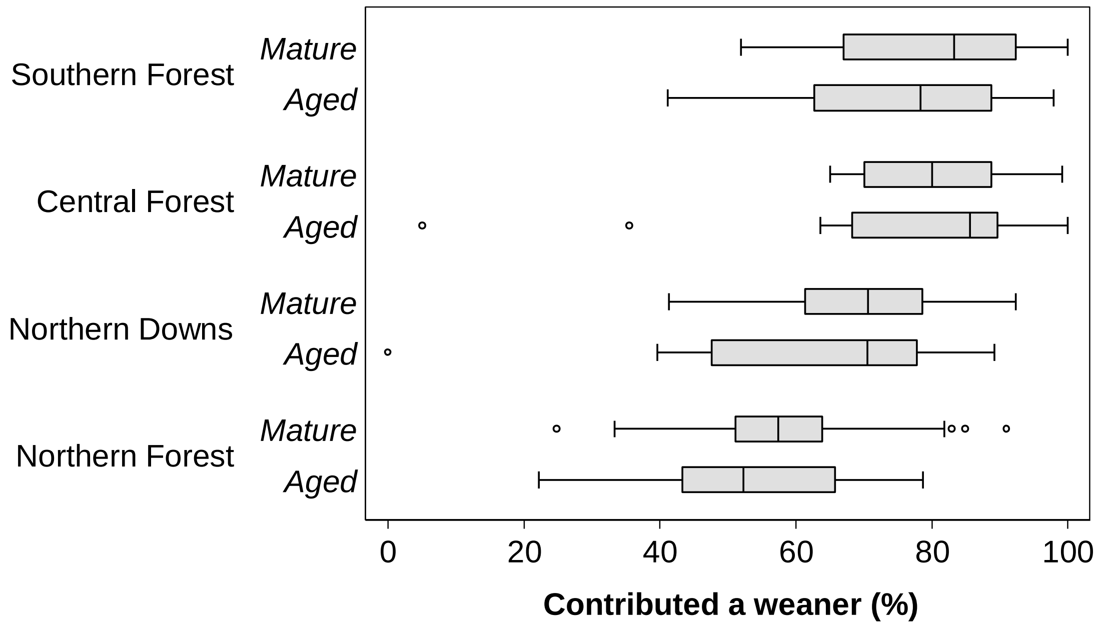

Figure 34: Box plot of property-year rates of mature cows and aged cows contributing a weaner by country type. The vertical line within the box indicates the median, boundaries of the box indicate the 25th and 75th percentiles, and the whiskers indicate the typical range of performance values recorded. The “o” marked outside the whiskers identify extreme values.

Table 34: Property-year rates for mature cows and aged cows contributing a weaner by country type. The shaded column indicates the derived achievable level of performance.

Country type	Age Group	No. of property-years	Contributed a weaner (%)		
			25th percentile	Median	75th Percentile (Achievable*)
Southern Forest	Mature	32	67	83	92
	Aged	22	63	78	89
Central Forest	Mature	21	70	80	89
	Aged	16	68	86	90
Northern Downs	Mature	20	61	71	79
	Aged	15	48	70	78
Northern Forest	Mature	40	51	57	64
	Aged	32	43	52	66
Overall	*Mature*	*113*	*58*	*69*	*85*
	Aged	*85*	*48*	*68*	*80*

* Achievable performance was defined as the 75th percentile value

4.5.4.4 Performance of all females

The overall outcome, contributing a weaner, has been summarised for all eligible females from 145 properties and is presented in **Figure 35** and **Table 35**. The achievable levels of performance have been derived for each country type and are presented in **Table 35**.

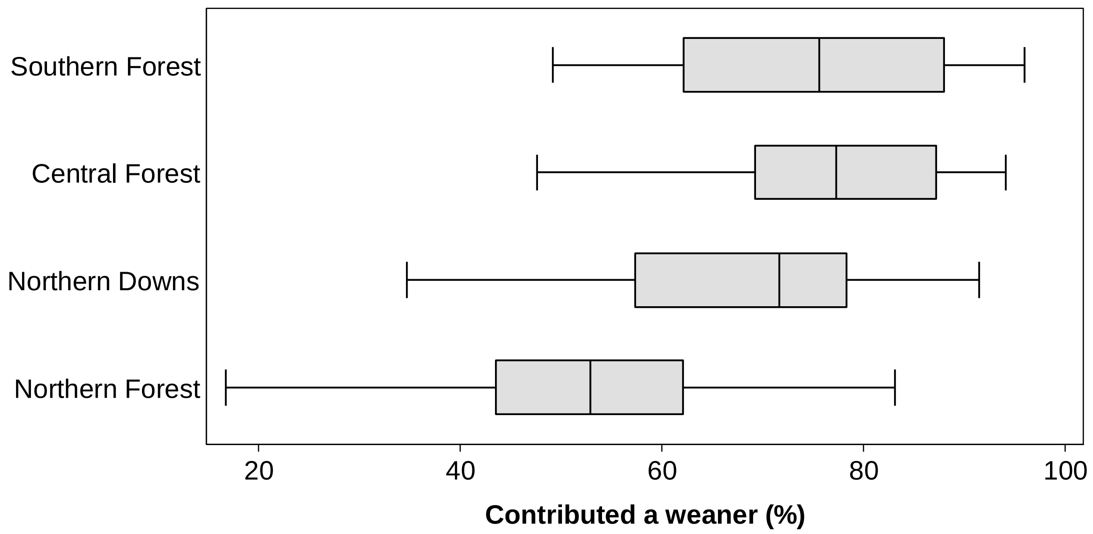

Figure 35: Box plot of property-year rates for females contributing a weaner by country type. The vertical line within the box indicates the median, boundaries of the box indicate the 25th and 75th percentile and the whiskers indicate the typical range of performance values recorded.

Table 35: Recorded property-year rates for females contributing a weaner by country type. The shaded column indicates the derived achievable level of performance.

Country type	No. of Property-years	Contributed a weaner (%)		
		25th percentile	Median	75th Percentile (Achievable*)
Southern Forest	35	62	76	88
Central Forest	32	69	77	87
Northern Downs	27	57	72	78
Northern Forest	51	44	53	62
Overall	*145*	*53*	*70*	*79*

* Achievable performance was defined as the 75th percentile value

4.5.5 Percentage pregnant cows missing (mortality)

Observed rates of pregnant cows going missing within an annual production cycle for each property by year were summarised using basic analytical techniques. This analysis was restricted to only those properties that NLIS transfers off the property were able to be cross referenced with missing animals. The achievable level of performance was derived for each cow age class and overall, defined as the upper boundary of the lower quartile (25th percentile).

The percentage of heifers missing has not been presented as they were only required to be mustered once during the year; at the pregnancy diagnosis muster, which also marked the end of the annual production cycle. Heifers that went missing subsequent to this muster, in the subsequent annual production cycle, have been defined as missing first-lactation cows.

4.5.5.1 Performance of first-lactation cows

The percentage of first-lactation cows observed as going missing for properties by years has been summarised from 40 properties and is presented below in **Figure 36**. The achievable levels of performance have been derived for each country type and are presented in **Table 36**. Note the higher than expected percentage missing in the Central Forest is likely to be due to significant mortalities recorded on several properties due to severe drought conditions in 2009-10.

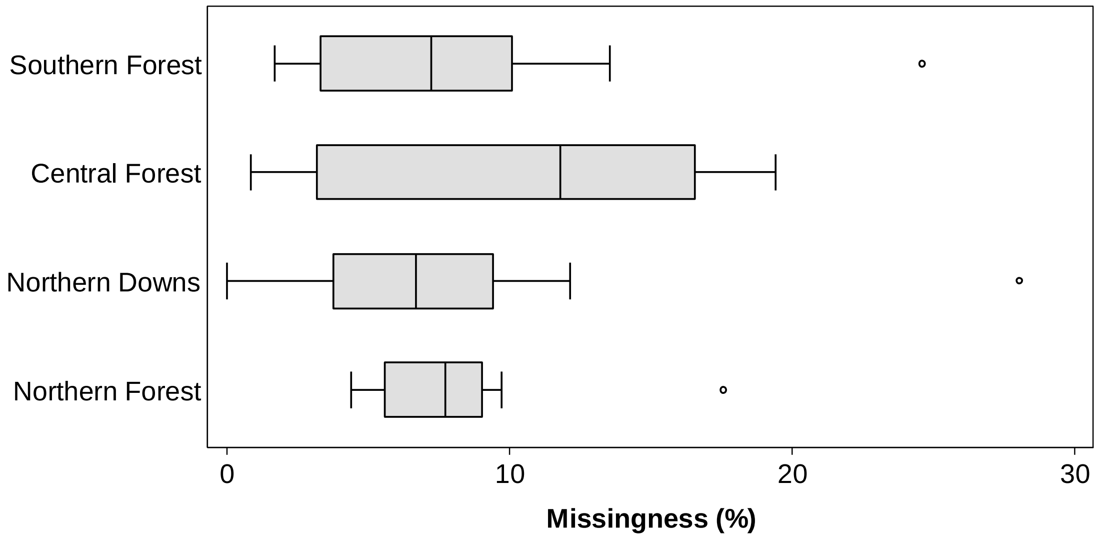

Figure 36: Box plot of property-year rates for percentage of first-lactation cows missing by country type. The vertical line within the box indicates the median, boundaries of the box indicate the 25th and 75th percentiles, and the whiskers indicate the typical range of performance values recorded.

Table 36: Observed property-year rates for percentage of first-lactation cows missing by country type. The shaded column indicates the derived achievable level of performance.

Country type	No. of Property-years	Percentage of missing pregnant cows (%)		
		25th percentile (Achievable*)	Median	75th Percentile
Southern Forest	12	3.3	7.2	10.1
Central Forest	11	3.2	11.8	16.6
Northern Downs	11	3.8	6.7	9.4
Northern Forest	8	5.6	7.7	9.0
Overall	42	4.2	8.0	11.8

* Achievable performance was defined as the 25th percentile value

4.5.5.2 Performance of mature and aged cows

This analysis has been restricted to cows that were approximately four years of age or older, determined by their year brand. Cows were categorised as mature if they were estimated to be ≥4 ≤ 8years old. Aged cows were estimated to be >8 years old. The percentage of mature and aged cows observed as being missing for properties by years has been summarised from 68 properties and is presented below in **Figure 37** and **Table 37**. The achievable levels of performance have been derived for each country type and are presented in **Table 37**.

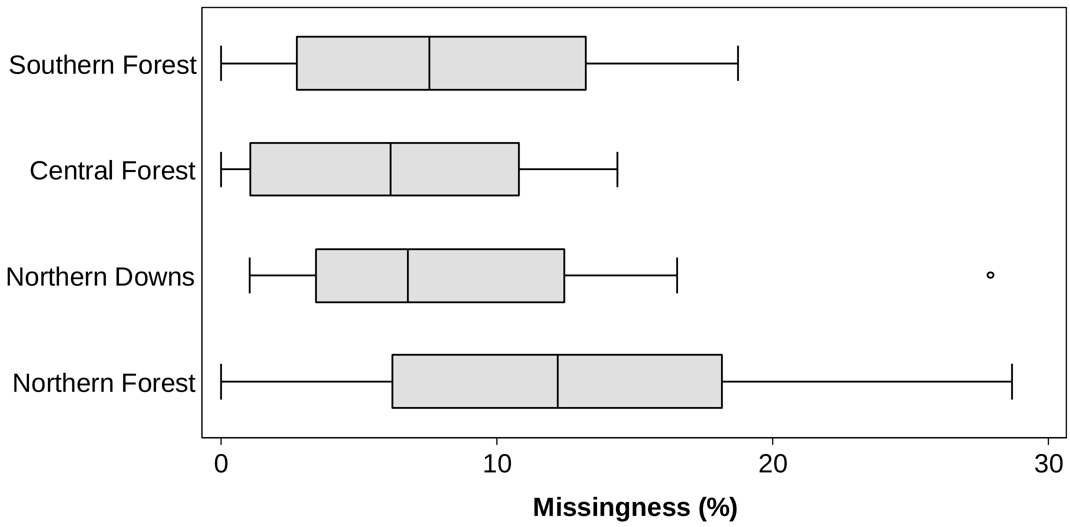

Figure 37: Box plot of observed property-year rates for percentage of missing pregnant mature and aged cows by country type. The vertical line within the box indicates the median, boundaries of the box indicate the 25th and 75th percentiles, and the whiskers indicate the typical range of performance values recorded.

Table 37: Observed property-year rates for percentage of missing pregnant mature and aged cows by country type. The shaded column indicates the derived achievable level of performance.

Country type	No. of Property-years	Percentage of missing pregnant cows (%)		
		25th percentile (Achievable*)	Median	75th Percentile
Southern Forest	16	2.8	7.6	13.3
Central Forest	11	1.1	6.2	10.8
Northern Downs	11	3.5	6.8	12.5
Northern Forest	17	6.2	12.2	18.2
Overall	55	3.5	7.1	14.4

* Achievable performance was defined as the 25th percentile value

Property-year rates of missing pregnant mature cows and pregnant aged cows were compared and are presented in **Figure 38** and **Table 38**.

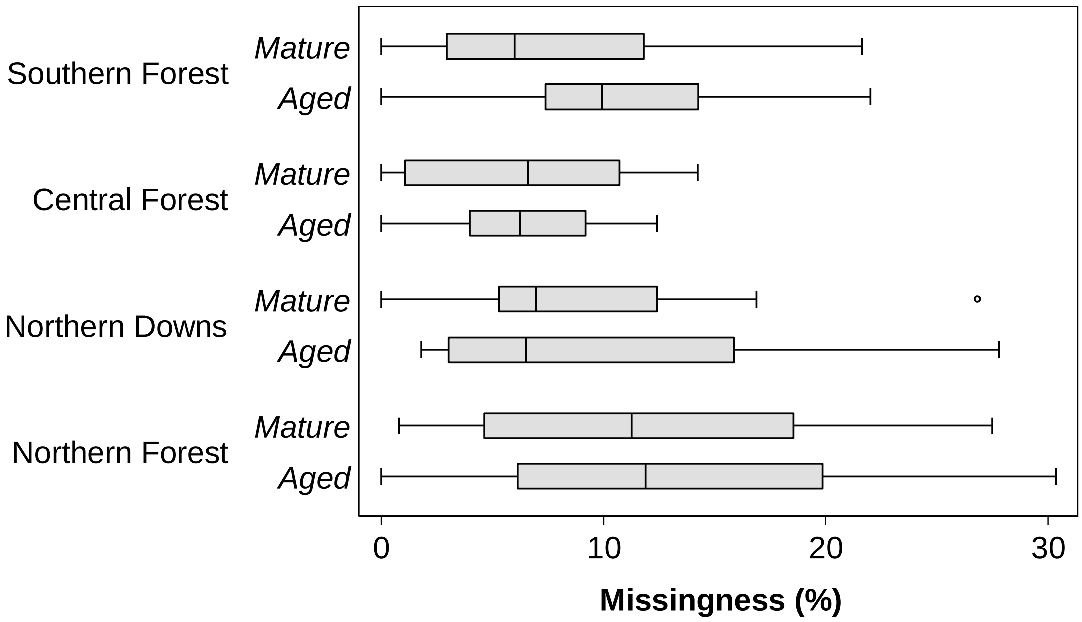

Figure 38: Box plot of observed property-year rates for percentage missing pregnant mature cows and aged cows by country type. The vertical line within the box indicates the median, boundaries of the box indicate the 25th and 75th percentiles, and the whiskers indicate the typical range of performance values recorded. The “o” marked outside the whiskers identify extreme values.

Table 38: Observed property-year rates for percentage missing pregnant mature cows and aged cows by country type. The shaded column indicates the derived achievable level of performance.

Country type	Age Group	No. of property-years	Percentage of missing pregnant cows (%)		
			25th percentile (Achievable*)	Median	75th Percentile
Southern Forest	Mature	15	3.0	6.0	11.8
	Aged	11	7.4	9.9	14.3
Central Forest	Mature	11	1.1	6.6	10.7
	Aged	9	4.0	6.3	9.2
Northern Downs	Mature	10	5.3	7.0	12.4
	Aged	7	3.0	6.5	15.9
Northern Forest	Mature	14	4.7	11.3	18.5
	Aged	12	6.0	11.9	19.8
Overall	*Mature*	*50*	*3.1*	*7.5*	*12.4*
	Aged	*39*	*4.0*	*8.8*	*15.0*

*Achievable performance was defined as the 25th percentile value

4.5.5.3 Performance of all females

Animal-level data were aggregated for properties by year to derive overall percentage of missing pregnant cows. These data were summarised and are presented in **Figure 39** and **Table 39**.

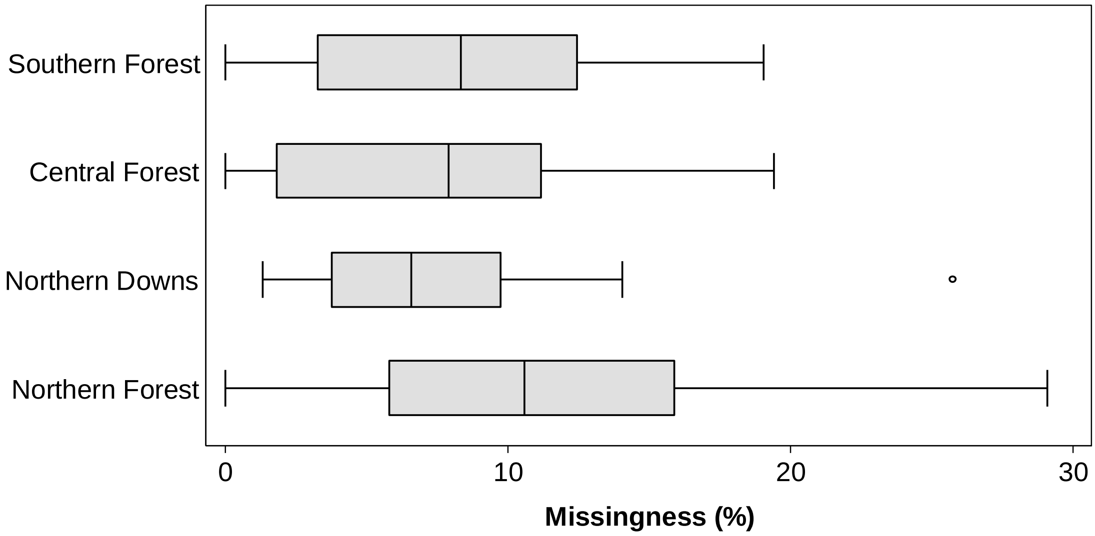

Figure 39: Box plot of property-year rates for percentage of missing pregnant cows by country type. The vertical line within the box indicates the median, boundaries of the box indicate the 25th and 75th percentiles, and the whiskers indicate the typical range of performance values recorded. The "o" marked outside the whiskers identify extreme values.

Table 39: Observed property-year rates for percentage of missing pregnant cows by country type. The shaded column indicates the derived achievable level of performance.

Country type	**No. of property-years**	**Percentage of missing pregnant cows (%)**		
		25th percentile (Achievable*)	**Median**	**75th Percentile**
Southern Forest	19	3.3	8.3	12.5
Central Forest	18	1.8	7.9	11.2
Northern Downs	15	3.8	6.6	9.8
Northern Forest	20	5.8	10.6	15.9
Overall	*72*	*3.8*	*8.4*	*12.4*

* Achievable performance was defined as the 25th percentile value

4.6 Factors affecting breeding performance of beef cattle in Northern Australia

4.6.1 Animal level factors

4.6.1.1 Breed

Breed was recorded as a mob level descriptor at the time of animals being inducted into the project. To investigate the impact of breed, three categories were used according to estimated *Bos indicus* content:

- Females estimated to be less than 50% *Bos indicus*
- Females estimated to be 50-<75% *Bos indicus*
- Females estimated to be ≥75% *Bos indicus*

A summary of the distribution of breed category by country type and cow age class is presented in **Table 40**. It should be noted that there were no animals enrolled in the Northern Forest that were less than 50% *Bos indicus* and a relatively small number within the Northern Downs. The cattle enrolled in the Southern Forest were predominantly <50% *Bos indicus* content.

Table 40: Distributions of breed category within country type for heifers and mature and age cows.

Country Type	Level of *Bos indicus* content						Total no. of cattle
	<50%		≥50-<75%		≥75%		
	No.	%	No.	%	No.	%	
Heifers							
Southern Forest	1,525	55	667	24	561	20	2,753
Central Forest	565	22	1,622	63	405	16	2,592
Northern Downs	135	4	3,365	88	328	9	3,828
Northern Forest	0	0	725	9	7,534	91	8,259
Total	2,225	13	6,379	37	8,828	51	17,432
Mature and Aged Cows							
Southern Forest	3,991	67	1,129	19	796	13	5,916
Central Forest	788	17	3,016	65	837	18	4,641
Northern Downs	950	7	11,017	80	1,838	13	13,805
Northern Forest	0	0	1,679	11	13,521	89	15,200
Total	5,729	14	16,841	43	16,992	43	39,562

4.6.1.2 Liveweight of breeding females

*This section summarises predicted liveweights of cows and heifers at both the weaning/branding and pregnancy diagnosis musters (**Table 41** and **Table 42**). The mean liveweights of heifers and cows have been produced using a linear regression model, which contained the fixed effects of country type and year with the interaction and clustering at the property level.*

It should be noted that there has not been any adjustment for weight associated with stage of pregnancy, age of heifers, or weighing protocol, the latter being accounted for in the model fixed effects. Therefore, differences between liveweights of pregnant and non-pregnant heifers and cows would be partly due to the total weight of the pregnant uterus, but it is very unlikely that the observed 40-60kg difference between pregnant and non-pregnant heifers is entirely due to this.

Across all classes of females, the Northern Forest consistently recorded lower average liveweights compared to all other regions at both the weaning/branding and pregnancy diagnosis musters (**Table 41** and **Table 42**).

Heifers and cows within the Central Forest recorded heaver liveweights at the pregnancy diagnosis muster than other country types. The Central Forest also recorded heaver mature and aged cows than other country types at the weaning/branding muster. However, the first-lactation cows in the Central Forest were similar in weight to those first-lactation cows in the Southern Forest.

Table 41: Mean liveweight of heifers and cows at the pregnancy diagnosis muster by country type.

Cow age class and Country type	Mean liveweight (kg) recorded at the pregnancy diagnosis muster									
	Pregnant					Not Pregnant				
	No. of cattle	Mean	SE	95% Confidence interval Lower	95% Confidence interval Upper	No. of cattle	Mean	SE	95% Confidence interval Lower	95% Confidence interval Upper
Heifers										
Southern Forest	2,020	409.1^{A}	17.1	375.6	442.6	490	386.9^{A}	14.8	357.9	415.9
Central Forest	1,817	453.2^{A}	26.6	401.1	505.4	558	419.7^{A}	28.7	363.5	475.9
Northern Downs	2,432	418.4^{A}	20.2	378.8	458.1	441	371.9^{A}	21.7	329.4	414.4
Northern Forest	4,005	353.0^{B}	12.0	329.5	376.6	1,267	314.9^{B}	14.3	286.9	342.9
Overall	10,274	408.5	10.5	387.9	429.0	2,756	373.3	10.9	352.0	394.7
First-lactation cows										
Southern Forest	955	468.7^{A}	7.9	453.3	484.2	300	436.7^{A}	9.6	417.9	455.5
Central Forest	790	497.1^{A}	22.1	453.8	540.4	196	468.0^{A}	19.0	430.8	505.2
Northern Downs	867	404.4^{B}	8.4	388.0	420.8	391	372.4^{B}	6.8	359.1	385.8
Northern Forest	606	353.8^{C}	13.0	328.3	379.3	434	333.3^{C}	11.4	311.0	355.6
Overall	3,218	431.0	7.7	416.0	446.0	1,321	402.6	7.1	388.7	416.5
Mature and Aged cows										
Southern Forest	8,185	497.3^{A}	10.3	477.0	517.6	1,795	466.0^{A}	12.3	442.0	490.1
Central Forest	6,641	518.6^{A}	9.0	501.0	536.2	1,583	486.7^{A}	11.4	464.4	509.1
Northern Downs	13,179	458.4^{B}	5.7	447.2	469.6	2,807	423.3^{B}	6.5	410.5	436.1
Northern Forest	12.678	406.7^{C}	6.9	393.2	420.3	7,366	351.4^{C}	7.4	336.9	366.0
Overall	40,683	470.3	4.1	462.3	478.3	13,551	431.9	4.8	422.4	441.4

Note: Within cow age class and pregnancy status, means that are not sharing a common superscript letter are significantly different at $P<0.05$.

Table 42: Mean liveweight of heifers and cows at the weaning/branding muster by country type.

Cow age class and Country type	Mean liveweight (kg) recorded at the weaning/branding muster									
	Lactating					Non-lactating				
	No. of cattle	Mean	SE	95% Confidence interval		No. of cattle	Mean	SE	95% Confidence interval	
				Lower	Upper				Lower	Upper
First-lactation cows										
Southern Forest	1,080	405.7^{A}	12.5	381.1	430.2	180	456.5^{A}	17.8	421.6	491.4
Central Forest	1,386	423.6^{A}	17.3	389.7	457.4	250	495.6^{A}	21.3	453.9	537.3
Northern Downs	1,335	409.2^{A}	10.2	389.1	429.3	558	476.6^{A}	11.4	454.2	499.0
Northern Forest	1,134	335.6^{B}	14.2	307.8	363.4	995	399.3^{B}	12.7	374.4	424.2
Overall	4,935	393.5	6.9	380.0	407.0	1,983	457.0	8.1	441.0	473.0
Mature and Aged cows										
Southern Forest	7,806	473.1^{A}	10.7	452.2	494.0	787	508.2^{AB}	12.8	483.2	533.2
Central Forest	6,925	485.1^{A}	11.7	462.2	508.0	745	531.9^{A}	9.8	512.8	551.0
Northern Downs	8,290	458.1^{A}	9.9	438.6	477.5	1,394	501.2^{B}	8.2	485.1	517.2
Northern Forest	12,862	376.6^{B}	7.1	362.8	390.5	8,411	441.1^{C}	6.6	428.2	454.1
Overall	35,883	448.2	5.0	438.4	458.0	11,337	495.6	4.8	486.2	505.0

Note: Within cow age class and lactation status, means that are not sharing a common superscript letter are significantly different at P<0.05.

4.6.1.3 Liveweight of weaners

Due to logistical reasons (most commonly inability to access scales), liveweight of weaners for each CashCow mob was not able to be collected. The number of properties contributing data each year is summarised in **Table 43** and the total numbers of weaners contributing liveweight data is summarised in **Table 44**.

Table 43: Number of properties contributing live weight data of weaners by year for each country type.

Year	Southern Forest	Central Forest	Northern Downs	Northern Forest	Total
2009	8	9	12	21	50
2010	14	11	12	19	56
2011	10	13	11	26	60
Total	*32*	*33*	*35*	*66*	*166*

Table 44: Number of weaners contributing live weight data by year for each country type.

Year	Southern Forest	Central Forest	Northern Downs	Northern Forest	Total
2009	1,293	2,155	3,781	4,410	11,639
2010	2,520	3,163	4,733	4,407	14,823
2011	2,079	2,958	8,078	5,820	18,935
Total	*5,892*	*8,276*	*16,592*	*14,637*	*45,397*

A linear regression model (Stata v12, *-xtmixed-*) was used to analyse the weaner data. The model included the main effect terms of year weaned, mob class, sex of weaner, and country type, with the interaction term of year*country type. Clustering for management group at the time of weaning within property was included. Model checking included observing the distribution of standardised residuals and the constancy of the error variance. The mean predicted liveweight of weaners by country type are in presented in **Table 45**. Mean liveweight of weaners in the Southern and Central Forest were similar and significantly higher than those in the Northern Downs and Forest. The predicted mean liveweight of weaners in the Northern Downs was significantly higher than that in the Northern Forest, which had the lowest mean liveweight of weaners.

Table 45: Mean predicted live weight of weaners by country type.

	Live weight of weaners (kg)	
Country Type	**Mean***	**95% confidence interval**
Southern Forest	232.5^{A}	218.7 - 246.2
Central Forest	225.5^{A}	210.7 - 240.3
Northern Downs	199.8^{B}	184.8 - 214.7
Northern Forest	162.7^{C}	151.4 - 174.1
Overall	*195.6*	*188.4 - 202.9*

*Means sharing a superscript letter are not significantly different at the 5% level.

4.6.1.4 Hip Height

Presented in this section is a summary of the recorded hip height of heifers and mature and aged cows that was measured at their time of induction into the project.

Hip height was measured at the peak of the sacrum, which is adjacent to the hip joints. A summary of the recorded hip height measurements of different genotype categories for heifers and mature and aged cows is provided below (**Table 46**).

Table 46: Average hip height measured for different genotype categories of heifers and mature and aged cows. These averages have been adjusted for clustering at the property level.

Cow age class and level of *Bos indicus* content	Hip Height (cm)				
	No. of cattle	Mean	SE	95% Confidence interval	
				Lower	Upper
Heifers					
<50%	1,517	135.2^{A}	1.2	132.8	137.6
≥50-<75%	5,675	137.3^{A}	0.7	135.9	138.7
≥75%	4,241	137.2^{A}	0.8	135.6	138.7
Mature and Aged cows					
<50%	3,577	132.8^{A}	1.3	130.3	135.3
≥50-<75%	5,888	134.9^{A}	1.0	133.1	136.8
≥75%	9,142	134.8^{A}	1.0	132.9	136.7

Note: Within cow age class, means that those not sharing a common superscript letter are significantly different at P<0.05.

Cow age class was significantly associated with average hip height at the time of induction (p<0.01). Conversely, genotype category was not found to be significantly associated with hip height at the time of induction (p=0.34). Across genotypes, mature and aged cows measured on average 2.5 (SE = 0.7) cm shorter than heifers ($p<0.01$).

4.6.1.5 Body condition score

This section presents the results from basic analytical procedures used to summarise body condition score of heifers and cows at both the weaning/branding and pregnancy diagnosis musters.

Box plots have been used to display the spread of body condition scores recorded for heifers and cows by either lactation or pregnancy status within country type. The spacing between the different parts of the box indicates the variation in recorded body condition scores. The blue vertical line within the box indicates the median, boundaries of the box indicate the 25th and 75th percentiles, and the whiskers indicate the typical range of values recorded. The "o" marked outside the whiskers identify extreme values.

As expected, when grouped by pregnancy, the body condition score for the pregnant groups was greater than that of the non-pregnant group across all cow age classes (**Figure 40**, **Figure 42** and **Figure 44**). Similarly, cows that were recorded as lactating at the weaning/branding muster had lower body condition to those cows that were not lactating **Figure 41** and **Figure 43**).

The body condition of heifers recorded at the pregnancy diagnosis muster was relatively consistent across country types with 50-75% of heifers having a body condition score of 3 or greater (**Figure 40**). The Central Forest appeared to have the largest variation in recorded body condition scores overall and between pregnant and non-pregnant heifers.

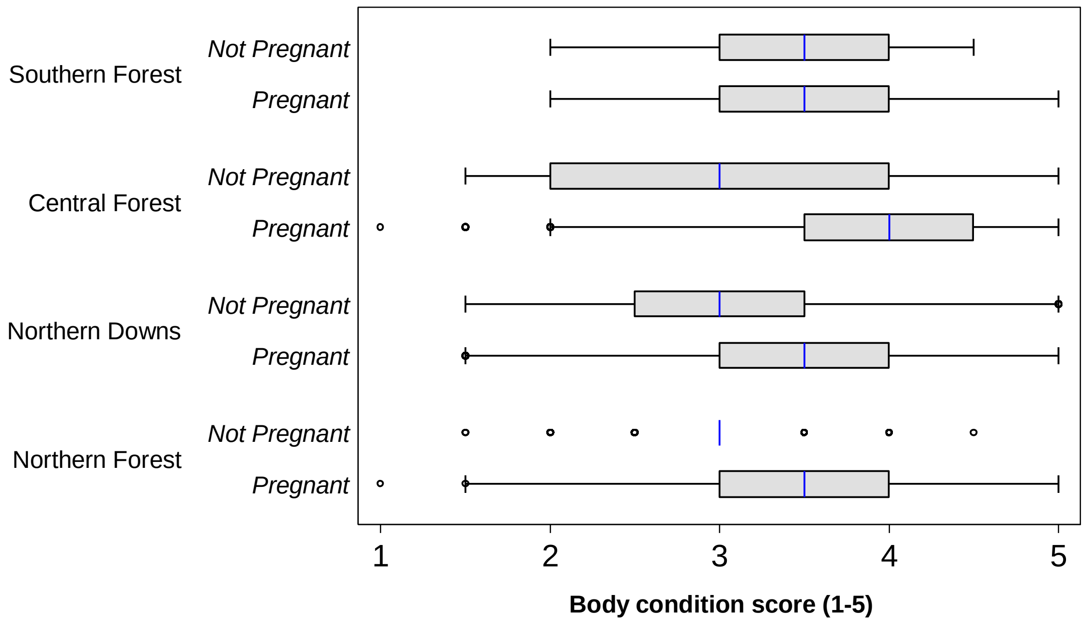

Figure 40: Box plot of recorded body condition scores of heifers at their pregnancy diagnosis muster grouped by pregnancy status and country type. Note the median, 25th and 75th percentiles were equal to 3 in Northern Forest heifers that were not pregnant.

The body condition score of lactating first-lactation cows in the Northern Forest was lower than that of other country types. Fifty percent of lactating first-lactation cows recorded a body condition score of 2.5 or less at the weaning/branding muster in the Northern Forest (**Figure 41**). For other country types, 75% of first-lactation cows recorded a body condition score of 2.5 or greater.

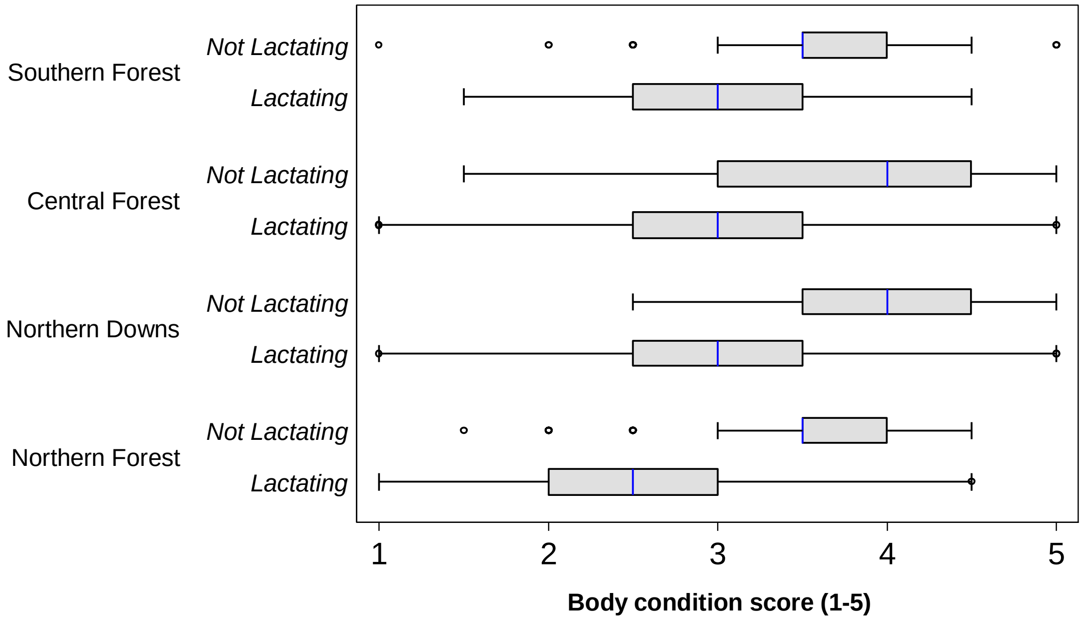

Figure 41: Box plot of recorded body condition scores in first-lactation cows at their weaning/branding muster grouped by lactation status and country type. Note the median and 25th percentile were equal to 3.5 in Northern and Southern Forest Heifers that were not lactating.

The variation in observed body condition scores for first-lactation cows at the pregnancy diagnosis muster was less than other cow age classes and other musters. With the exception of pregnant first-lactation cows in Southern Forest and non-pregnant first-lactation cows in the Northern Forest, at least 50% of observed body condition scores were within a range of half a body condition score (**Figure 42**).

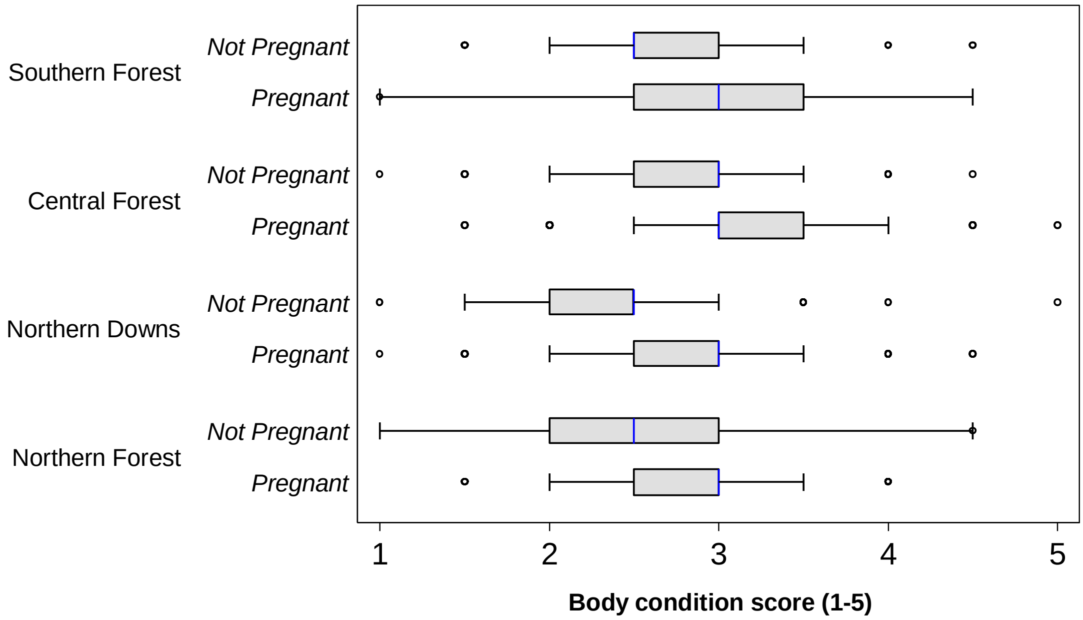

Figure 42: Box plot of recorded body condition scores in first-lactation cows at their pregnancy diagnosis muster grouped by pregnancy status and country type. Note the median and either or both the 25th and 75th percentiles were often equal and have been shown as a single vertical line.

The body condition score of lactating mature and aged cows in the Northern Forest was less than that of other country types with 75% of cows having a body condition score 3 or less at the weaning/branding muster (**Figure 43**). Northern Downs had the higher body condition for lactating and non-lactating cows with 75% of cows having a body condition score of 3 or greater or 3.5 or greater, respectively.

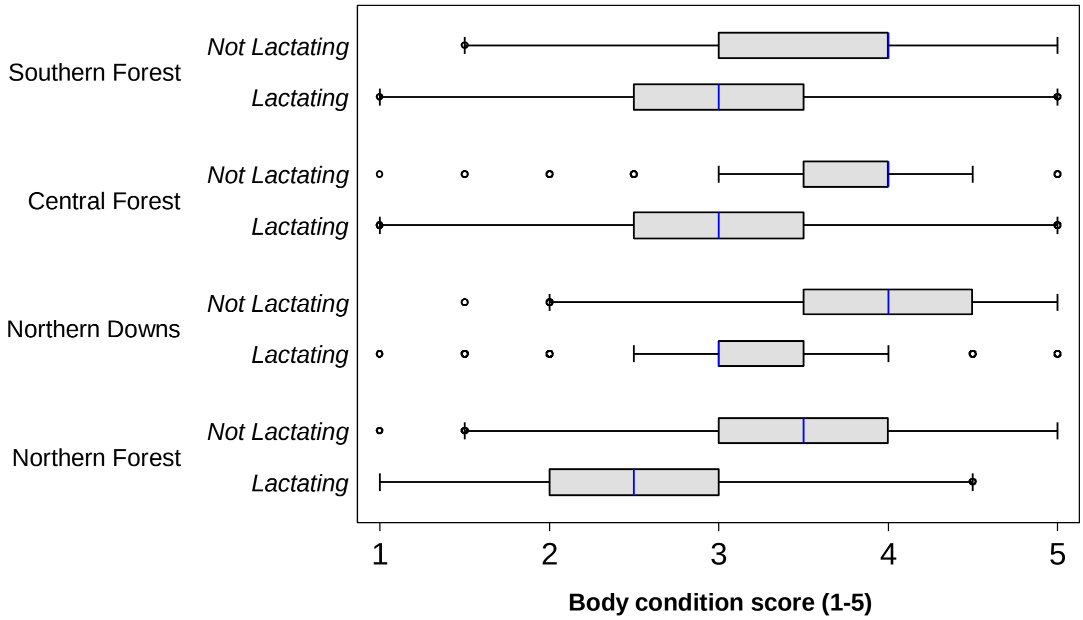

Figure 43: Box plot of recorded body condition scores in mature and aged cows at their weaning/branding muster grouped by lactation status and country type. Note the median and either or both the 25th and 75th percentiles were often equal and have been shown as a single vertical line.

The body condition of mature and aged cows at the pregnancy diagnosis muster was less in the Northern Forest than for other country types (**Figure 44**). Seventy-five percent of pregnant and non-pregnant cows in the Northern Forest were recorded as having a body condition score of 3 or less. The variation in recorded body condition scores of mature and aged cows that were not pregnant at the pregnancy diagnosis muster appeared to be greater for Central Forest and Northern Downs than other country types.

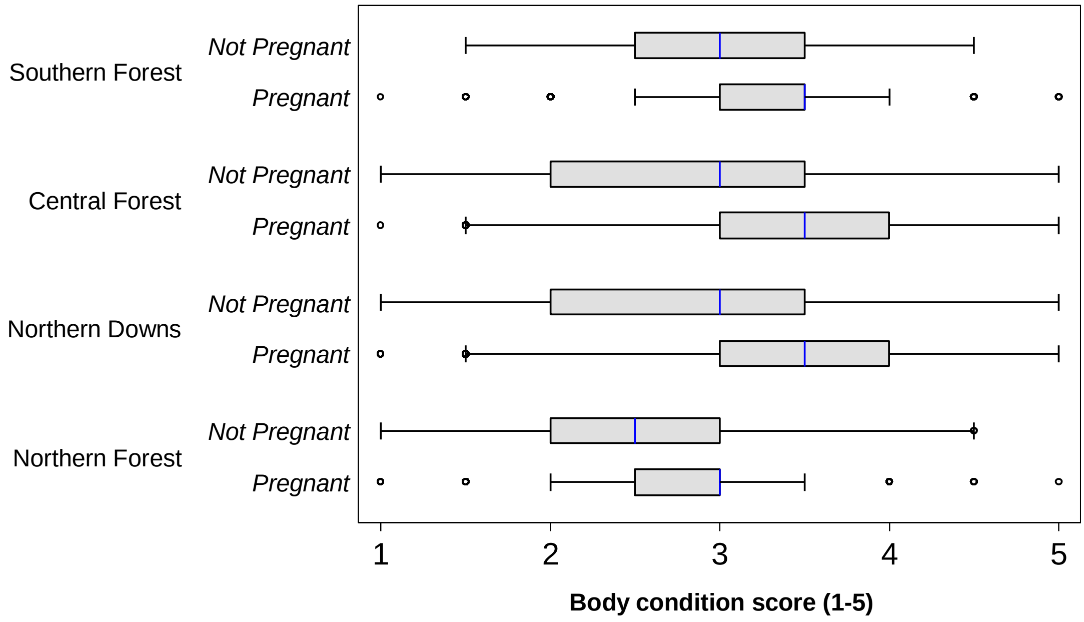

Figure 44: Box plot of recorded body condition scores in mature and aged cows at their pregnancy diagnosis muster grouped by pregnancy status and country type. Note the median and either or both the 25th and 75th percentiles were often equal and have been shown as a single vertical line.

4.6.2 Nutritional factors

4.6.2.1 Dietary crude protein (CP)

NIRS analysis of faeces (F.NIRS) was used to estimate the crude protein concentration of the diet. Faecal samples were usually collected five times each year during the months of January, March, May, August and November. Crude protein was generally highest during January, markedly decreasing between March and May, where only 50% properties had CP values exceeding 7% (**Figure 45** and **Figure 46**). Northern Forest generally had the lowest CP values and Southern Forest and Northern Downs were generally highest.

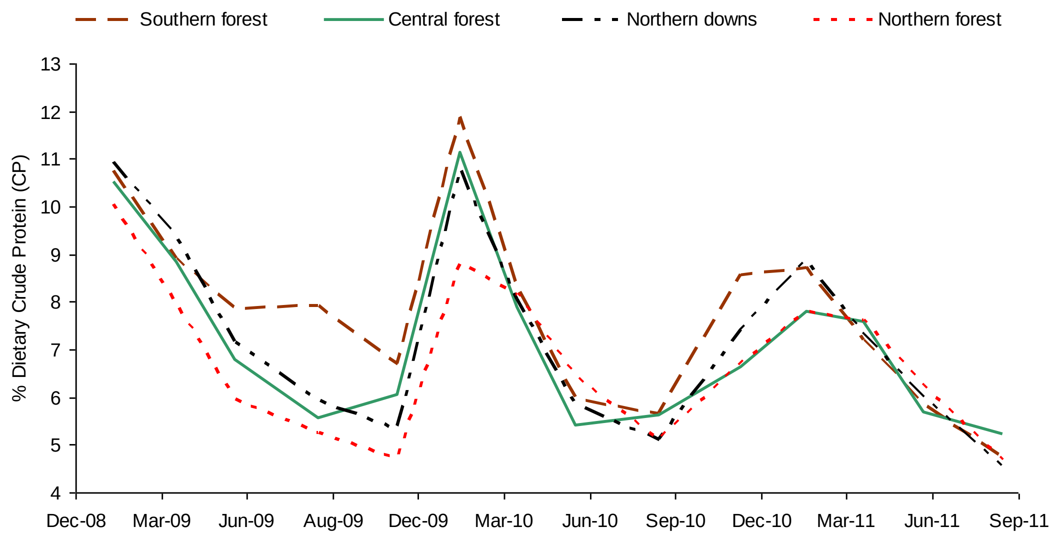

Figure 45: Mean dietary crude protein averaged over all properties in each country type by month of year.

Above average rainfall received during August-September 2010 produced an early increase in CP for all regions, though the peak CP values were not recorded under these conditions. The Southern Forest consistently recorded CP values rising earlier following the dry season, and Northern Forest consistently later.

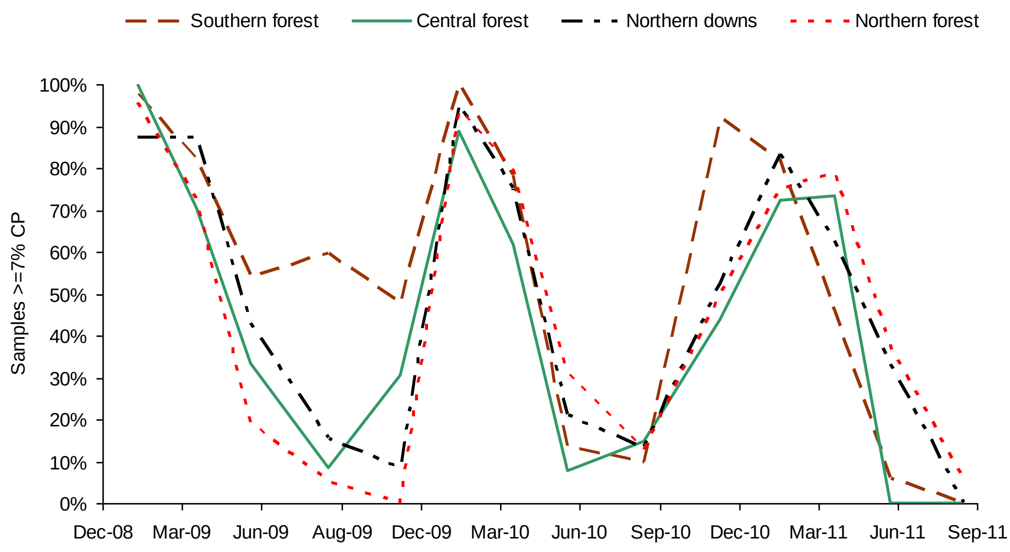

Figure 46: Percentage of samples in which dietary CP was >7%. Note estimates of dietary CP sample results were averaged over all properties in each country type by month of year.

4.6.2.2 Dry matter digestibility (DMD)

NIRS analysis of faeces (F.NIRS) was used to estimate the dry matter digestibility of the diet. Faecal samples were usually collected five times each year during the months of January, March, May, August and November. Overall, the average DMD was highest in the Northern Downs compared to the other three country types. Northern Forest generally had the lowest DMD throughout the year (**Figure 47**) and typically less than 30% of Northern Forest properties had DMD values exceeding 55% between May and October each year (**Figure 48**).

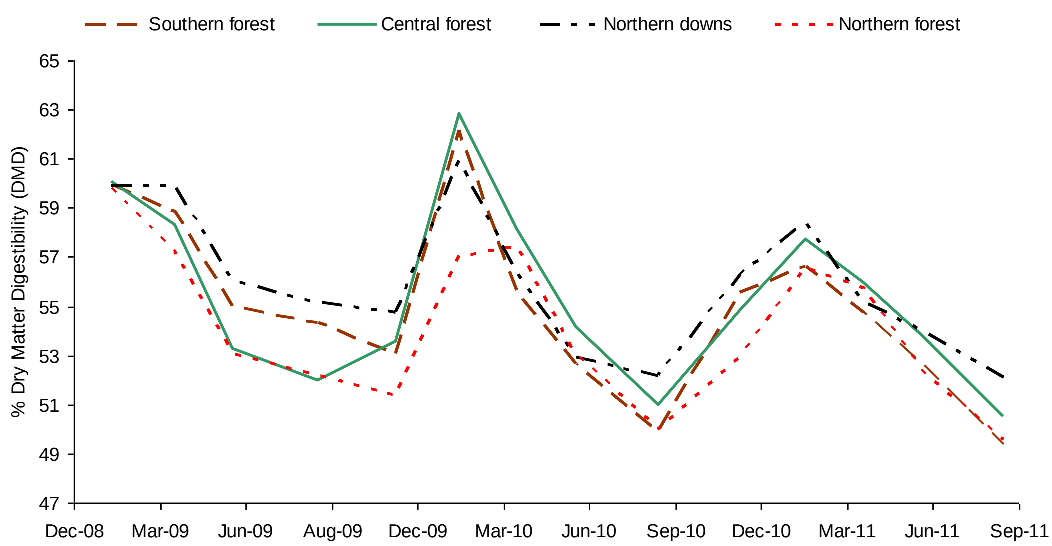

Figure 47: Average dry matter digestibility as estimated by faecal NIRS.

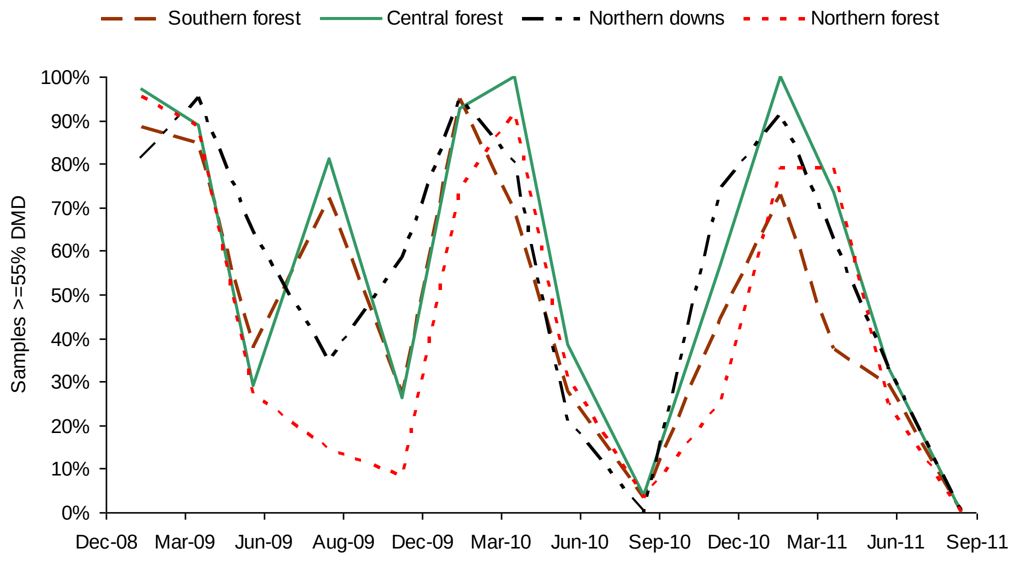

Figure 48: Percentage of samples with ≥55% dry matter digestibility.

Although the 2009 June-November rainfall was extremely low, and the previous December-February was mostly below average, Southern Forest DMD was generally satisfactory during 2009. However, average DMD of the Southern Forest was lower than the other country types through much of 2010 (March to September) (**Figure 47**). Central Forest DMD was very low in May–August 2009. Note: average DMD of Northern Downs was markedly higher than both Central and Southern Forest in August 2009.

A greater percentage of the samples collected at the same sampling time from both the Central and Southern Forest had DMD levels ≥55% (80% and 70% of samples respectively) compared with the Northern Downs (35%) (**Figure 48**).

4.6.2.3 Ratio of crude protein to dry matter digestibility (CP:DMD)

Rumen degradable nitrogen is usually the first limiting nutrient of cattle grazing dry season pastures. The ratio of CP:DMD provides a measure of the availability of rumen degradable nitrogen to metabolisable energy in the diet. However, caution is needed in the use of the ratio because if F.NIRS either over-estimates dietary crude protein or under-estimates dry matter digestibility, a deficiency of dietary crude protein relative to digestibility may not be detected.

Ruminant nutritionists currently recommend that a ratio of CP:DMD of 0.1-0.11 (DMD:CP ratio of 9-10) is appropriate for areas other than coastal speargrass areas of eastern Queensland. Trial results from northern speargrass pastures also concluded that a ratio of DMD:CP >8:1 was appropriate[55], and as a number of properties within the Northern Forest country type are speargrass dominated pastures, the project analyses were conducted using a conservative CP:DMD measure of 0.125:1 (DMD:CP = 8:1).

The ratio of CP:DMD follows a similar pattern as other nutritional indicators, with lower nutritional value during the dry season (May-October) and higher values during

[55] Dixon & Coates (2005)

wet season (November-April) (**Figure 49** and **Figure 50**). CP:DMD ratio follows the same pattern as both CP and DMD. Pasture protein was inadequate for a majority of properties between May and October each year. Protein adequacy was highest on average in the Southern Forest and lowest in the Northern Forest.

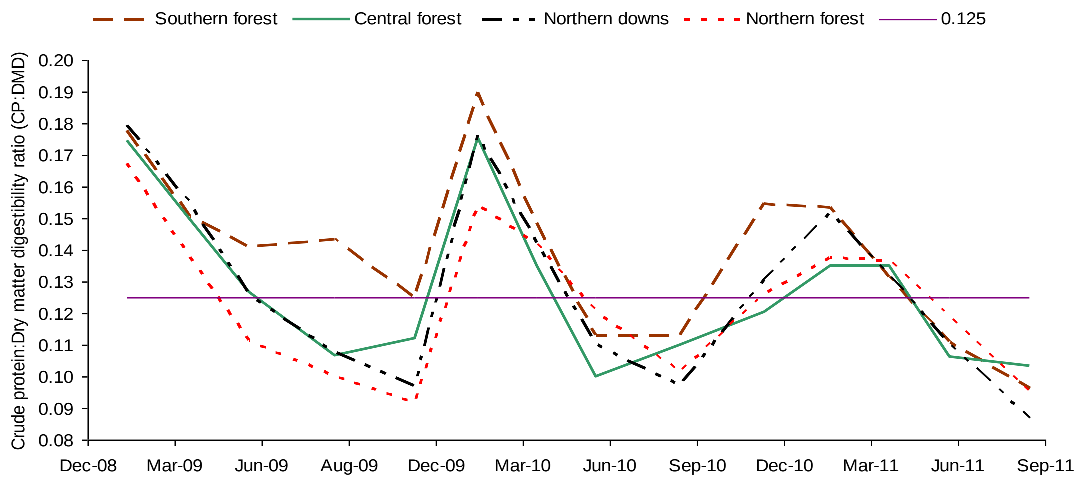

Figure 49: Average CP:DMD ratio and a target of 0.125.

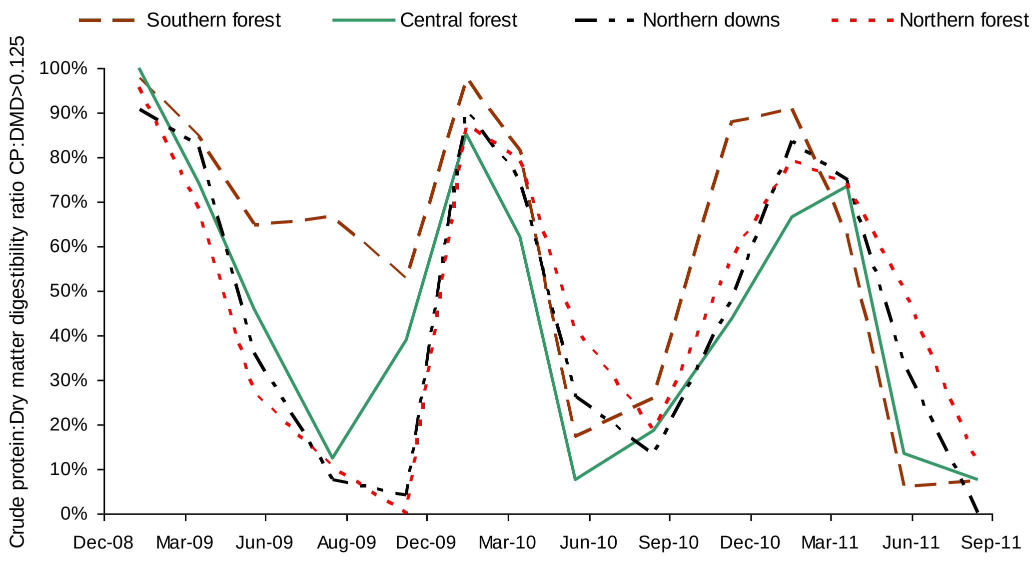

Figure 50: Percentage of CP:DMD ratios >0.125.

4.6.2.4 Phosphorous

During the dry season, the major limiting nutrient is often nitrogen rather than metabolisable energy or phosphorous. Phosphorous requirements are usually low during the dry season (except for lactating females and females in late pregnancy). The results presented in this section largely relate to the wet season (November-April) as this is the period of expected greatest risk of P deficiency.

Since the amount of phosphorous required depends on the amount of energy the animal is consuming, its need for phosphorous can be estimated from the ratio of the phosphorous concentration in faeces and the level of dietary energy[56]. The results presented in this section summarise the measured concentrations of faecal phosphorous and faecal phosphorous relative to metabolisable energy by country type and by month of sample collection.

Also, these descriptive results do not differentiate whether phosphorous supplement was fed or not and in most cases for practical reasons supplemental P was not removed from animals 1-2 weeks prior to sample collection, as is recommended.

During the project, there was much discussion around what FP:ME threshold values to use. Dr Rob Dixon was consulted and reviewed the preliminary findings from the FP:ME analysis. The results presented in this section use a FP:ME ratio of 500 as a cut point. This cut point was based on an assessment of the preliminary univariable logistic regression models fitting FP:ME as the sole predictor of cow reproductive performance data collected during this project.

A threshold value of 420:1 is the current recommended threshold value[57] and relates to a 400kg cow maintaining weight on a 54% DMD pasture and producing 5L of milk per day[58]. Factors which may have contributed to the higher CashCow threshold value are the average liveweight of cows being ~460 kg at the weaning/branding muster and the fact that most cows lost weight while lactating during the wet season. However, it is acknowledged that the observed average DMD during the wet season was often in the range of 58-60%. A further factor that was considered was the possibility of laboratory error. A stratified random sample (n=20) of stored faecal samples were selected, and each sample was subsampled and sent to three different laboratories (including the UQ laboratory, which analysed all the CashCow samples) for analysis. The two laboratories selected to do the comparative testing were recognised for their work in estimating mineral content of forages, soils and faeces. There was a high degree of agreement between the results from the three laboratories, although there was some variation in results between laboratories primarily due to the fact that some expressed results on an as received basis whereas others expressed them on the basis of percentage dry matter. Overall, when all samples were compared on a dry matter basis, the UQ laboratory estimates of faecal P were 1.08 and 1.13 times higher than results from the other laboratories. Taking all this into account, the current recommended threshold value[59] and the value determined by analysis of the CashCow data are very similar.

Average faecal P (**Figure 51**) and the ratio FP:ME (**Figure 52**) consistently followed a seasonal pattern with higher values recorded during November-March, which coincided with the wet season. Consequently, the proportion of samples that were ≥500 mg P/MJ ME was greater during the wet season (**Figure 53**). In relation to the seasonal cycles, as a grass plant increases in biomass and matures most of the P is translocated from older leaves to new leaf growth. As the plant matures further and dries off, much of the P is translocated back into the roots. Plant P concentration, and the P concentration of the diet selected by grazing cattle, therefore declines in line with increasing plant biomass and physiological maturity. Also, it has been shown that soil available P increases during the wet season and decreases during the dry season.

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[56] Jackson *et al* (2012)
[57] Jackson *et al* (2012)
[58] Jackson *et al* (2012)
[59] Jackson *et al* (2012)

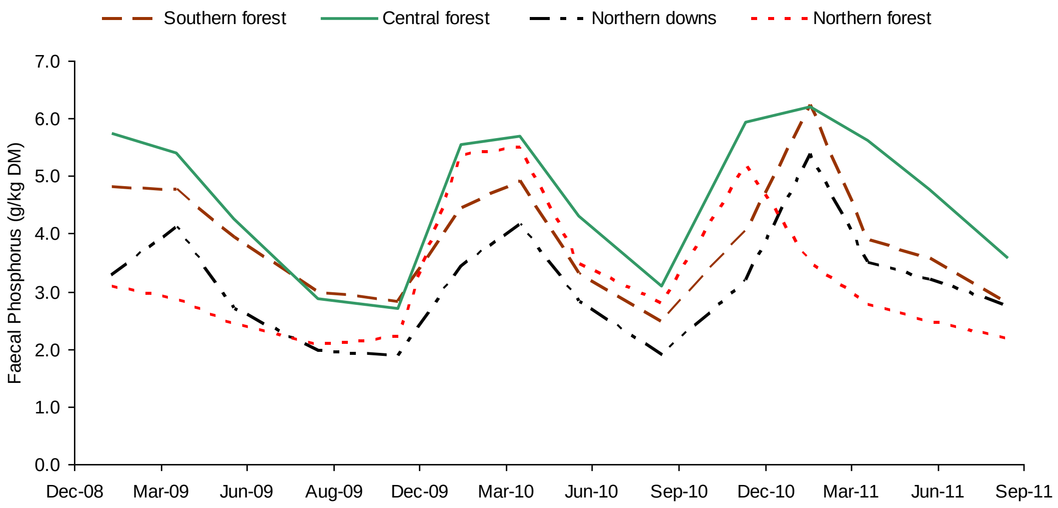


Figure 51: Plot of the average faecal phosphorous (g of P/kg of DM) recorded for each country type.

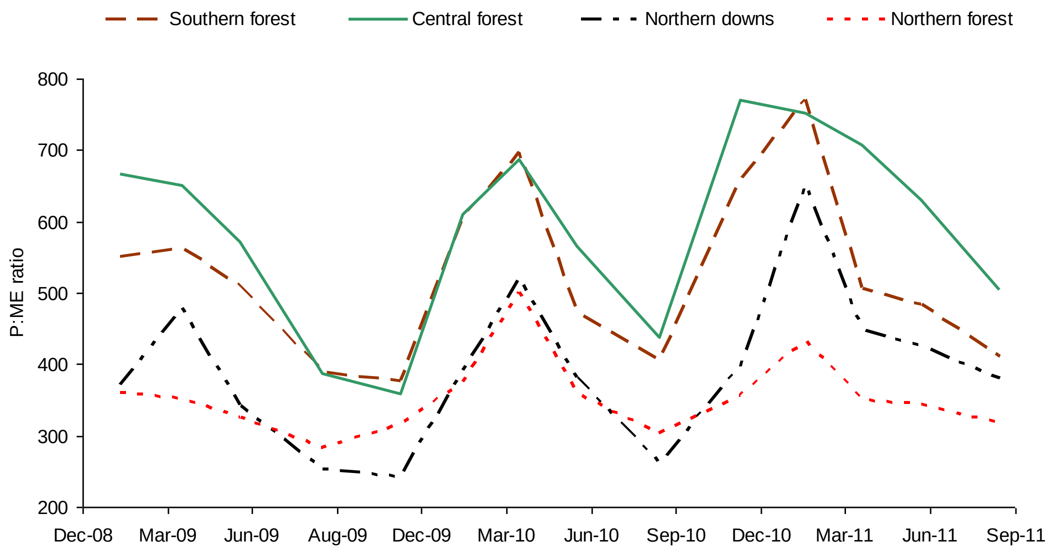


Figure 52: Plot of the average FP:ME ratio (mg P per kg faecal DM)/(MJ of ME per kg DMI) recorded for each country type.

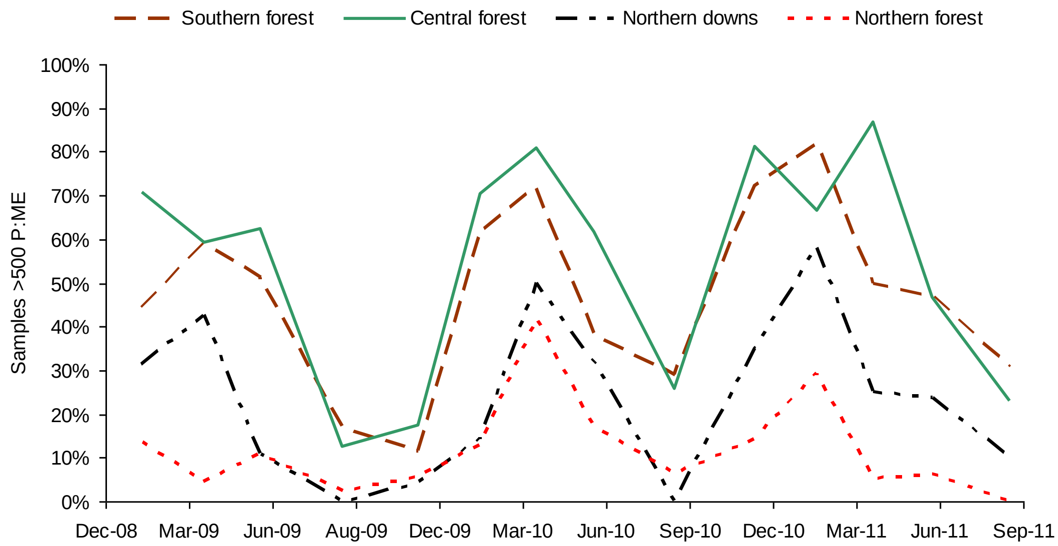


Figure 53: Plot of the percentage of properties with an average wet season FP:ME ratio ≥500 for each country type.

The distribution of observed wet season FP:ME values is summarised in **Table 47** according to the following FP:ME categories: <300, ≥300-420, ≥420-<500 and ≥500. Southern and Central Forest appeared to have a higher proportion of samples ≥500 mg P/MJ ME than the Northern Downs and Forest. However, it should be noted that 9% of observed wet season FP:ME values in these country types were <300 mg P/MJ ME. The proportion of samples in the ≥420-500 category was relatively consistent across country types. The Northern Forest and Downs tended to have a greater proportion of observed wet season FP:ME values in the <300 mg P/MJ ME category.

Table 47: Distribution of observed FP:ME values recorded for each country type during the wet season. Note that some properties contributed more samples than others due to study animals being managed in more than one mob.

Average Wet Season FP:ME category	**<300**		**≥300-<420**		**≥420-<500**		**≥500**	
	no. samples collected	%*	no. samples collected	%*	no. samples collected	%*	no. samples collected	%*
Southern Forest	27	9.4	48	16.8	47	16.4	164	57.3
Central Forest	18	9.1	31	15.7	25	12.6	124	62.6
Northern Downs	70	38.9	43	23.9	15	8.3	52	28.9
Northern	81	32.7	97	39.1	34	13.7	36	14.5

Forest

*Percentages have been calculated as the number of samples within the FP:ME category of interest relative to the total number of samples collected for that country type.

To account for the fixed effects of country type and year and clustering for paddock and property, a linear regression model was used to predict average wet season ratio FP:ME. The interaction between country type and year was explored but was not retained due to it not being significant. There appeared to be some clustering of observed values within properties and paddocks within properties.

The predicted average wet season FP:ME ratio was significantly lower in the Northern Forest and Downs than in the Southern and Central Forest (**Table 48**). The variation in FP:ME values recorded during the wet season was greatest in the Central Forest and least in the Northern Forest. The changes in predicted FP:ME by country type and month are presented in **Figure 54**.

Table 48: Predicted average FP:ME (mg P/MJ ME) values measured during the wet season (November-April). The predicted wet season mean FP:ME was produced using linear regression analysis with clustering for property and paddock.

Country Type	Average wet season FP:ME (mg P/MJ ME)				
	No. of samples	Mean	SE	95% Confidence interval	
				Lower	Upper
Southern Forest	281	606.4^{A}	36.0	535.7	677.0
Central Forest	191	607.0^{A}	49.8	509.3	704.7
Northern Downs	176	427.1^{B}	35.3	358.0	496.3
Northern Forest	244	368.4^{B}	13.7	341.6	395.2

Note: Means that are not sharing a common superscript letter are significantly different at P<0.05.

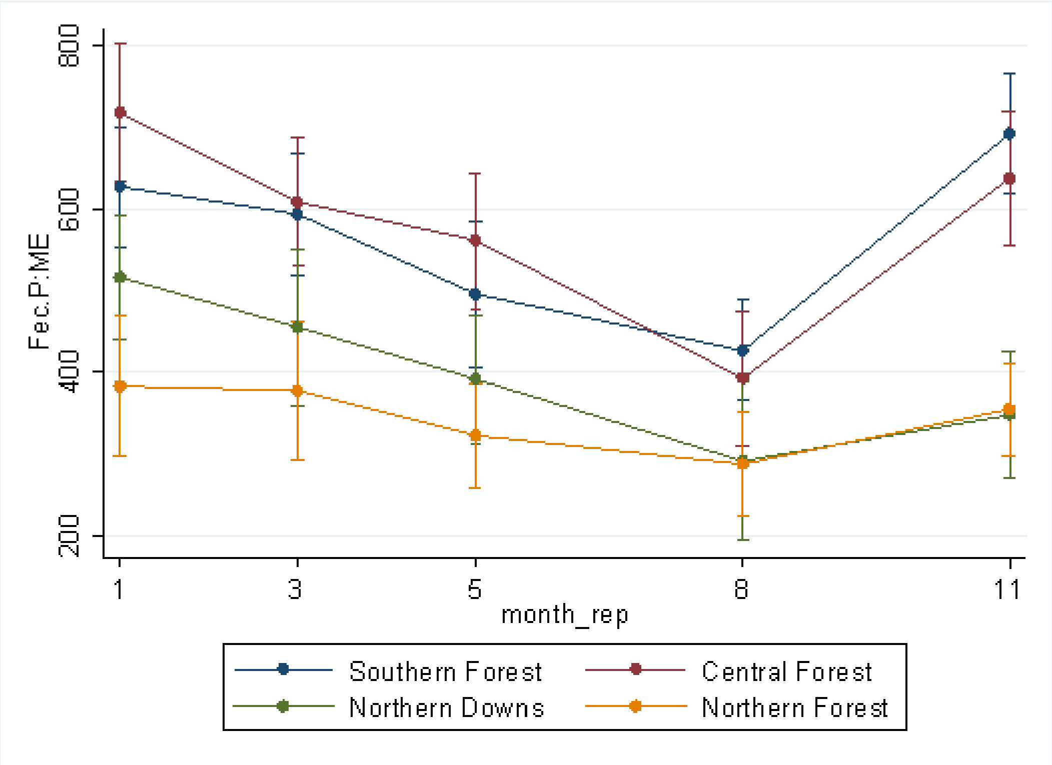


Figure 54: Predicted faecal P:ME by country type and month of faecal sampling (1=January; 3-March; 5=May; 8=August; 11=November). Derived from a linear regression model with clustering of paddock within property.

Overall, average wet season FP:ME values were derived for 192 property-years. Using a Poisson regression analysis with clustering for property and the fixed effects of country type, year, and provision of P supplement, the incidence of an average wet season FP:ME ratio of less than 500 mg P/MJ ME was not significantly associated with the provision of supplemental P (P=0.10) (**Table 49**). Also, within country types, there was no significant association between the provision of supplemental P and the incidence of average wet season FP:ME ratio less than 500 mg P/MJ ME. This finding should not be interpreted as saying that feeding supplemental P was of no value, as it is quite possible that properties feeding supplemental P were aware that they were P deficient and this is why they were feeding a P supplement.

Table 49: The percentage of property-years recorded with average wet season FP:ME values <500 mg P/MJ ME, expressed as the percentage of wet seasons <500 mg P/MJ ME per 100 properties at risk per year.

	Percentage of wet season average FP:ME <500 mg P/MJ ME (%)				
Country type by whether supplemental P was provided or not	**No. of property-years**	**Incidence (%)**	**SE**	**Lower***	**Upper***
Southern Forest					
No P supplement	35	26	9	9	43
P supplemented	16	56	19	20	93
Central Forest					
No P supplement	23	30	12	8	53
P supplemented	14	43	17	9	77
Northern Downs					
No P supplement	22	64	17	30	97
P supplemented	12	83	26	32	~100
Northern Forest					
No P supplement	24	83	19	47	~100
P supplemented	46	93	14	66	~100

* Lower and upper limits of 95% confidence interval

4.6.3 Grazing Land Management

Grazing land management in this project has been described by

1. Availability of pasture (yield)
2. Distance from water (1.5, 2.5km buffers) and
3. Grazing system used

The primary grazing management measure used was pasture quantity, estimated five times annually using photo standards. The hypothesis was if pasture quantity was limiting, there could be an impact on animal performance. For this project, the indication of overgrazing (limited pasture availability) was the incidence of pasture yields below 1000kg/ha.

Also, distance (access) to water was mapped using GIS software as an indicator of the proportion of each paddock likely to be grazed by cattle. Distance zones were 1.5km and 2.5 km.

Describing annual stocking rates was problematic due to cattle movements between paddocks (i.e., time factor) and fluctuating cattle numbers within the paddocks. In addition, the absence of recommended standardised stocking rates for the properties at the paddock level makes it difficult to conclude whether the stocking rate was high or low. Long term carrying capacities for the paddocks could be determined with the technique used in Grazing Land Management workshops; however, such analyses were outside of the scope of this project.

4.6.3.1 Pasture yields

Pasture yields in paddocks grazed by project cows were measured five times annually during the project (January, March, May, August-November).

The distribution of yields followed seasonal patterns and peaked in March in all areas and years (**Figure 55** to **Figure 58**). Low yields by November occurred more consistently in the Northern Forest.

In all areas, pasture yields were frequently very low during June-November, 2009, particularly in the Southern Forest.

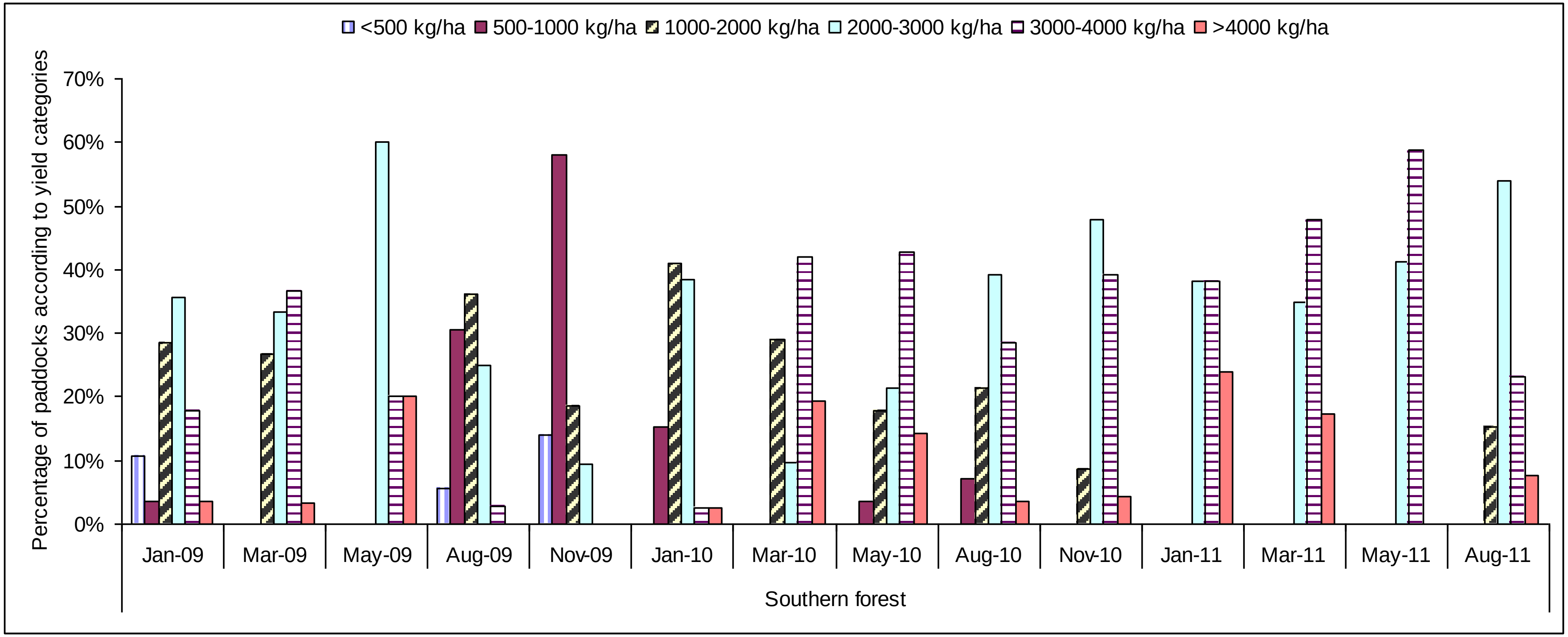


Figure 55: Distribution of pasture yields in the Southern Forest. By November 09 nearly three quarters of the paddocks recorded had very low yields (<1000kg/ha).

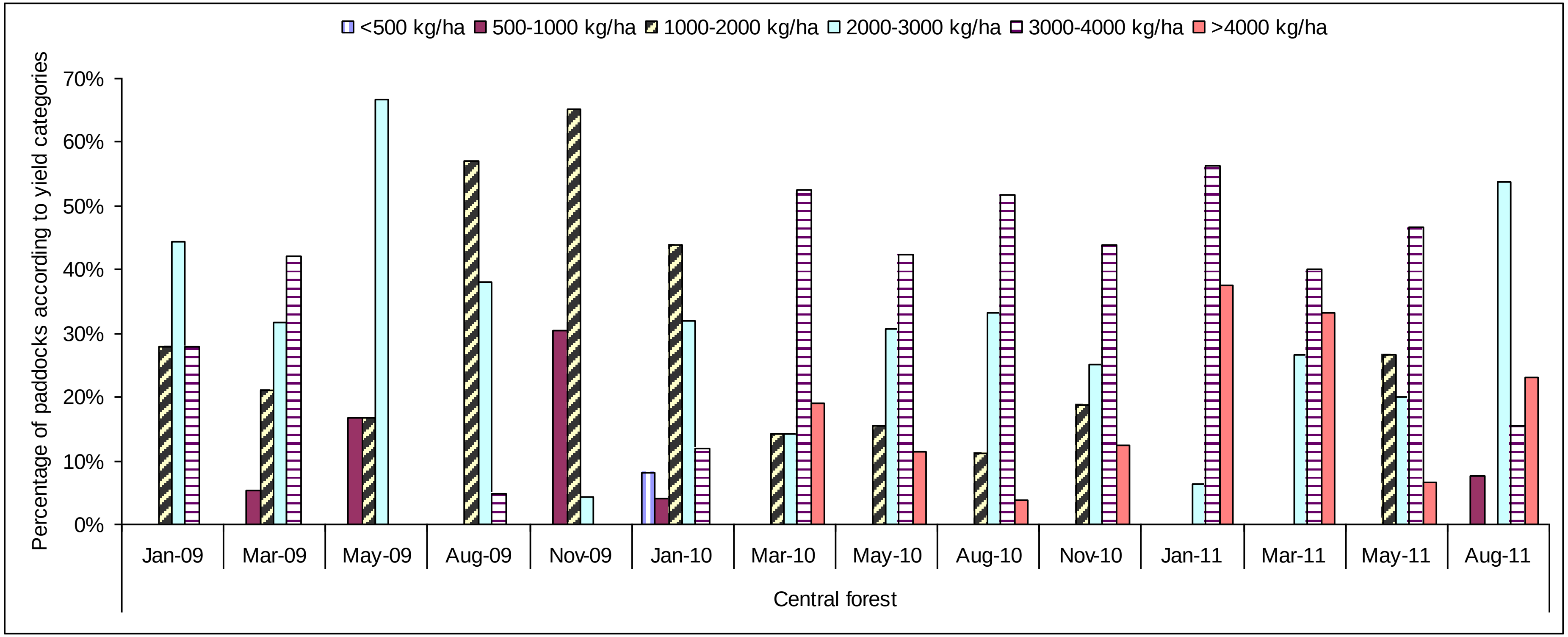


Figure 56: Distribution of pasture yields in the Central Forest. With the exception of 2009 and January 2010, pasture yields were generally maintained at moderate to high levels.

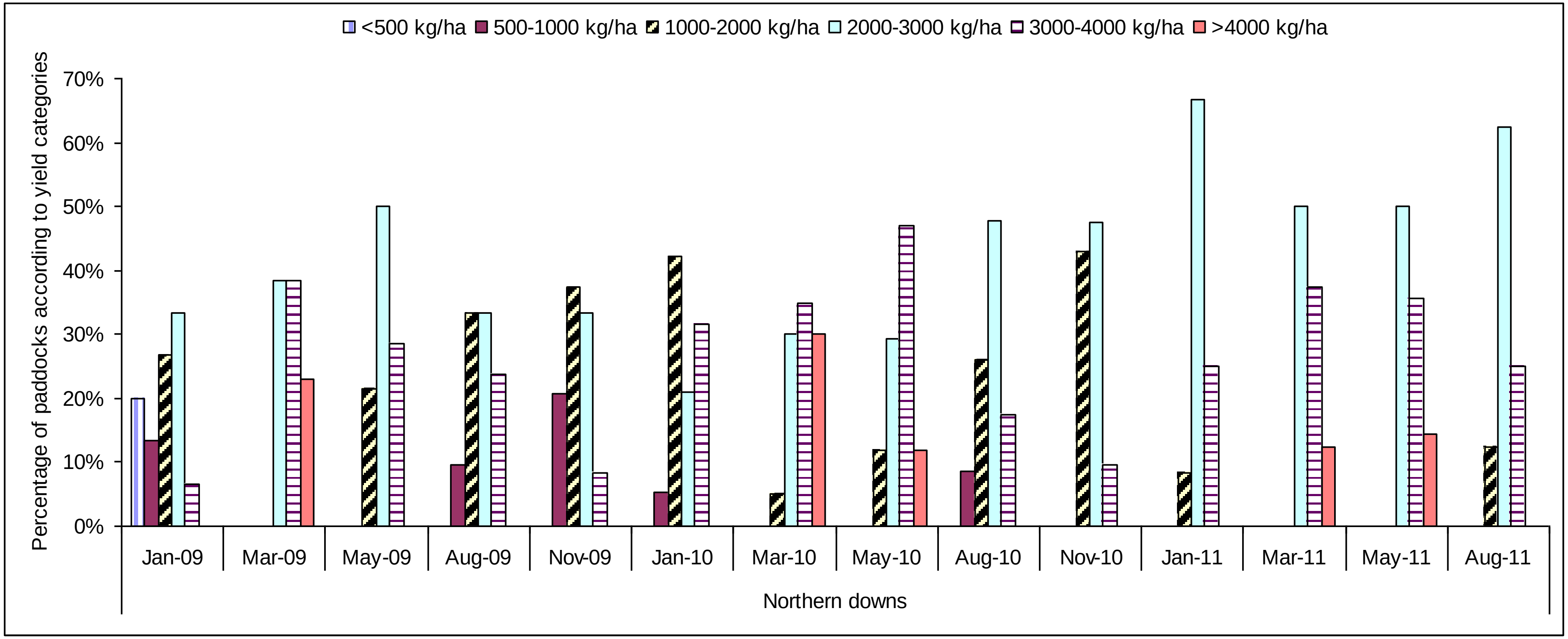


Figure 57: Distribution of pasture yields in the Northern Downs. With the exception of 2009, low pasture yields were not an issue.

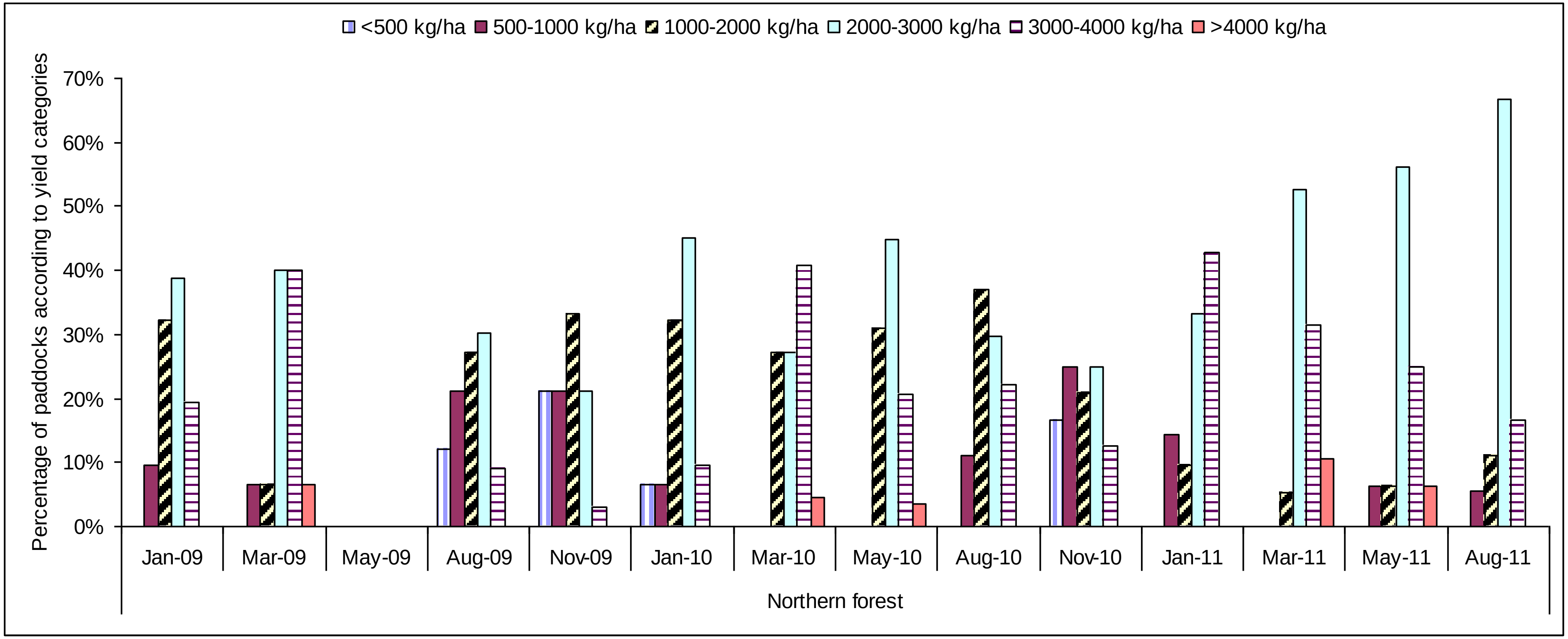


Figure 58: Distribution of pasture yields in the Northern Forest. By November in 2009 and 2010, pasture yields had reduced to very low levels (<1000kg/ha).

4.6.3.2 Access to water

In the paddocks used by project cows, more than 50% of the area was within 1.5 km of a permanent water point, and in the Southern and Central Forest almost 100% were within 2.5 km of a permanent water point (**Figure 59** and **Figure 60**).

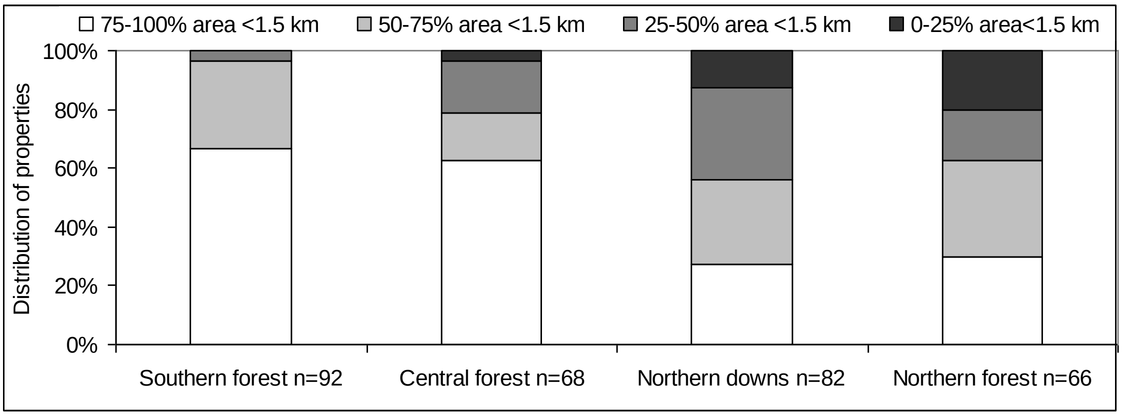


Figure 59: Distribution of properties within region on percentage paddock areas within 1.5 km of water, n=number of paddocks.

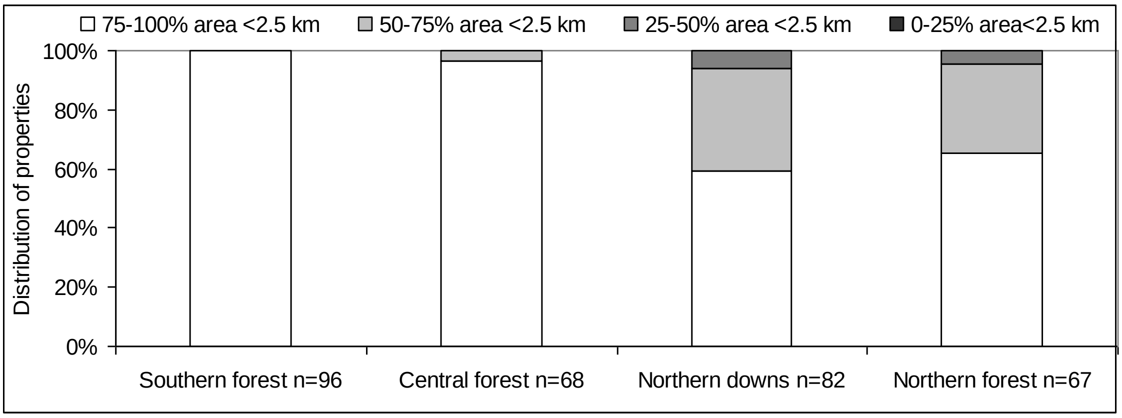


Figure 60: Distribution of properties within region on percentage paddock areas within 2.5 km of water, n=number of paddocks.

4.6.3.3 Grazing systems

A range of grazing systems were utilised by the participating properties. Analysis of data from 410 paddocks monitored over a three to four year period indicated that three properties used cell-grazing (counted as one paddock each), approximately 10% used four to six paddocks during the measurement period and a third used more than six paddocks over the period of the project. Overall 90% of properties practiced some form of paddock rotation.

4.6.4 Environmental factors

4.6.4.1 Rainfall

Average monthly rainfall over the project followed the same summer dominant pattern across all regions, with some variation in totals (**Figure 61**). The major differences that occurred were between the Southern/Central Forest (sub-tropical) and the Northern Downs/Northern Forest (tropical) areas. These differences were:

- A poor and good wet season in 2009 in the sub-tropical and tropical areas, respectively.
- Higher early wet season rainfall in late 2010 in sub-tropical areas.

Rainfall for the 2009 dry season was extremely low, and then was followed by average to well-above average rainfall during the same period in 2010 across the project region.

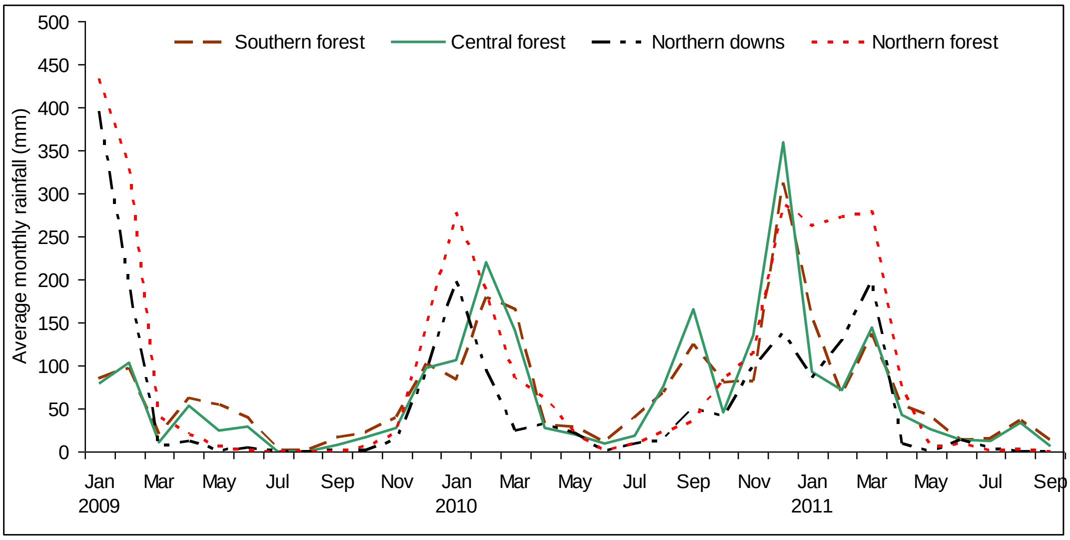


Figure 61: Average monthly rainfall by country type.

4.6.4.2 Temperature

Maximum and minimum average temperatures were as expected, with Southern and Central Forests generally being lower than the Northern Downs and Northern Forest (**Figure 62** and **Figure 63**). The average monthly temperature-humidity index (THI) is presented in **Figure 64**. Over the course of the project, the average THI was highest in the Northern Forest, except during the summer of 2011 when it was highest on the Northern Downs. The average monthly THI during the summer months was generally at least 79 across all country types. A THI of 79 indicates that cattle are at risk of experiencing the adverse effects associated with a moderate increase in body heat load.

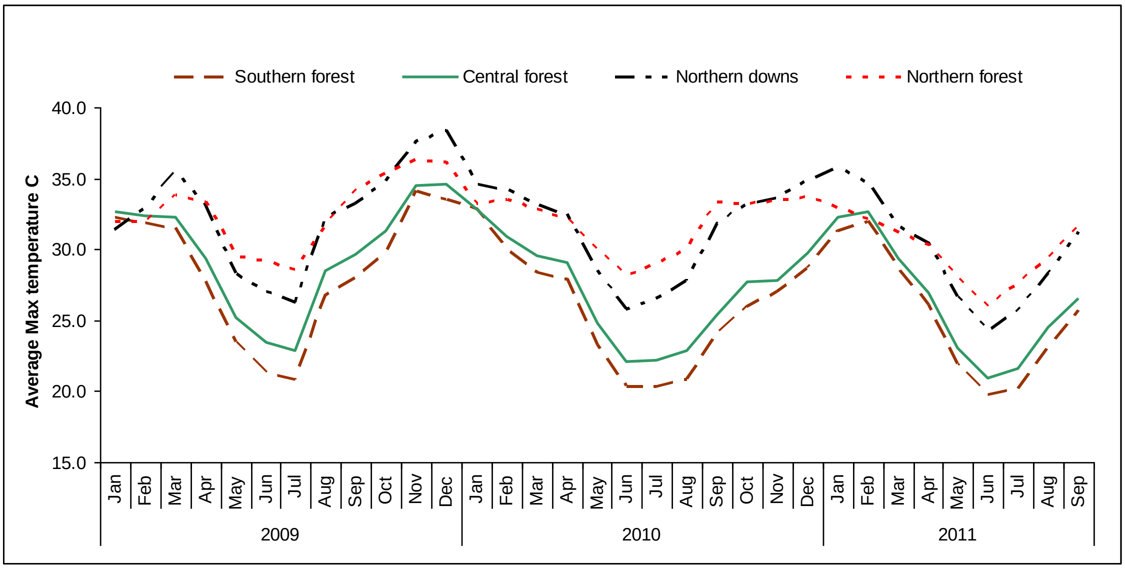


Figure 62: Average monthly maximum temperatures (^oC) by country type.

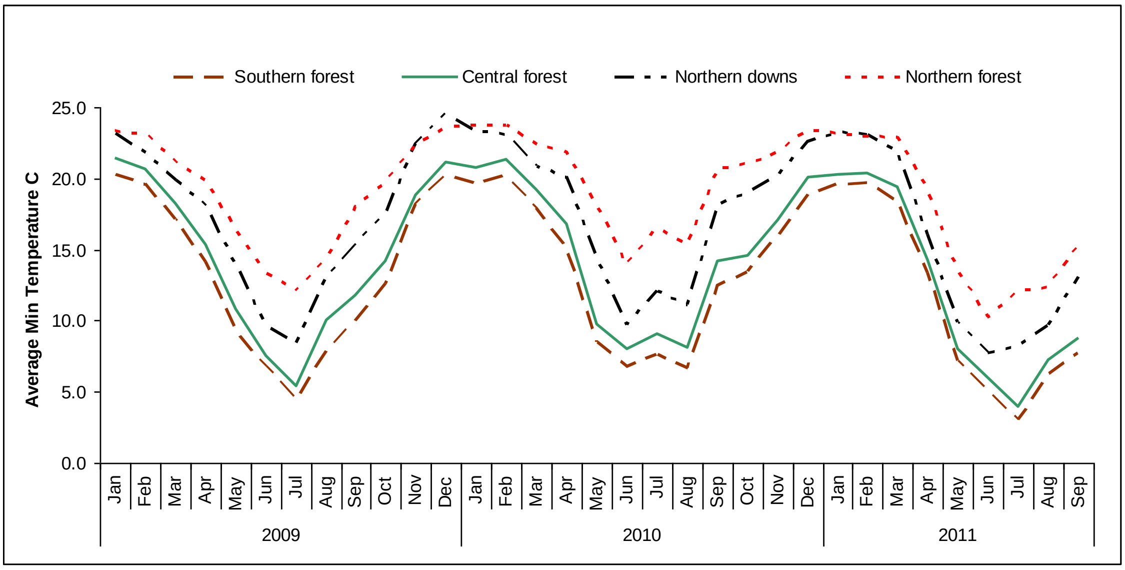


Figure 63: Average monthly minimum temperatures (^oC) by country type. Higher temperatures were recorded in the more northern areas.

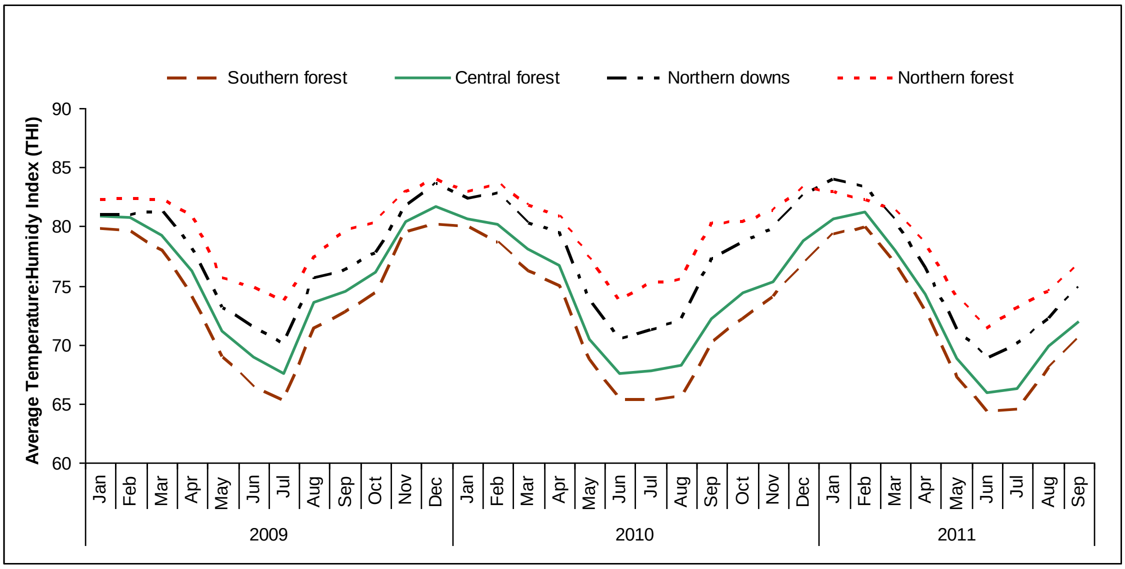


Figure 64: Average monthly temperature-humidity index (THI) by country type. Higher temperature and humidity was recorded in the northern areas.

4.6.4.3 Wild dogs

The Management Survey (**Appendix XI**) asked managers to indicate if dingoes (wild dogs) were impacting on breeder productivity. Presence of wild dogs and control measures varied considerably (**Figure 65**, **Figure 66**). Where dingoes were present, the majority of producers had implemented a regular baiting programme. Data from an Invasive Animals CRC project demonstrated the varied distribution of wild dogs (**Figure 66**). All areas of northern Australia showed a presence of wild dogs, from occasional to abundant. Only southern Australia recorded areas where wild dogs were absent.

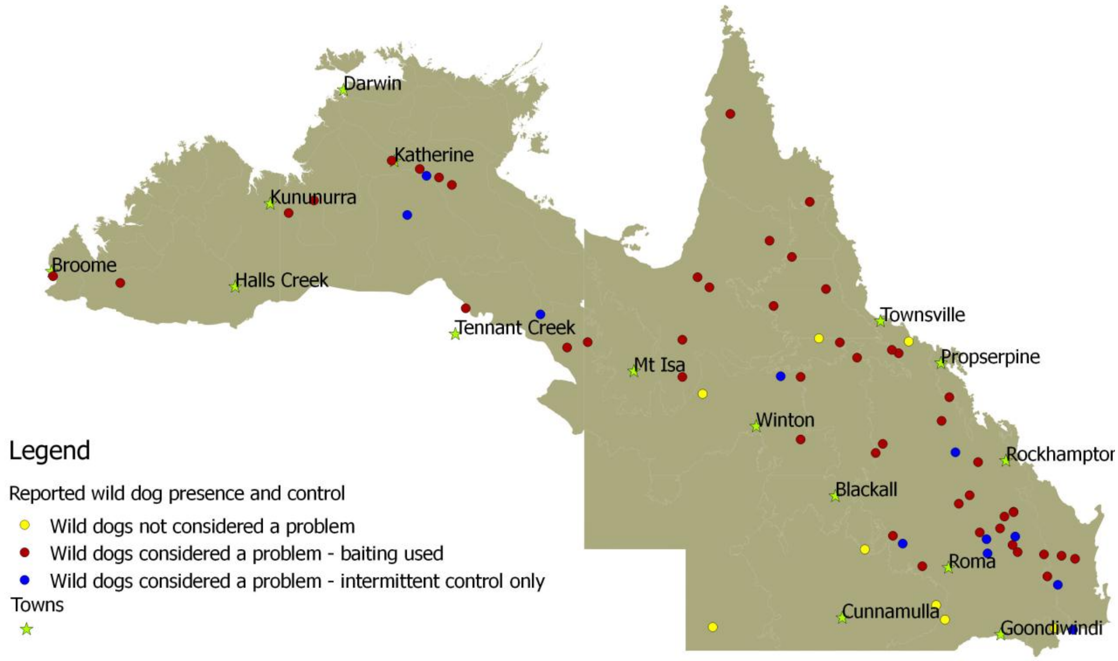


Figure 65: Map of reported property-level wild dog presence and control for each project property.

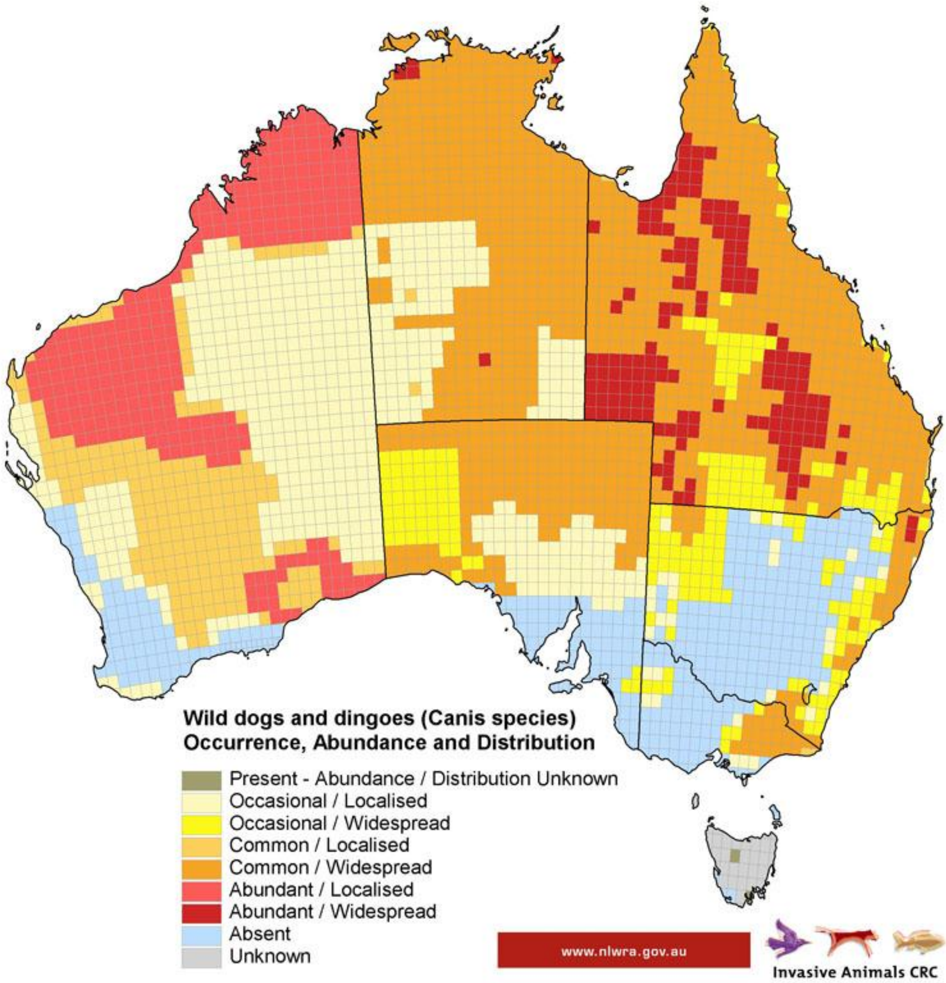


Figure 66: Occurrence, abundance and distribution of wild dogs in Australia[60].

[60] West (2008)

4.6.5 Prevalence of infectious causes of reproductive loss

The number of serum samples tested for each of the potential infectious causes of reproductive loss depended on:

1. The number of samples submitted by the data collector from each mob (management group), and the quality of these samples. It is important to recognise that due to events beyond the control of the data collector or producer a small proportion of mobs could not be sampled at the scheduled time.

2. The amount of sera available for testing. In many cases a single serum sample was used for more than one serological test.

Further, after the first scheduled blood sampling in 2009 (at first annual branding/weaning muster), it was recognised that blood sampling 30 animals in mobs of <200 cows was excessive and thus a sampling schedule based on number of cattle in the management group was introduced. However, as the serological testing for BVDV was performed on this first lot of blood samples collected, the number of samples tested was higher than that for other infectious agents, which utilised samples collected at the next muster (pregnancy diagnosis muster) after introduction of the modified sampling schedule.

It should be noted that the findings of the summary analysis presented in the following sections are presented by actual management group (mob), and the total number of mobs sampled varied from what was originally enrolled because some mobs were not sampled, for example due to flood events, and also because at the time of sampling some mobs may have been combined for management reasons. Population estimates of the seroprevalence of each infectious disease were derived from a model which contained country type, year and cow age class/cohort, whereas the observed seroprevalence was based on unadjusted data. Finally, the data for the small number of mobs which were blood sampled in 2010 were combined with the 2009 data, as there was no evidence of significant differences between years in overall seroprevalence.

4.6.5.1 Bovine viral diarrhoea virus (BVDV)

The overall seroprevalence was similar for heifers and cows and between years, varying between 50.3% and 77.2% (**Table 50**). Therefore, on average about 30 to 50% of females were seronegative and thus susceptible to infection with BVDV. These findings are consistent with previous serological surveys conducted in northern Australia in the past 20 years[61]. The median mob seroprevalence was similar across country types and years ranging from 46 to 90% for cow/mixed mobs and 21 to 93% for heifer mobs (**Figure 67**; **Table 51**). Note these analyses included both unvaccinated and the small number of vaccinated mobs.

Overall, in 2009 and 2011 (**Table 52**) 21% and 15% respectively of cow/mixed mobs were mostly naïve (<20% seroprevalence), and 40% and 35% of mobs respectively were mostly naturally immune (>80% seroprevalence). Interestingly, in both years there were a higher proportion of mostly immune mobs in the Northern Downs than elsewhere.

The prevalence of cow/mixed mobs with low or high seroprevalence did not change greatly between 2009 and 2011, although the frequency of mostly naïve mobs tended to be lower in 2011, the frequency of moderately (seroprevalence of 20-80%)

[61] Taylor *et al* (2006); Schatz *et al* (2008)

immune mobs tended to be higher in 2011 and the frequency of mostly immune mobs tended to be lower in 2011. This was probably due to the cyclical change over time in immune status of endemically infected mobs.

Table 50: Population estimate of BVDV seroprevalence by cow age class.

Cow age class/Cohort	Year	No of samples	Seroprevalence of BVDV*		
			Mean (%)	95% Confidence interval	
				Lower	Upper
Main Heifers	2009	538	55.4	42.5	68.4
	2011	203	50.3	31.9	68.6
Pilot Heifers	2009	153	60.2	26.1	94.2
	2011	75	77.2	50.2	104.2
Cows/mixed	2009	1,115	50.3	50.3	69.2
	2011	927	53.1	53.1	70.5

*Seropositive - AGID test result >0

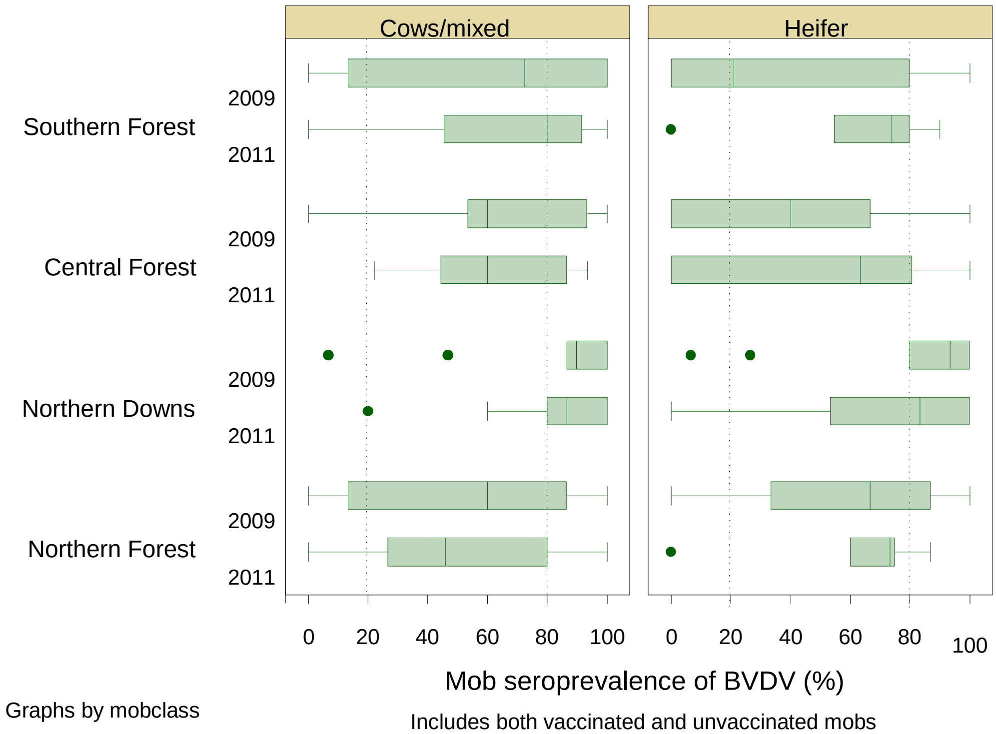


Figure 67: Observed mob BVDV seroprevalence by cow age class and year within country type.

Table 51: Observed mob BVDV seroprevalence by cow age class and year within country type.

Country type	Year	Cow/mixed			Heifer		
		No. of Mobs	Median	IQR*	No. of Mobs	Median	IQR*
Southern Forest	2009	18	73	13-100	14	21	0-80
	2011	17	80	45-92	6	74	55-80
Central Forest	2009	9	60	53-93	9	40	0-67
	2011	11	60	44-87	8	63	0-81
Northern Downs	2009	12	90	87-100	9	93	80-100
	2011	10	87	80-100	6	83	53-100
Northern Forest	2009	23	60	13-87	10	67	33-87
	2011	22	46	27-80	5	73	60-75

*IQR – interquartile range

Table 52: Distribution of cow/mixed mobs by BVDV seroprevalence category.

Country type	Year	No of Mobs	Mob seroprevalence category*		
			Low	Moderate	High
Southern Forest	2009	18	27.8%	44.4%	27.8%
	2011	17	17.6%	41.2%	41.2%
Central Forest	2009	9	11.1%	55.6%	33.3%
	2011	11	0.0%	72.7%	27.3%
Northern Downs	2009	12	8.3%	8.3%	83.3%
	2011	10	10.0%	30.0%	60.0%
Northern Forest	2009	23	26.1%	43.5%	30.4%
	2011	22	22.7%	54.5%	22.7%
Total	*2009*	62	21.0%	38.7%	40.3%
	2011	60	15.0%	50.0%	35.0%

*Seroprevalence category defined as Low: <20%; Moderate: 20-80% and High: >80% seropositive.

As expected there tended to be a higher proportion of heifer mobs with a low seroprevalence (31 and 24% in 2009 and 2011; **Table 53**), but the pattern of prevalence of mostly naïve, moderately immune and mostly immune mobs across country types and years was similar to that for the cow/mixed mobs. The reason for the much higher proportion of mostly immune heifer and cow/mixed mobs in the Northern Downs may be due to the almost complete reliance on controlled watering points and thus greater regular mixing of cattle than elsewhere.

The overall prevalence of recent infection in unvaccinated heifer and cow/mixed mobs was consistently higher in 2009 compared to 2011 (**Table 54**). However, the median seroprevalence of recent infection (**Figure 68**; **Table 55**) varied considerably across country types and years for both heifer (0 to 36.7%) and cow/mixed mobs (0 to 20%). In 2009 about 20% of unvaccinated cow/mixed mobs had a high prevalence (>30%) of recent infection except in the Northern Forest where the prevalence was only 9% of mobs (**Table 56**). In 2011, the overall proportion of mobs with a high prevalence of recent infection was much lower (about 4%). This may be due to persistently infected cattle dying or being culled or mobs becoming mostly immune.

In 2009 about 30 to 50% of unvaccinated heifer mobs had a high prevalence of recent infection except in the Northern Forest where there was no evidence of a high prevalence of recent infection (**Table 57**). However, in 2011 the prevalence of mobs with a high prevalence of recent infection was nil in the Southern Forest and Northern Downs and only 14% in the central forest, but was 20% in the Northern Forest. It should be noted that fewer heifer mobs were sampled in 2011 compared to 2009.

In every country type except the Northern Forest there was evidence of heifer mobs experiencing major outbreaks of infection (prevalences of recent infection > 60%; **Figure 68**).

Table 53: Distribution of heifer mobs by BVDV seroprevalence category.

Country type	Year	No of Mobs	Mob seroprevalence category*		
			Low	**Moderate**	**High**
Southern Forest	2009	14	50.0%	28.6%	21.4%
	2011	6	16.7%	66.7%	16.7%
Central Forest	2009	9	33.3%	44.4%	22.2%
	2011	8	37.5%	37.5%	25.0%
Northern Downs	2009	9	11.1%	22.2%	66.7%
	2011	6	16.7%	33.3%	50.0%
Northern Forest	2009	10	20.0%	50.0%	30.0%
	2011	5	20.0%	60.0%	20.0%
Total	2009	42	31.0%	35.7%	33.3%
	2011	25	24.0%	48.0%	28.0%

*Seroprevalence category defined as Low: <20%; Moderate: 20-80% and High: >80% seropositive

Table 54: Population estimate of the prevalence of recent BVDV infection by cow age class (vaccinated mobs not included).

Cow age class/cohort	Year	No of Samples	Prevalence of recent BVDV infection*		
				95% Confidence interval	
			Mean	Lower	Upper
Main Heifers	2009	538	22.2%	13.6	30.7
	2011	203	5.1%	1.3	8.9
Pilot Heifers	2009	153	22.5%	10.0	34.9
	2011	75	14.5%	11.0	40.0
Cows/mixed	2009	1,115	14.8%	11.0	18.7
	2011	927	7.6%	5.0	10.1

*AGID test result ≥3

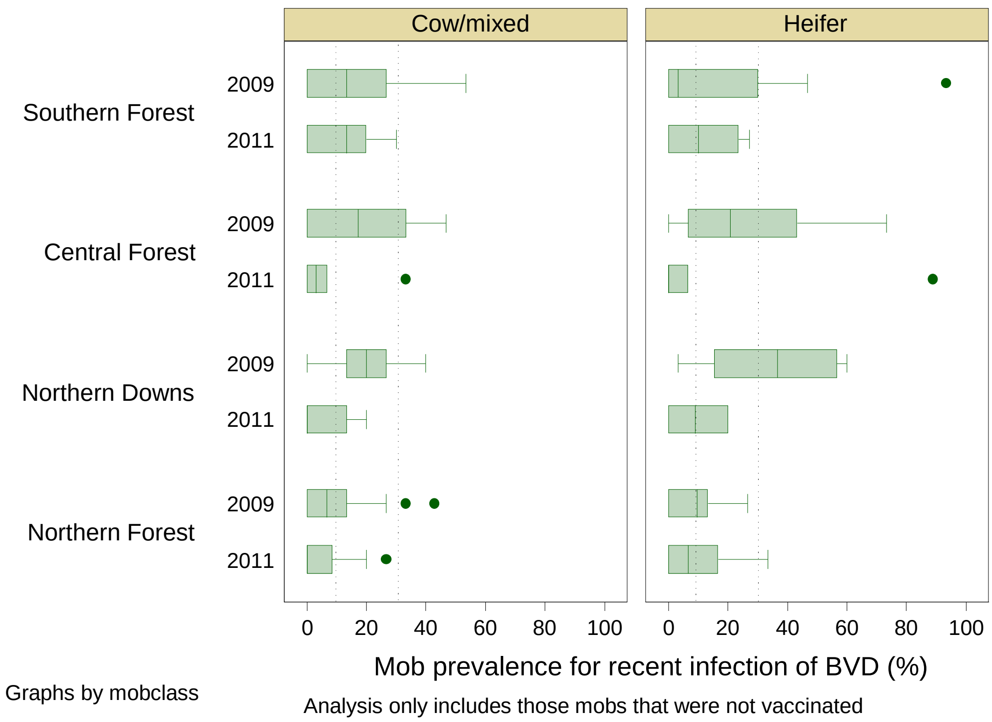


Figure 68: Observed mob prevalence of recent BVDV infection by cow age class and year within country type (vaccinated mobs not included).

Table 55: Observed mob prevalence of recent BVDV infection by cow age class and year within country type (vaccinated mobs not included).

Country type	Year	Cows/mixed			Heifers		
		No. of Mobs	Median	IQR*	No. of Mobs	Median	IQR
Southern Forest	2009	15	13.3%	0-27%	10	3.3%	0-30.%
	2011	13	13.3%	0-20%	4	10.0%	0-24%
Central Forest	2009	8	17.1%	0-33%	8	20.7%	7-43%
	2011	10	3.1%	0-7%	7	0%	0-7%
Northern Downs	2009	11	20%	13-27%	8	36.7%	15-57%
	2011	9	0%	0-13%	6	8.9%	0-20%
Northern Forest	2009	23	6.7%	0-13%	10	9.6%	0-13%
	2011	22	0%	0-8%	5	6.7%	0-17%

*IQR – interquartile range

Table 56: Distribution of cow/mixed mobs by prevalence of recent BVDV infection (11 mobs vaccinated for BVDV were excluded from analysis).

Country type	Year	No of Mobs	Frequency of recent infection*		
			Low	Moderate	High
Southern Forest	2009	15	40.0%	40.0%	20.0%
	2011	13	46.2%	46.2%	7.7%
Central Forest	2009	8	37.5%	37.5%	25.0%
	2011	10	90.0%	0.0%	10.0%
Northern Downs	2009	11	18.2%	63.6%	18.2%
	2011	9	55.6%	44.4%	0.0%
Northern Forest	2009	23	56.5%	34.8%	8.7%
	2011	22	77.3%	22.7%	0.0%
Total	*2009*	57	42.1%	42.1%	15.8%
	2011	54	68.5%	27.8%	3.7%

* Mob prevalence of recent BVDV infection defined as Low: <10%; Moderate: 10-30% and High: >30% AGID test result ≥3.

Table 57: Distribution of heifer mobs by prevalence of recent BVDV infection (nine mobs vaccinated for BVDV were excluded from analysis).

Country type	Year	No of Mobs	Frequency of recent infection*		
			Low	**Moderate**	**High**
Southern Forest	2009	10	60.0%	10.0%	30.0%
	2011	4	50.0%	50.0%	0.0%
Central Forest	2009	8	25.0%	37.5%	37.5%
	2011	7	85.7%	0.0%	14.3%
Northern Downs	2009	8	25.0%	25.0%	50.0%
	2011	6	50.0%	50.0%	0.0%
Northern Forest	2009	10	50.0%	50.0%	0.0%
	2011	5	60.0%	20.0%	20.0%
Total	2009	36	41.7%	30.6%	27.8%
	2011	22	63.6%	27.3%	9.1%

* Mob prevalence of recent BVDV infection defined as Low: <10%; Moderate: 10-30% and High: >30% AGID test result ≥3.

4.6.5.2 Neospora caninum

The mean *N. caninum* seroprevalence was similar for heifers and cows (**Table 58**), and was similar for each between years. This latter finding suggests that horizontal transmission is only occurring at a low level and the primary means of transmission is likely to be vertical. On average between 9.4 and 12.8% of females were seropositive. The distribution of mob seroprevalence by country type and cow age class is depicted in **Figure 69** and in **Table 59**. Again the median mob seroprevalence was similar for heifer and cow/mixed mobs and was similar across country types; the median seroprevalence ranged between 6.7% and 13.6% across country types and cow age class.

Overall, across both heifer and cow mobs about 20% mobs had no evidence of infection, whereas about 50% had evidence of a low prevalence of infection and about 25% mobs had evidence of a moderate to high level of infection (**Table 60; Table 61**).

The distribution of mob seroprevalence category varied considerably between regions and over years highlighting the impact of property and mob level factors on the epidemiology of infections. The high prevalence of infected mobs is consistent with the recent finding that wild dogs, which are widespread in northern Australia, are commonly infected with this parasite[62]. However, the association between reported presence or absence of wild dogs and *N.caninum* seroprevalence was only slight (**Figure 70**).

[62] King *et al* (2012)

Table 58: Population estimate of *N. caninum* seroprevalence by cow age class.

Cow age class/cohort	Year	No of samples	Seroprevalence of *N.caninum*		
				95% Confidence interval	
			Mean	Lower	Upper
Main Heifers	2009	46	10.9%	4.8	16.9
	2011	202	10.4%	6.5	14.3
Pilot Heifers	2009	32	9.4%	0.2	18.6
	2011	78	12.8%	4.5	21.1
Cows/mixed	2009	601	11.8%	8.5	15.2
	2011	921	12.6%	9.6	15.3

There were a small number of cow/mixed mobs with seroprevalences of >30% (**Figure 69**) suggesting either that these are herds in which there has been little culling and most replacement heifers were infected transplacentally, or there has been an outbreak of horizontal infection from a point source(s).

Figure 69: Observed mob *N. caninum* seroprevalence by cow age class and year within country types.

Table 59: Observed mob *N. caninum* seroprevalence by cow age class and year within country types.

Country type	Year	Cows/mixed			Heifers		
		No. of Mobs	Median	IQR*	No. of Mobs	Median	IQR
Southern Forest	2009	14	6.7%	0.0-20.0%	4	6.9%	3.3-11.9%
	2011	17	9.1%	6.7-13.3%	6	6.7%	0.0-18.2%
Central Forest	2009	8	13.3%	6.7-16.7%	1	NA	
	2011	13	7.1%	0.0-15.0%	9	13.3%	0.0-22.2%
Northern Downs	2009	8	6.7%	3.3-8.9%	0		
	2011	10	6.7%	6.7-7.1%	6	11.7%	6.7-20.0%
Northern Forest	2009	12	10.0%	6.7-16.7%	0		
	2011	22	13.6%	6.7-20.0%	5	11.1%	6.7-16.7%

*IQR – interquartile range

Table 60: Distribution of cow/mixed mobs by *N.caninum* seroprevalence category by year within country types.

Country type	**Year**	**No of Mobs**	**Prevalence of infection***		
			Nil	**Low**	**Moderate to High**
Southern Forest	2009	14	35.7%	28.6%	35.7%
	2011	17	23.5%	58.8%	17.6%
Central Forest	2009	8	0.0%	75.0%	25.0%
	2011	13	38.5%	38.5%	23.1%
Northern Downs	2009	8	25.0%	62.5%	12.5%
	2011	10	10.0%	90.0%	0.0%
Northern Forest	2009	12	8.3%	66.7%	25.0%
	2011	22	22.7%	40.9%	36.4%
Total	*2009*	42	19.0%	54.8%	26.2%
	2011	62	24.2%	53.2%	22.6%

* Mob prevalence of recent *N.caninum* infection defined as Nil: 0%; Low: 0-20%; Moderate to High: ≥20%

Table 61: Distribution of heifer mobs by *N.caninum* seroprevalence category by year within country types.

Country type	**Year**	**No of Mobs**	**Prevalence of infection***		
			Nil	**Low**	**Moderate to High**
Southern Forest	2009	4	25.0%	75.0%	0.0%
	2011	6	50.0%	33.3%	16.7%
Central Forest	2009	1	0.0%	0.0%	100.0%
	2011	9	33.3%	22.2%	44.4%
Northern Downs	2009	0			
	2011	6	0.0%	66.7%	33.3%
Northern Forest	2009	0			
	2011	5	20.0%	60.0%	20.0%
Total	*2009*	5	20.0%	60.0%	20.0%
	2011	26	26.9%	42.3%	30.8%

* Mob prevalence of *N.caninum* infection defined as Nil: 0%; Low: 0-20%; Moderate to High: ≥20%

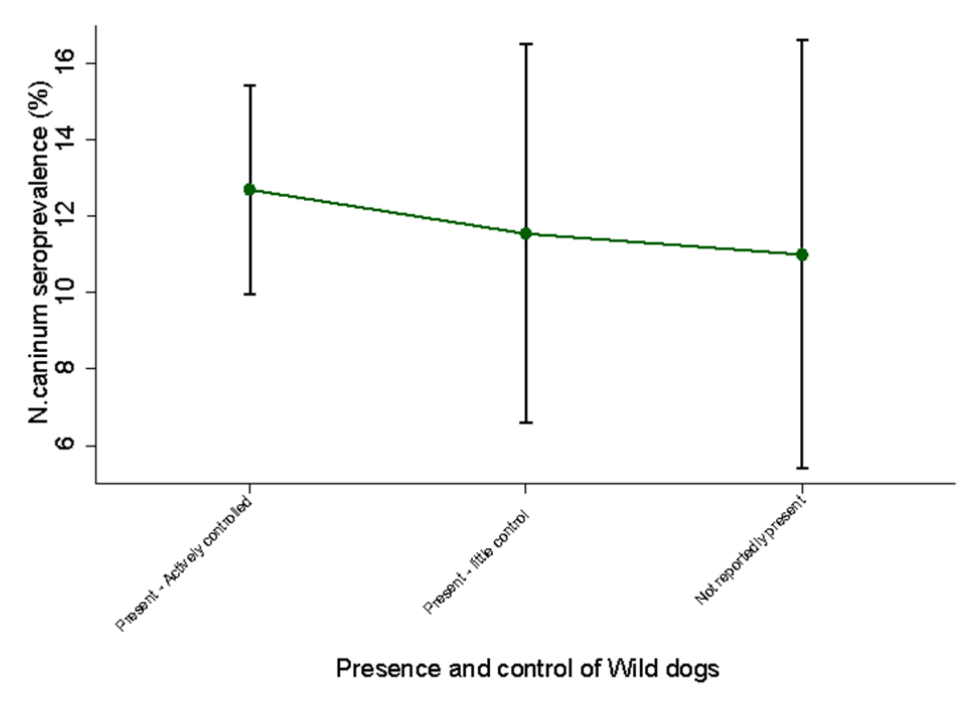


Figure 70: Association between *N.caninum* seroprevalence and reported presence or absence of wild dogs.

4.6.5.3 Bovine ephemeral fever

Only females sampled in 2011 were tested for evidence of BEF virus infection. The mean seroprevalence for heifers and cows was similar and very high (**Table 62**).

Across country types, the median seroprevalence in heifer and cow/mixed mobs was similar and very high (≥80%) (**Figure 71**). The interquartile range indicated that most mobs had a seroprevalence >70% (**Table 63**).

Across country types, there was some variation in the proportion of mobs with a high BEF seroprevalence (**Table 64** and **Table 65**). However, between 50 to100% of heifer and cow/mixed mobs had a seroprevalence of ≥80%. These findings are not surprising given the widespread flood rains in 2010 and 2011 across much of northern Australia.

The mean prevalence of recent infection was similar among heifers and cows, 10.2-13.5% (**Table 66**). Similarly, across country types the median prevalence of recent infection with BEF in unvaccinated heifer and cow/mixed mobs ranged between 4 to 16% and **Figure 72**). In the Southern Forest 6.3% of cow/mixed mobs, and in the Central Forest 25% of heifer mobs and 9.1% of cow/mixed mobs had a high prevalence (>30%) of recent infection (**Table 68** and **Table 69**), but elsewhere mobs commonly had evidence of a moderate prevalence (10-30%) of recent infection.

Table 62: Population estimate of BEF seroprevalence by cow age class.

Cow age class/ cohort	Year	No of samples	Seroprevalence*		
				95% Confidence interval	
			Mean	Lower	Upper
Main Heifers	2011	150	90.0%	85.0	95.0
Pilot Heifers	2011	53	90.6%	82.7	98.4
Cows/mixed	2011	764	86.1%	83.1	89.1

*BEF VNT ≥40 and includes unvaccinated and vaccinated mobs

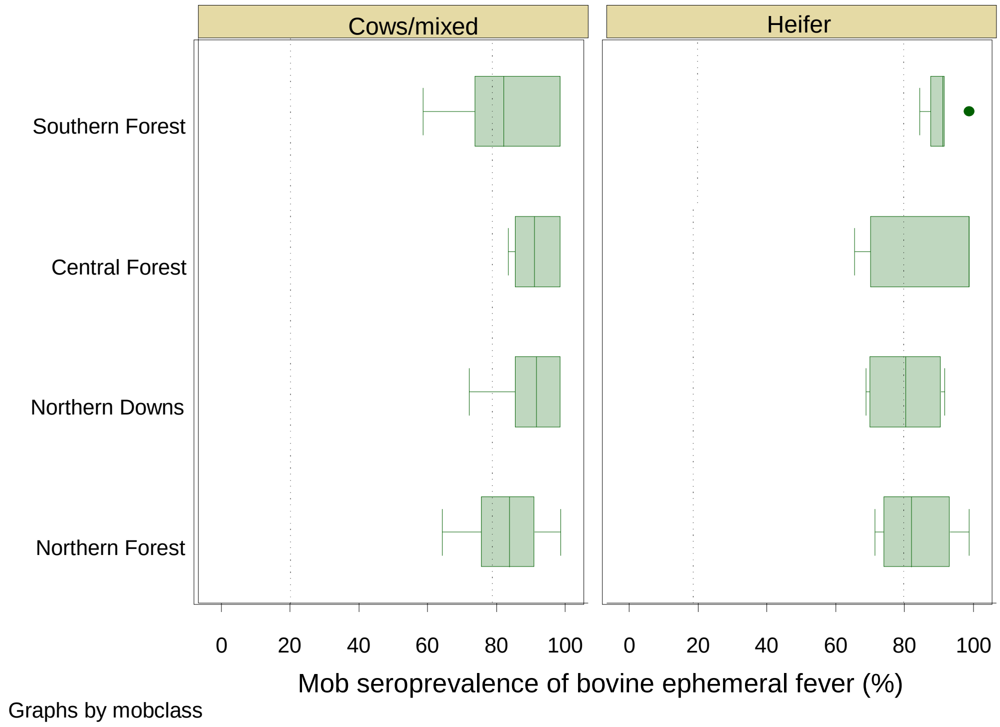


Figure 71: Observed mob BEF seroprevalence by cow age class and year within country types.

Table 63: Observed mob BEF seroprevalence by cow age class and year within country types.

Country type	Cows/mixed			Heifers		
	No. of Mobs	Median	IQR	No. of Mobs	Median	IQR
Southern Forest	17	83.3%	75-100%	5	92.3%	88.9-92.9%
Central Forest	11	92.3%	86.7-100%	7	100%	71.4-100%
Northern Downs	10	92.9%	86.7-100%	4	81.6%	71.1-91.9%
Northern Forest	22	85.2%	76.9-92.3%	4	83.3%	75.3-94.4%

Table 64: Distribution of cow/mixed mobs by BEF seroprevalence category.

Country type	No of Mobs	Mob seroprevalence category *		
		Low	Moderate	High
Southern Forest	17	0.0%	47.1%	52.9%
Central Forest	11	0.0%	0.0%	100.0%
Northern Downs	10	0.0%	10.0%	90.0%
Northern Forest	22	0.0%	36.4%	63.6%
Total	60	0.0%	28.3%	71.7%

*Seroprevalence category defined as Low: <20%; Moderate: 20-80% and High: >80% seropositive

Table 65: Distribution of heifer mobs by BEF seroprevalence category.

Country type	No of Mobs	Mob seroprevalence category *		
		Low	Moderate	High
Southern Forest	5	0.0%	0.0%	100.0%
Central Forest	7	0.0%	28.6%	71.4%
Northern Downs	4	0.0%	50.0%	50.0%
Northern Forest	4	0.0%	50.0%	50.0%
Total	20	0.0%	30.0%	70.0%

*Seroprevalence category defined as Low: <20%; Moderate: 20-80% and High: >80% seropositive

Table 66: Population estimate of prevalence of recent BEF infection by cow age class (vaccinated mobs excluded).

Cow age class/cohort	No of Samples	Prevalence of recent BEF infection*		
			95% Confidence interval	
		Mean	Lower	Upper
Main Heifers	150	11.3%	6.2	16.5
Pilot Heifers	37	13.5%	4.8	22.2
Cows/mixed	749	10.2%	7.5	13.0

*BEF VNT ≥640

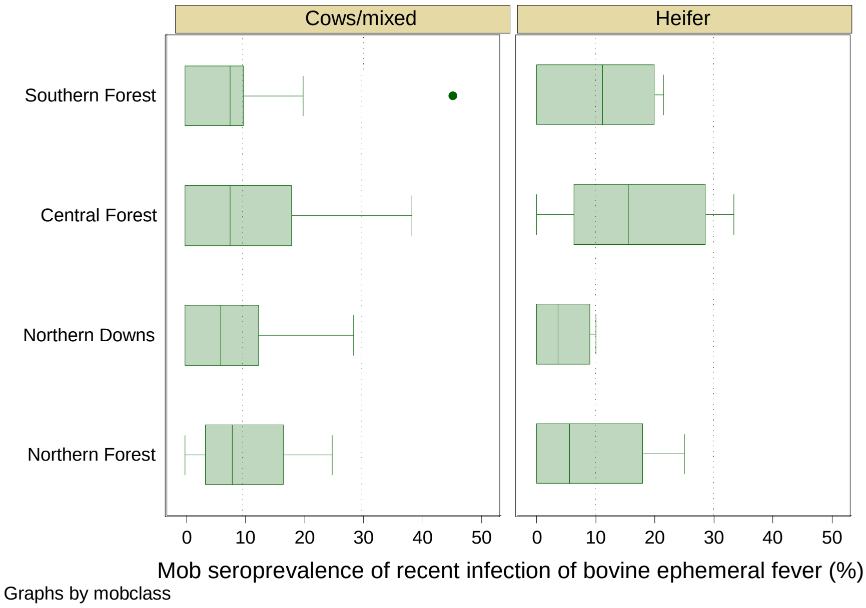


Figure 72: Observed mob prevalence of recent BEF infection by cow age class and year within country type (vaccinated mobs excluded).

Table 67: Observed mob prevalence of recent BEF infection by cow age class and year within country type (vaccinated mobs excluded).

Country type	Cows/mixed			Heifers		
	No. of Mobs	Median	IQR	No. of Mobs	Median	IQR*
Southern Forest	17	7.7%	0-10%	7	11.1%	0.0-20%
Central Forest	11	7.7%	0-18.2%	8	15.5%	6.3-28.6%
Northern Downs	10	6.1%	0-12.5%	6	3.6%	0.0-9.1%
Northern Forest	22	8.0%	3.4-16.7%	4	5.6%	0.0-18.1%

*IQR – interquartile range

Table 68: Distribution of cow mobs by prevalence of recent BEF infection (vaccinated mobs excluded).

Country type	No of Mobs	Mob prevalence of recent infection *		
		Low	Moderate	High
Southern Forest	16	68.8%	25.0%	6.3%
Central Forest	11	54.5%	36.4%	9.1%
Northern Downs	10	70.0%	30.0%	0.0%
Northern Forest	22	54.5%	45.5%	0.0%
Total	59	61.0%	35.6%	3.4%

* Mob prevalence of recent BEF infection defined as Low: <10%; Moderate: 10-30% and High: >30% BEF VNT ≥640

Table 69: Distribution of heifer mobs by prevalence of recent BEF infection (vaccinated mobs excluded).

Country type	No of Mobs	Mob prevalence of recent BEF infection *		
		Low	Moderate	High
Southern Forest	6	50.0%	50.0%	0.0%
Central Forest	8	25.0%	50.0%	25.0%
Northern Downs	6	83.3%	16.7%	0.0%
Northern Forest	4	50.0%	50.0%	0.0%
Total	24	50.0%	41.7%	8.3%

* Mob prevalence of recent BEF infection defined as Low: <10%; Moderate: 10-30% and High: >30% BEF VNT ≥640

4.6.5.4 Leptospirosis

L. hardjo

The overall *L. hardjo* seroprevalence by year and cow age class/cohort was low, approximately 10% (**Table 70**). However, the small number of samples tested for heifer cohorts in 2009 prevented accurate interpretation. The median seroprevalence in unvaccinated heifer and cow/mixed mobs was similarly low across country types (**Figure 73**). However, in 2009 in the Southern Forest and Northern Downs 25% of cow/mixed mobs had seroprevalences of >30%, and in 2011 in the Northern Downs 25% of heifer mobs had seroprevalences of >30%.

The prevalence of recent infection by year and cow age class/cohort was very low (**Table 71**). No cow/mixed mob sampled in 2009 and 2011 showed evidence of widespread recent infection (>30% of samples from an unvaccinated mob had an MAT titre of ≥800) with *L. hardjo* (**Table 72**). As abortion rates tend to be only relatively low in *L. hardjo* infected herds (seldom greater than 10%), finding no herds with evidence of widespread recent infection and a low overall seroprevalence suggest that at a herd level *L. hardjo* is not a common cause of foetal/calf loss in Northern Australia.

L. pomona

The overall *L. pomona* seroprevalence by year and cow age class/cohort was low, approximately 10% (**Table 70**). The median seroprevalence in unvaccinated heifer and cow/mixed mobs was similarly low across country types (**Figure 74**). However, in 2009 in the Southern Forest and Northern Downs 25% of cow/mixed mobs had seroprevalences of >30%, and in 2011 in the Northern Downs 25% of heifer mobs had seroprevalences of >30%.

The prevalence of recent infection by year and cow age class/cohort was very low (**Table 71**). No cow/mixed mob sampled in 2009 and 2011 showed evidence of significant recent infection (>30% of samples tested had an MAT titre of ≥800) with *L. pomona* (**Table 73**).

Table 70: Population estimate of *Leptospira hardjo* and *L. pomona* seroprevalence. (N/A—too few samples for meaningful analysis)

Cow age class/ cohort	Year	No of samples	Seroprevalence of *L. hardjo* (MAT titres ≥200)		Seroprevalence of *L. pomona* (MAT titres ≥200)	
			Mean	95% Confidence interval (Lower-Upper)	Mean	95% Confidence interval (Lower-Upper)
Main Heifers	2009	N/A	N/A	N/A	N/A	N/A
	2011	120	5.9%	0.3 - 11.5%	3.0%	-1.4-7.4%
Pilot Heifers	2009	N/A	N/A	N/A	N/A	N/A
	2011	34	15.3%	0 – 37.1%	0.0%	-
Cows/mixed	2009	383	12.3%	6.8 - 17.7%	9.9%	3.6 – 16.3%
	2011	634	8.6%	4.1 – 13.1%	10.6%	6.5 - 14.8%

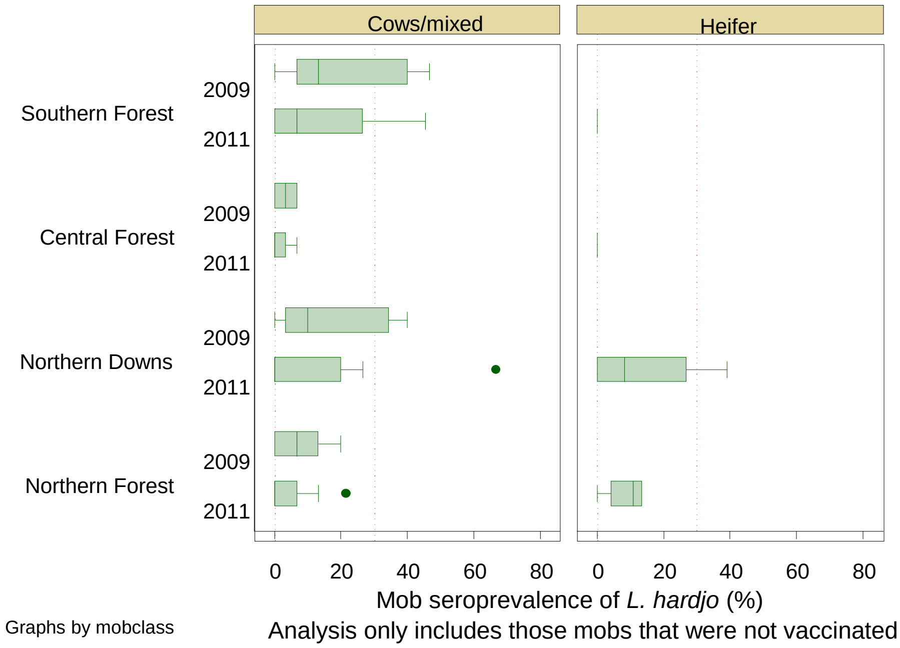


Figure 73: Observed mob *L. hardjo* seroprevalence by year and country type.

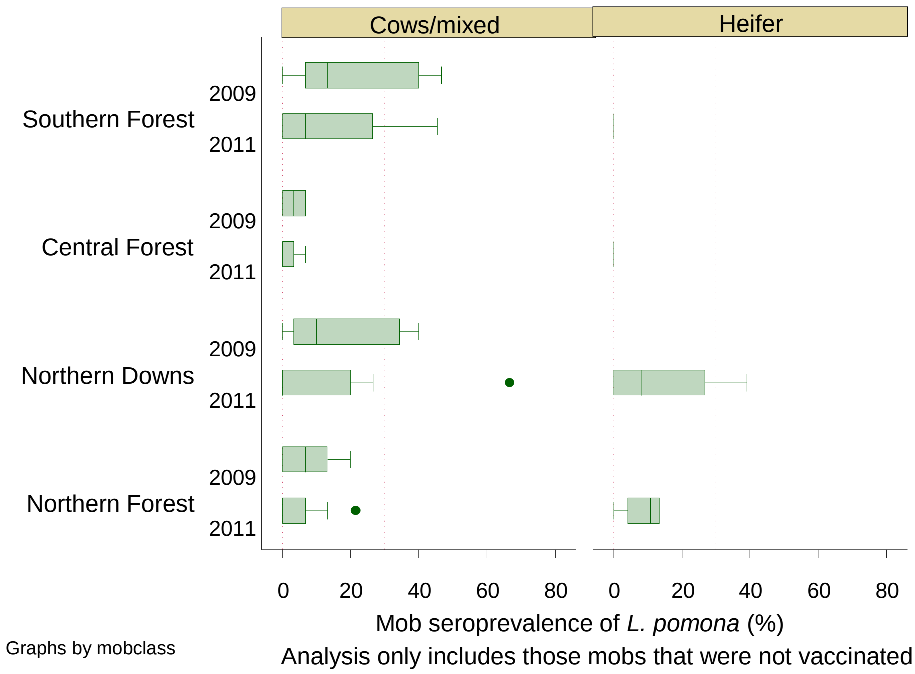


Figure 74: Observed mob *L. pomona* seroprevalence by year and country type.

Table 71: Population estimates of the prevalence of recent *L. hardjo and L. pomona* infection. (N/A—too few samples for meaningful analysis)

Cow age class/ cohort	Year	No of samples	Prevalence of recent *L. hardjo* infection (MAT titres ≥800)		Prevalence of recent *L. pomona* infection (MAT titres ≥800)	
			Mean	95% Confidence interval (Lower-Upper)	Mean	95% Confidence interval (Lower-Upper)
Main Heifers	2009	N/A	N/A	-	N/A	
	2011	120	0.0%	-	0.8%	-0.7-2.4%
Pilot Heifers	2009	N/A	N/A	-	N/A	-
	2011	34	2.9%	-2.7-8.6%	0.0%	-
Cows/mixed	2009	383	1.9	0.3-3.4%	2.6%	-0.4-5.5%
	2011	634	0.5%	0.0-1.0%	2.2%	0.8-3.7%

Table 72: Distribution of cow/mixed mobs by prevalence of recent *L. hardjo* infection.

Country type	Year	No of Mobs	Prevalence of recent infection*		
			Low	Moderate	High
Southern Forest	2009	6	67%	33%	0%
	2011	8	100%	0%	0%
Central Forest	2009	2	100%	0%	0%
	2011	4	100%	0%	0%
Northern Downs	2009	8	88%	13%	0%
	2011	10	100%	0%	0%
Northern Forest	2009	11	100%	0%	0%
	2011	19	100%	0%	0%
Total	*2009*	27	89%	11%	0%
	2011	41	100%	0%	0%

* Mob prevalence of recent *L. hardjo* infection defined as Low: <10%; Moderate: 10-30% and High: >30%

Table 73: Distribution of cow/mixed mobs by prevalence of recent *L. pomona* infection.

Country type	Year	No of Mobs	Prevalence of recent infection*		
			Low	Moderate	High
Southern Forest	2009	6	100.0%	0.0%	0.0%
	2011	8	100.0%	0.0%	0.0%
Central Forest	2009	2	100.0%	0.0%	0.0%
	2011	4	50.0%	50.0%	0.0%
Northern Downs	2009	8	87.5%	12.5%	0.0%
	2011	10	100.0%	0.0%	0.0%
Northern Forest	2009	11	81.8%	9.1%	9.1%
	2011	19	89.5%	10.5%	0.0%
Total	*2009*	27	88.9%	7.4%	3.7%
	2011	41	90.2%	9.8%	0.0%

* Mob prevalence of recent *L. pomona* infection defined as Low: <10%; Moderate: 10-30% and High: >30%

4.6.5.5 Campylobacter subsp. fetus venerealis infection

The prevalence of vaginal mucus ELISA positives (our estimate of the prevalence of *C subsp. fetus veneralis* infection) for main study heifers and cows was similar, between 7.4% and 12.6%, with only minor variation between years (**Table 74**). The median cow/mixed mob prevalence of positives was less than 10% for both years and across country types except for the Central Forest in 2009 when the median was 10.3% (**Table 75**). Similarly, for the heifer mobs, the median prevalence was <10% across all country types and years. The prevalence of mobs with a high percentage of positives (≥30%) indicating that vibriosis may be adversely affecting reproductive performance[63] is shown in **Figure 75**, **Table 76** and **Table 77**.

In 2009 and 2011 21.4% and 20% of heifer mobs in the Southern Forest, respectively, had a high prevalence of positives. However, in the Northern Forest where bull control is considered problematic, there were no mobs with a high prevalence of positives. The prevalence of cow/mixed mobs with a high percentage of positives was generally very low, except in the Southern Forest and Northern Downs in 2011 where the prevalence was 20%. The occurrence of a relatively high proportion of mobs in the Southern Forest having a high percentage of positives may be due to the lower frequency of routine vaccination of bulls against vibriosis in these properties (**Table 14**).

[63] Hum *et al* (1994)

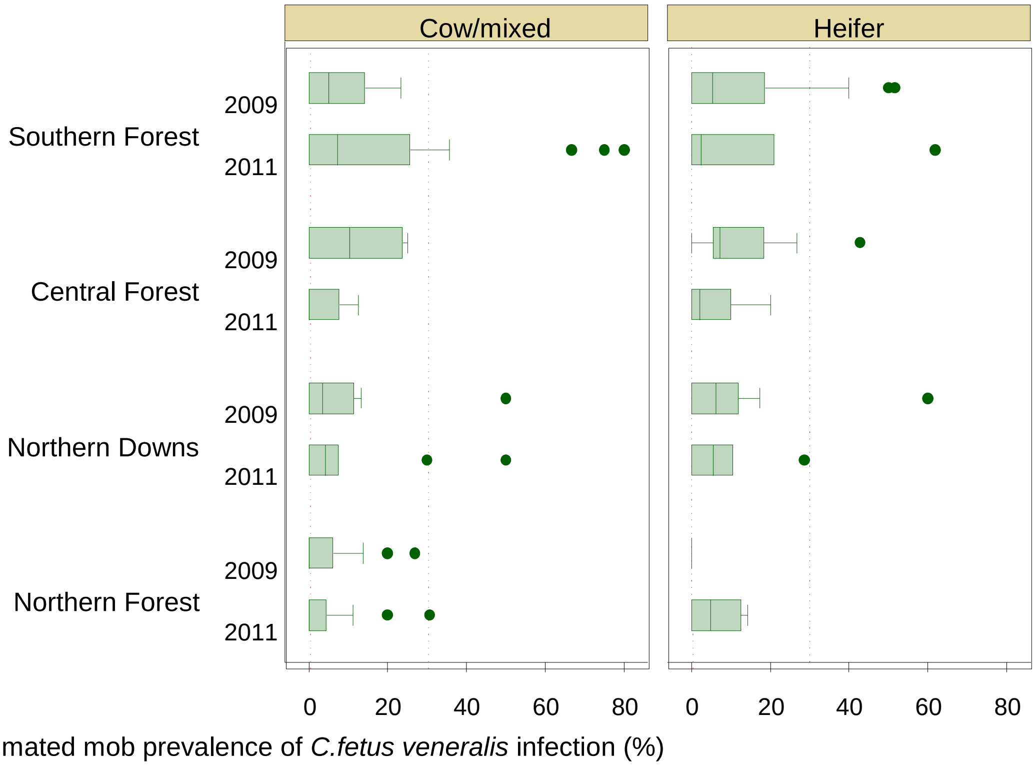
Table 74: Population estimate of prevalence of *C.fetus venerealis* infection by cow age class within country type.

Cow age class/ cohort	Year	No of Samples	Prevalence of test positives	
			Mean	95% Confidence interval (Lower-Upper)
Main Heifers*	2009	722	12.1%	6.1 – 18.2%
	2011	273	12.6%	6.0 – 19.1%
Pilot Heifers*	2009	136	5.1%	2.6 – 7.6%
	2011	62	21.0%	-8.6 – 50.6%
Cows/mixed	2009	1,629	7.4%	4.8 – 9.9%
	2011	1192	9.7%	5.1 – 14.2%

*Analysis only includes those heifer mobs that were not vaccinated. Mobs that were reported as having been vaccinated as heifers were not included in the analysis.

Table 75: Observed mob prevalence of *C.fetus venerealis* infection by cow age class within country-type.

Country type	Year	No. of Mobs	Median	IQR*
Cows/mixed				
Southern Forest	2009	19	5.0%	0.0 - 14.3%
	2011	20	7.3%	0.0 – 25.8%
Central Forest	2009	9	10.3%	0.0 - 23.8%
	2011	11	0.0%	0.0 – 7.7%
Northern Downs	2009	12	3.5%	0.0 - 11.3%
	2011	10	4.2%	0.0 – 7.4%
Northern Forest	2009	23	0.0%	0.0 - 6.3%
	2011	21	0.0%	0.0 – 4.5%
Heifers				
Southern Forest	2009	14	5.3%	0.0 - 18.8%
	2011	5	2.5%	0.0 – 21.1%
Central Forest	2009	8	7.2%	5.5 - 18.3%
	2011	6	2.1%	0.0 – 10.0%
Northern Downs	2009	9	6.3%	0.0 - 11.8%
	2011	6	5.5%	0.0 – 10.7%
Northern Forest	2009	5	0.0%	0.0 - 0.0%
	2011	6	4.9%	0.0 – 12.5%



Analysis only includes those heifer mobs that were not vaccinated.

Figure 75: Observed mob prevalence of *C.fetus venerealis* infection by cow age class, country type and year.

Table 76: Distribution of cow/mixed mobs by prevalence of *C.fetus venerealis infection.*

Country type	Year	No of Mobs	Mobs prevalence of *C.fetus venerealis infection**		
			Nil	Moderate	High
Southern Forest	2009	19	36.8%	63.2%	0.0%
	2011	20	45.0%	35.0%	20.0%
Central Forest	2009	9	33.3%	66.7%	0.0%
	2011	11	54.5%	45.5%	0.0%
Northern Downs	2009	12	33.3%	58.3%	8.3%
	2011	10	30.0%	50.0%	20.0%
Northern Forest	2009	23	60.9%	39.1%	0.0%
	2011	21	66.7%	28.6%	4.8%
Total	2009	63	44.4%	53.9%	1.6%
	2011	62	51.6%	37.1%	11.3%

* Mob prevalence of *C.fetus venerealis infection* defined as Nil: 0%; Moderate: >0 to <30% and High: ≥30%

Table 77: Distribution of heifer mobs by prevalence of *C.fetus venerealis* infection.

Country type	Year	No of Mobs	mobs prevalence of *Campylobacter* category *		
			Low	**Moderate**	**High**
Southern Forest	2009	14	35.7%	42.9%	21.4%
	2011	5	40.0%	40.0%	20.0%
Central Forest	2009	8	12.5%	75.0%	12.5%
	2011	6	50.0%	50.0%	0.0%
Northern Downs	2009	9	44.4%	44.4%	11.1%
	2011	6	33.3%	66.7%	0.0%
Northern Forest	2009	5	100.0%	0.0%	0.0%
	2011	6	50.0%	50.0%	0.0%
Total	2009	36	41.7%	44.4%	13.9%
	2011	23	43.5%	52.2%	4.3%

* Mob prevalence of *C.fetus venerealis* infection defined as Nil: 0%; Moderate: >0 to <30% and High: ≥30%

4.6.5.6 Q-fever (Coxiella burnetii)

Samples were obtained from 58 mobs on 56 beef CashCow properties located in Queensland only. Overall seroprevalence to either or both antigenic phases of *C. burnetii* was 16.8%[64]. Seroprevalence was similar across country types. Positive samples were detected in 78.2% of properties surveyed.

[64] Cooper *et al* (2011)

5 Multivariable model analyses and results

5.1 Factors affecting the percentage of cows pregnant within four months of calving

This section presents the findings from the final multivariable model used to identify important explanatory variables that influence the outcome “percentage P4M” for those females that reared their calf. This means that all cows included in this analysis were believed to be **lactating** while at risk of becoming pregnant within four months of calving. For each factor (variable) and interaction term included in the final multivariable model, the following section provides the predicted mean percentage P4M at the referent level for all other factors in the model. Referent levels used are shown in Appendix XII.

Note that the performance by country type and cow age class/age reported in this section will be different to that presented in the descriptive summaries of performance presented in Section 4 , as the mean performance is predicted from the multivariable model and takes into account the impacts of all other major factors included in the final model. Producers looking for typical measures of performance and what is commercially achievable for comparison with their own herd’s performance should use the summary data presented in **Section 4.5** .

The purpose of the multivariable modelling process is to identify the major drivers of P4M and to explain the effect of each factor after adjustment for all other factors in the model. All candidate factors were initially considered for inclusion in the multivariable model building process, and all factors with significant and biologically plausible associations with the outcome were retained in the final model. It is important to be aware that when comparing the predicted difference(s) between percentage P4M for each factor, the absolute difference is expressed in terms of percentage points increase or decrease i.e., the difference between 50% and 55% is 5 percentage points.

The starting dataset for this multi-level logistic regression analysis included all female records that had valid entries for the outcome P4M, and was restricted to those females that reared their calf. This outcome was a binary outcome with 0=failed to be pregnant within four months of calving and 1=pregnant within four months of calving.

A description of the model building process is provided in **Section 3.5.5** .

The full model utilised 22,891 animal records from 17,135 individual cows from 58 properties. Animal records that were missing data for any of the variables included in the final model resulted in that animal-record being omitted from the model. This explains why a number of animals and properties have not contributed data to the final model. The average number of records per animal was 1.3. **Table 78** provides a summary of the number of analytical mobs and animals that contributed data to the final multivariable model for percentage P4M.

Model checking revealed a lack of fit which appeared to be confined to the lower and upper deciles of expected probabilities. The model appeared to be overestimating the negatives in the upper decile of expected probabilities and under-estimating the positives in the lower decile. However, the model predicted all other deciles within 6% of the observed values. The fit of the model did not appear to improve by removing candidate variables or interactions. All attempts in improving the fit of the model did not result in changes to the overall significance of covariates or direction of the coefficients for the risk factors. An inspection of covariate values revealed all values to be biologically plausible, and as a result no observations were removed from the dataset.

This may suggest that the model could be potentially improved by the inclusion of additional variables or re-categorising current explanatory variables. However, all known factors impacting on reproductive performance were measured under commercial conditions on a large number of cattle on multiple properties across northern Australia and these were considered for inclusion during the model building process.

The following sections outline the effects in the final model. Note that factors which are not in the final model were screened out because they were either non-significant, or explained by a closely-related variable. A full list of variables available at the commencement of the analysis is presented in **Appendix XII**.

Table 78: Number of cows and properties that contributed data to the final multivariable model.

Region	Number of properties (n)	Total number of unique animals within region (n)	Total number of animals within region (n)
Southern Forest	12	2,693	3,982
Central Forest	13	3,710	5,626
Northern Downs	11	6,394	8,468
Northern Forest	22	4,338	4,815
Total	58	17,135	22,891

The final multivariable model P4M contained the following terms:

Main effects:

- Country type (Southern Forest, Central Forest, Northern Downs, Northern Forest)
- Cow age class (first-lactation cow, second-lactation cow, mature cow, aged cow)
- Estimated period of calving expressed as predicted window when the cow calved (October-November, , December-January, February-March, April-June, July-September)
- Year (2008-09, 2009-10, 2010-11)
- BCS at the pregnancy diagnosis muster (1 - 2, 2.5, 3, 3.5, 4 - 5)
- Average ratio of dietary crude protein to dry matter digestibility (CP:DMD) during wet season (November-April) (<0.125, ≥0.125)
- Average ratio of faecal phosphorous to metabolisable energy (FP:ME) during wet season (November-April) (<500, ≥500)

- BCS change between pregnancy diagnosis and weaning/branding musters (Maintained or Lost, Gained)

Interaction terms:

- BCS at the pregnancy diagnosis muster x country type
- Cow age class x average wet season FP:ME
- Cow age class x country type

The following sections provide predicted pregnancy rates of cows within four months of calving expressed as a percentage and generated as marginal means from the final multivariable model for each of the explanatory variables in the final model. Pair-wise statistical comparisons have been conducted to generate p-values for comparisons between different levels within each variable or interaction term from the final model.

5.1.1 Predicted impact of country type

After adjustment for all other variables, the main effect of country type was significantly associated with the outcome P4M (P<0.001). The highest predicted percentage of cows being pregnant within four months of calving was in the Southern Forest and the lowest was in the Northern Forest (**Figure 76**; **Table 79**). The mean performance of cows in the Northern Downs and Northern Forest were significantly lower than that for cows in the Southern Forest (23.4 percentage points; P=0.01 and 59.0 percentage points; P<0.001 respectively). The mean percentage P4M in the Central Forest was 11.8 percentage points lower than those in the Southern Forest, although the difference was not significant (P=0.18). The mean percentage P4M in the Northern Forest was significantly lower than in the Central Forest and Northern Downs (47.3 percentage points; P<0.001 and 35.7 percentage points; P<0.001 respectively). As country type interacts with BCS at the pregnancy diagnosis muster and cow age class, further information is given on these comparisons in subsequent sections.

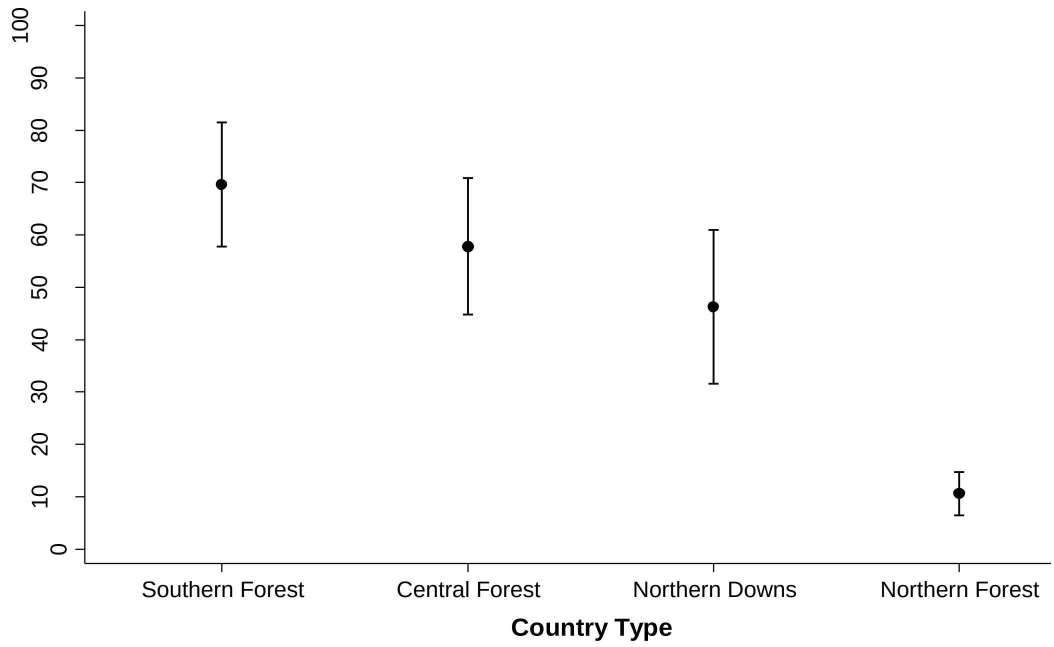


Figure 76: Predicted percentage P4M by country type, based on marginal means generated from the final multivariable model. Bars represent 95% confidence interval.

Table 79: Predicted percentage P4M by country type, based on marginal means generated from final multivariable model and adjusted for all other factors in the model.

Country Type	**Mean percentage P4M * (%)**	**95% Confidence interval**	
		Lower	Upper
Southern Forest	69.6^{B}	57.7	81.4
Central Forest	57.8^{AB}	44.8	70.8
Northern Downs	46.2^{A}	31.5	61.0
Northern Forest	10.5^{C}	6.4	14.7

*Means not sharing a common superscript letter are significantly different at P<0.05.

5.1.1.1 Application and Further work

The impact on performance described above takes into account the impacts of all major factors in the model and thus demonstrates the large effect country type is having on performance. Unfortunately there is little that producers can do to deal with this impact but it does demonstrate that it is generally unrealistic to expect high performance for this measure in the Northern Forest. However, it is recognised that within each broad country type there is also likely to be quite significant variation in performance due to differences in soil fertility, rainfall patterns etc.

Analysis of the impact of country type indicates there is a large difference in the performance of cows in the Northern Forest compared to those in other country types. Investigation of additional factors contributing to this country type impact is recommended.

5.1.2 Predicted impact of year observed

Year observed was a significant factor contributing to the percentage P4M (P<0.001). Females calving in 2009 (includes all age-classes of females) had a lower percentage P4M than those calving in 2011 (**Figure 77**; **Table 80**).Comparisons of percentage P4M between years indicated that all three comparisons were statistically significant. It is important to note that there were no interactions with year, so the effect was consistent across all other factors in the model.

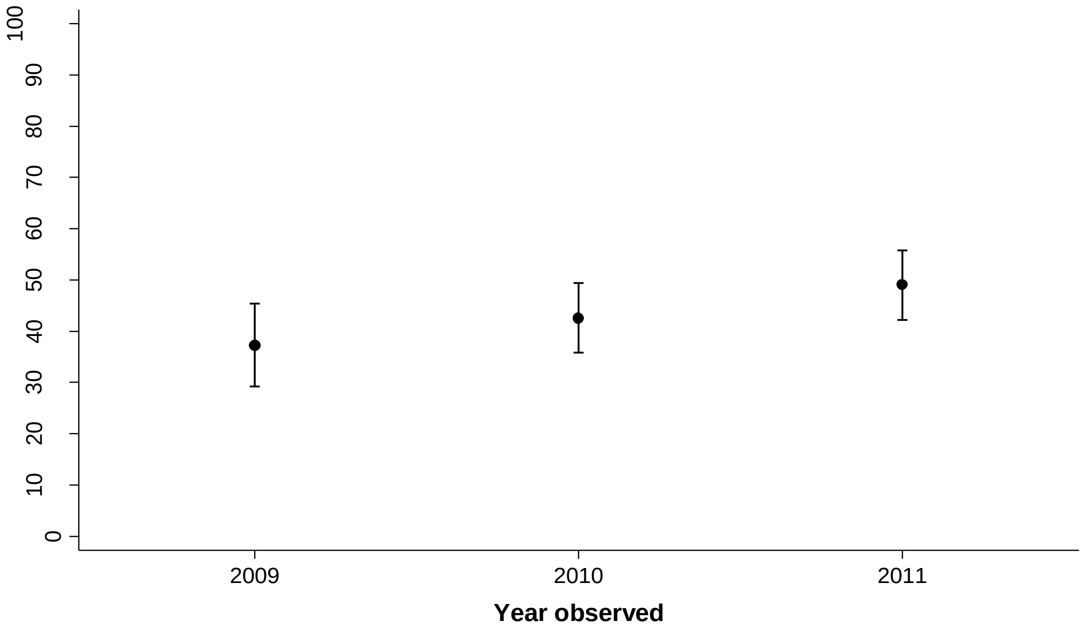


Figure 77: Predicted percentage P4M by year observed, based on marginal means generated from the multivariable model and adjusted for all other factors in the model. Bars represent 95% confidence interval.

Table 80: Predicted percentage P4M by year observed, based on marginal means generated from final multivariable model and adjusted for all other factors in the model.

Year observed	Mean P4M * (%)	95% Confidence interval	
		Lower	Upper
2008-2009	37.3^{A}	29.2	45.3
2009-2010	42.6^{B}	35.8	49.3
2010-2011	49.0^{C}	42.2	55.7

*Means that are not sharing a common superscript letter are significantly different (P<0.05).

5.1.2.1 Application and Further work

The impact on performance described above takes into account the impacts of all major factors in the model and thus demonstrates the large and consistent effect season can have on performance.

5.1.3 Predicted impact of cow age class

Females that were experiencing lactation for their first and second time have been defined as first- and second-lactation cows, respectively. 'Cow ages' were derived from year brands recorded at the time a cow was first enrolled in the study. Cows greater than nine years old were classed as aged cows. Mature cows were all cows nine years or younger, excluding first- and second-lactation cows.

Cow age class was a significant determinant of predicted P4M (P<0.001) and its interaction with country type was also statistically significant (P<0.001) (**Table 81**; **Figure 78**;**Table 82**). Generally across all country types, percentage P4M tended to increase with cow age class. However, comparisons of the mean percentage P4M between all cow age classes in the Southern Forest were not statistically significant (P<0.05).

The mean percentage P4M for first-lactation cows was significantly lower than that for second-lactation cows in the Central Forest (14.1 percentage points; P<0.001) and Northern Downs (11.1 percentage points; P<0.001). However, in the Northern Forest, first-lactation cows were predicted to have a higher percentage P4M than second-lactation cows (3.2 percentage points; P=0.04).

The mean percentage P4M for aged cows tended to be higher than for mature cows in all country types, but comparisons between mean percentage P4M were only found to be significant in the Northern Downs (4.1 percentage points; P=0.03).

Table 81: Predicted percentage P4M by cow age class, based on marginal means generated from the final multivariable model and adjusted for all other factors in the model.

Cow age class	Mean percentage P4M * (%)	95% Confidence interval	
		Lower	Upper
First-lactation cows	34.6^{A}	28.2	41.0
Second-lactation cows	39.5^{B}	32.1	46.9
Mature cows	47.2^{C}	40.2	54.2
Aged cows	50.7^{D}	43.3	58.2

*Means not sharing a common superscript letter are significantly different (P<0.05).

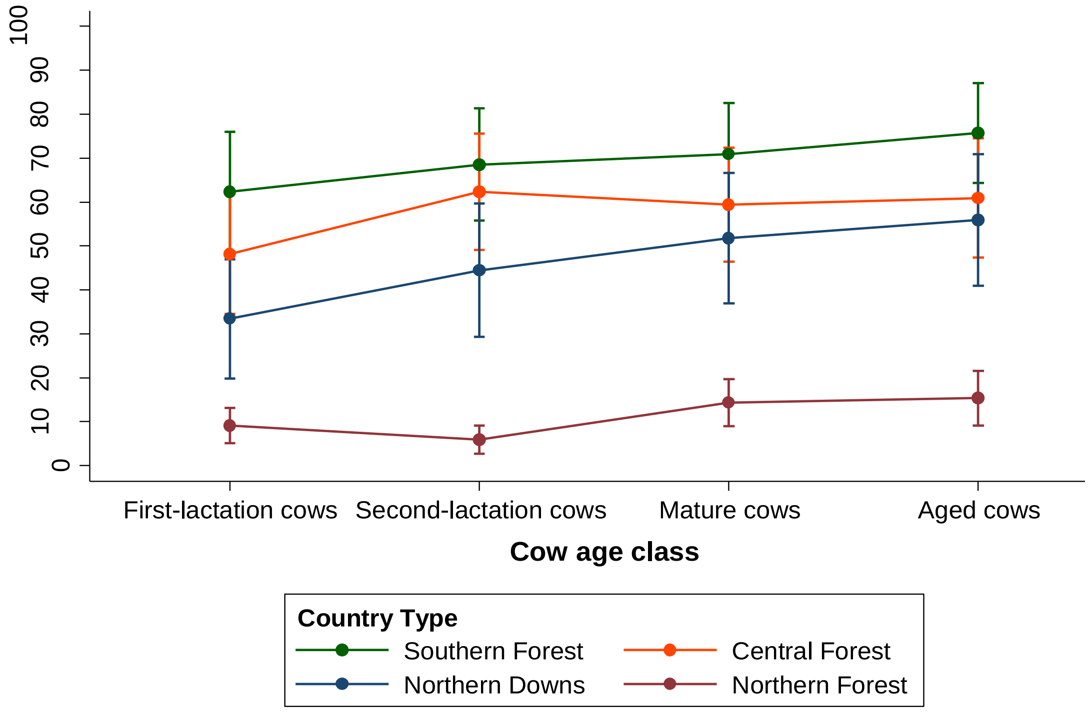


Figure 78: Percentage P4M by the predicted interaction between cow age class and country type, based on marginal means generated from the final multivariable model and adjusted for all other factors in the model. Bars represent 95% confidence interval.

Table 82: Percentage P4M by the predicted interaction between cow age class and country type, based on marginal means generated from the final multivariable model and adjusted for all other factors in the model. The lower and upper 95% confidence intervals are reported in parentheses.

Cow age class	Mean percentage P4M* (%)			
	Southern Forest	Central Forest	Northern Downs	Northern Forest
First-lactation cows	62.4^{A}	48.2^{A}	33.4^{A}	9.2^{A}
	(48.7-76.0)	(34.6-61.9)	(19.8-47.0)	(5.2-13.1)
Second-lactation cows	68.5^{A}	62.3^{B}	44.5^{B}	5.9^{B}
	(55.7-81.3)	(49.1-75.6)	(29.3-59.6)	(2.7-9.2)
Mature cows	70.9^{A}	59.4^{B}	51.8^{C}	14.3^{C}
	(59.3-82.5)	(46.4-72.4)	(36.9-66.6)	(8.9-19.6)
Aged cows	75.7^{A}	60.9^{B}	55.9^{D}	15.4^{C}
(>9years old)	(64.3-87.1)	(47.3-74.6)	(40.9-70.9)	(9.2-21.6)

Note: Within Country Type, means not sharing a common superscript are significantly different (P<0.05).

5.1.3.1 Application and Further work

These findings are consistent with previous research and industry observations that in the Northern Downs and Northern Forest mature and aged cows have a higher likelihood of becoming pregnant while lactating than first- and second-lactation cows. Further, although particularly in the Northern Forest where percentage P4M is low, selection of bull calves—for herd replacements—from those females that conceived while lactating for the first time will likely result in long term improvement in herd fertility[65].

The data presented in **Table 82** indicates that there is significant scope for improvement in percentage P4M across all country types. Further investigation of how some properties are achieving high levels of performance for this outcome is recommended.

5.1.4 Predicted impact of calving period in the previous reproductive cycle

The predicted month of calving was calculated using estimated foetal age at the date of the pregnancy test muster and projected forward using an assumed gestation length of 287 days. As foetal age was recorded in months, it was multiplied by 30.4 (365/12) days per month to estimate foetal age in days. The predicted months of calving were grouped into two or three month periods beginning with July-September of the previous year and moving progressively forward to April-June in the current year.

It should be noted that the data observed for cows calving in the periods February-March and April-June in the Southern and Central Forest were limited as bulls were managed such that cows did not become pregnant in this period and cows predicted to calve in this period were often culled at the time of pregnancy diagnosis. Due to the low number of observations for cows calving between February and June in the Southern and Central Forest, the interaction between calving period and country type could not be assessed in the final model.

The percentage P4M has been predicted for each calving period across and within country types (**Figure 79**; **Table 83**; **Table 84**).

Within all country types, cows calving in July-September had a significantly lower percentage P4M compared to cows calving during either October-November or December-January periods (*P*<0.05). Overall, cows calving in December-January had a significantly higher percentage P4M than those calving in each of the other periods (*P*<0.05).

[65] Johnston (2013).

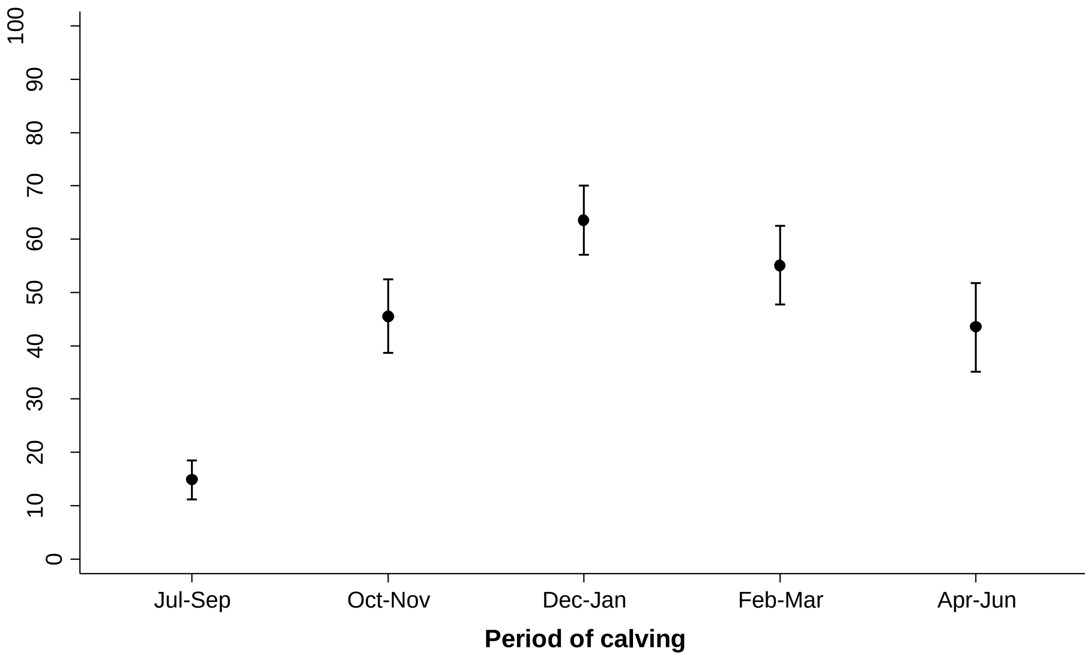


Figure 79: Predicted percentage P4M by estimated period of calving, based on marginal means generated from the final multivariable model and adjusted for all other factors in the model. Note that there were limited observations recorded for the February-March and April-June periods in the Southern or Central Forest. Bars represent 95% confidence interval.

Table 83: Predicted percentage P4M by estimated period of calving, based on marginal means generated from the final multivariable model and adjusted for all other factors in the model. Note that there were limited observations recorded for the February-March and April-June periods in the Southern or Central Forest.

Previous calving period	Mean P4M* (%)	95% Confidence interval	
		Lower	Upper
Jul-Sep	14.8^{A}	11.1	18.4
Oct-Nov	45.5^{B}	38.6	52.4
Dec-Jan	63.6^{C}	57.1	70.1
Feb-Mar	55.1$^{D\,\#}$	47.8	62.4
Apr-Jun	43.4$^{B\,\#}$	35.1	51.8

* Means not sharing a common superscript are significantly different (P<0.05).
[#] Limited observations recorded in Southern or Central Forest

Table 84: Predicted percentage P4M by estimated period of calving, based on marginal means generated within country type from the final multivariable model and adjusted for all other factors in the model (mean & 95% CI).

Previous calving period	**Southern Forest**	**Central Forest**	**Northern Downs**	**Northern Forest**
Jul-Sep	34.6^{A} 22-47.2	24.0^{A} 14.3-33.8	16.6^{A} 8.2-24.9	2.7^{A} 1.5-3.8
Oct-Nov	71.8^{B} 60.5-83.1	60.4^{B} 47.7-73.1	48.9^{B} 34.1-63.8	11.6^{B} 7.1-16.2
Dec-Jan	84.2^{C} 76.7-91.7	76.1^{C} 66.4-85.8	66.6^{D} 53.5-79.8	21.5^{D} 14.1-29
Feb-Mar	ID*	ID*	58.4^{C} 43.9-73	16.2^{C} 10.1-22.2
Apr-Jun	ID*	ID*	46.8^{B} 31.4-62.3	10.8^{B} 6.2-15.3

Within country type, means not sharing a common superscript are significantly different (P<0.05); *ID – insufficient data for analysis

There was some concern over the representativeness of the main effect of previous calving period for the Southern Forest, particularly for those producers who reportedly mate for three months aiming to calve in the late-winter to spring period and therefore would be expected to have a high percentage of cows calve before the end of September. The percentage P4M for each mating system by calving period was investigated by adding a mating system risk factor with calving period to the final multivariable model, which was restricted to the Southern Forest.

The main effect for mating system was not significant (P=0.31). However, the main effect of calving period and its interaction with mating system were both significant (*P*<0.001 and P=0.04, respectively). Consistently, those cows that calved during the period July-September in the Southern Forest had a lower percentage P4M than those calving in either October-November or December-January periods (**Figure 80**). This finding challenges the belief within the industry that July-September is the preferred time for calving in this region. However, this preferred calving period may be driven by other factors, such as markets and weaning weights, which have not been taken into consideration in this analysis.

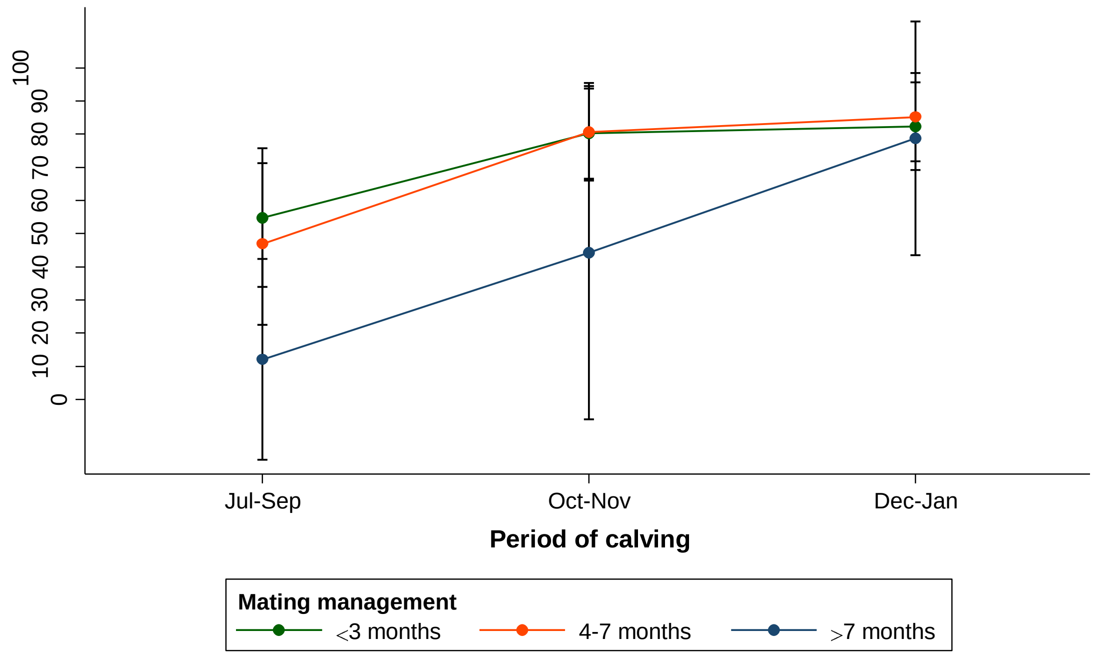


Figure 80: Percentage P4M in the Southern Forest by the predicted interaction between calving period and mating system, based on marginal means generated from a multivariable model and adjusted for all other factors in the model. Bars represent 95% confidence interval.

5.1.4.1 Application and Further work

Implementation of strategies to prevent females calving in the July-September period is recommended. In continuously mated herds this can be achieved by removing bulls from females at the time of the second annual muster during the mid-dry season, and then re-introducing them to the herd in January. The system of segregation of females at the time of pregnancy diagnosis based on estimated foetal age enables identification of females likely to calve in the July-September period. Different strategies ranging from aborting these females to late weaning them to increase likelihood of them reconceiving and then calving during the preferred period of the year have been developed to practically and economically manage these out-of-season calving females. In control mated herds consideration should be given to mating heifers and cows to ensure they do not calve in the July-September period.

Removal and re-introduction of bulls can be problematic where bull control is difficult and labour is seasonal. Development of better methods of managing bulls to prevent ‘out-of-season’ calves is recommended. Further, investigation of the economic impact of changing the period of calving and calving pattern of herds by country type is strongly recommended.

5.1.5 Predicted impact of body condition score at PD muster

Body condition score (BCS) at the time of pregnancy diagnosis was a significant determinant of the percentage P4M (P<0.001) and its interaction with country type was also significant (P<0.001). The distribution of cow BCS by country type are presented in **Figure 81**. Across country types, the percentage P4M progressively increased as BCS increased (**Figure 82**; **Table 85**). This progressive increase was consistent across all country types (**Figure 83**; **Table 86**).

In the Northern Downs and Northern and Central Forest, cows in poor body condition (BCS 1.0-2.0) at the time of pregnancy diagnosis were significantly less likely to become pregnant within four months of calving than those cows of fair body condition or better (BCS >2.5). However, in the Southern Forest, although cows in poor body condition (BCS 1.0-2.0) were predicted to be less likely to be pregnant within four months of calving than those in fair condition (BCS 2.5) the difference was not significant (2.0 percentage points; *P*=0.62). Also, although the percentage P4M for cows in forward or better condition (BCS 4.0-5.0) was higher than for those cows in good condition (BCS 3.5), only in the Southern Forest was this difference significant (4.7 percentage points; *P*=0.03).

Part of the explanation for the differences in magnitude of response to increased BCS at the PD muster for cows in the Northern Forest is that cows in this country type across all BCS categories were much more likely to lose condition between the PD muster and the WD muster the following year (**Figure 84**).

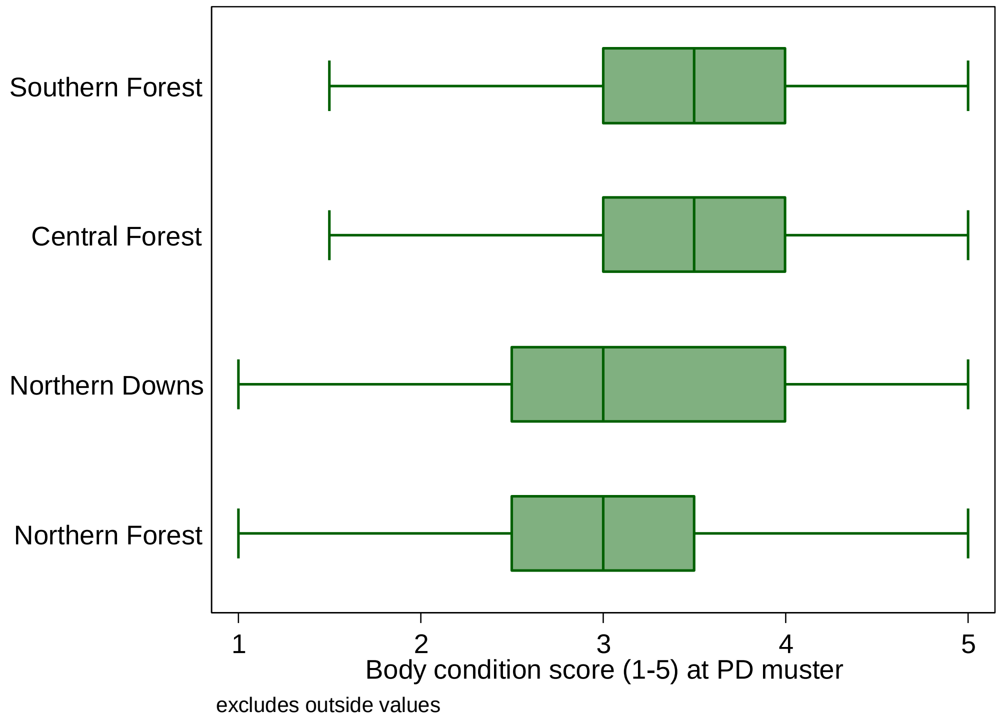


Figure 81: Distribution of body condition score at PD muster by country type.

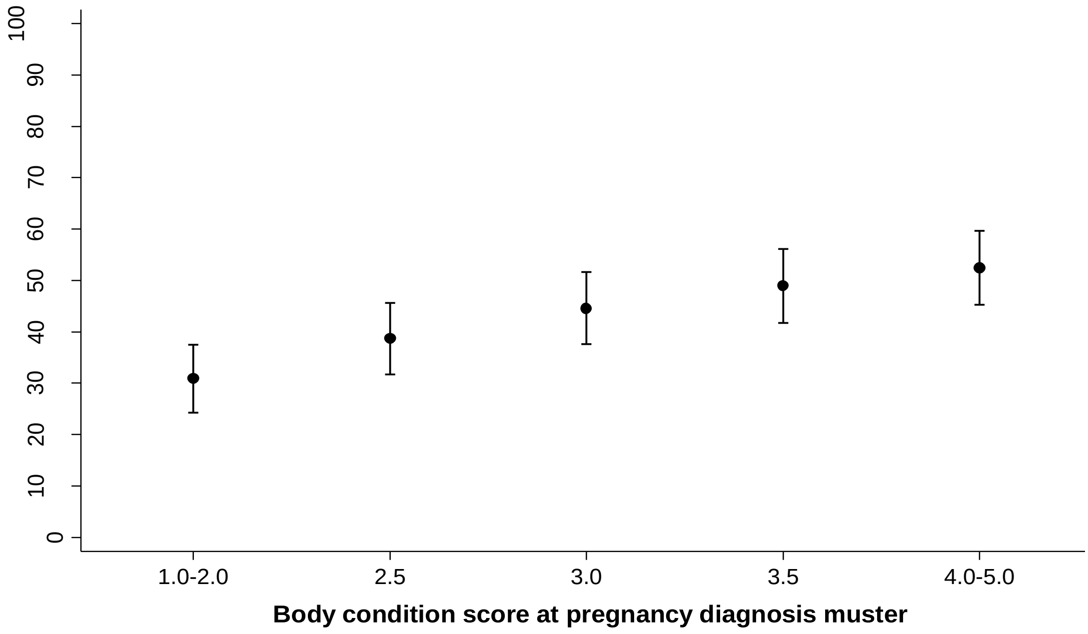


Figure 82: Predicted percentage P4M by body condition score at the previous PD muster, based on marginal means generated from the multivariable model and adjusted for all other factors in the model. Bars represent 95% confidence interval.

Table 85: Predicted percentage P4M by body condition score at the previous PD muster, based on marginal means generated from the multivariable model and adjusted for all other factors in the model.

Body condition Score	Mean percentage P4M*	95% Confidence interval	
		Lower	Upper
1.0-2.0	30.9^{A}	24.3	27.4
2.5	38.6^{B}	31.6	45.6
3.0	44.6^{C}	37.5	51.6
3.5	48.9^{D}	41.7	56.1
4.0-5.0	52.4^{E}	42.3	59.6

* Means not sharing a common superscript are significantly different (P<0.05).

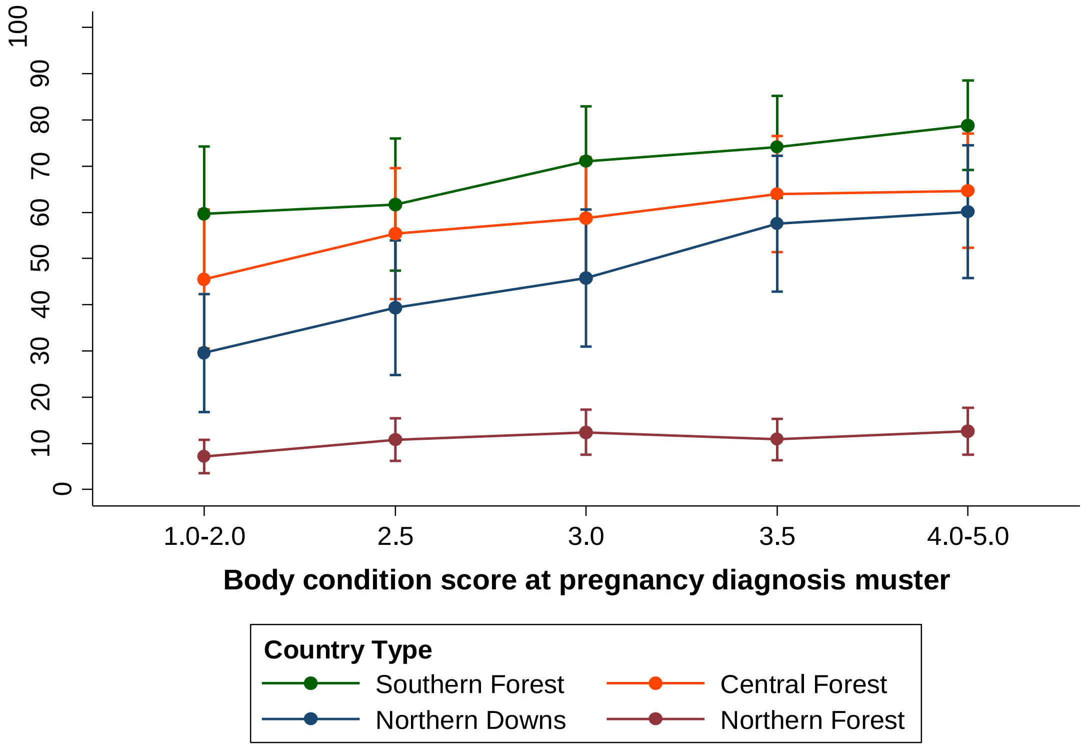


Figure 83: Percentage P4M by the predicted interaction between country type and body condition score category at the pregnancy diagnosis muster based on marginal means generated from the final multivariable model. Bars represent 95% confidence interval.

Table 86: Percentage P4M by the predicted interaction between country type and body condition score category at the pregnancy diagnosis muster based on marginal means generated from the final multivariable model. The lower and upper 95% confidence interval has been reported in parentheses.

Body condition score category	Mean percentage P4M* (%)			
	Southern Forest	Central Forest	Northern Downs	Northern Forest
1.0-2.0	59.7^{A}	45.6^{A}	29.6^{A}	7.1^{A}
	(45.1-74.3)	(30.5-60.6)	(16.8-42.3)	(3.5-10.7)
2.5	61.7^{A}	55.4^{B}	39.4^{B}	10.8^{B}
	(47.4-76.0)	(41.2-69.6)	(24.8-53.9)	(6.2-15.4)
3.0	71.1^{B}	58.8^{B}	45.8^{C}	12.4^{B}
	(59.2-83.0)	(45.6-72.0)	(30.9-60.7)	(7.5-17.3)
3.5	74.2^{B}	64.0^{C}	57.5^{D}	10.9^{B}
	(63.1-85.2)	(51.4-76.6)	(42.8-72.2)	(6.4-15.3)
4.0-5.0	78.8^{C}	64.7^{C}	60.1^{D}	12.6^{B}
	(69.1-88.5)	(52.3-77.0)	(45.7-74.6)	(7.5-17.7)

* Within country types, means not sharing a common superscript are significantly different (P<0.05).

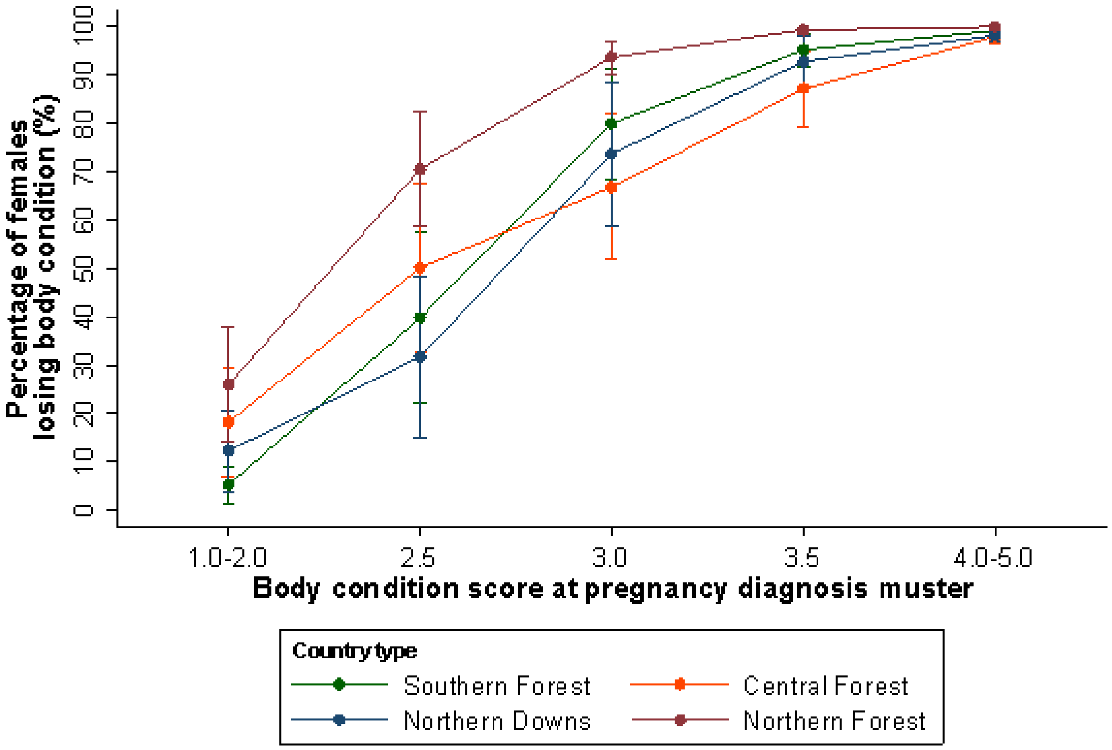


Figure 84: Probability of pregnant females losing body condition between the PD muster and the first annual WD muster the following year by body condition score at the PD muster and country-type.

5.1.5.1 Application and Further work

Most of the publications reporting a significant relationship between cow body condition and reproductive performance have analysed the relationship between cow body condition at or near to calving and various measures of postpartum reproductive performance. However, accurately assessing cow body condition in extensive rangeland environments is challenging and thus a more practical time to assess cow condition is at the time of pregnancy diagnosis, typically four to five months prior to calving. The CashCow findings demonstrate that assessment of cow body condition at the time of pregnancy diagnosis provides a useful indicator of post-partum reproductive performance.

A number of practical cost effective strategies have already been developed to ensure most cows are in good condition prior to calving. One of the key issues producers need to better understand is how long it will take a cow in poor condition to gain sufficient condition to be considered in good condition. For a 450kg cow in BCS 3, one condition score equals 13% of body weight i.e., 60kg[66]. Thus if a cow in poor condition (BCS 1-2) is able to gain weight at 0.5kg per day she will require about four months to be in good condition (**Appendix XIII**). In the majority of cases, the most effective means of achieving this rate of growth is to wean the calf from the cow at a time when there will still be sufficient good quality pasture available for several

66 Fordyce *pers comm*

months for the cow to gain the required weight. Therefore, managing cows to calve just prior to or early in the wet season and timing weaning to occur at the end of the wet season will help enable cows to recover good body condition prior to the next calving and thus be more likely to become pregnant again within four months of calving.

The increased energy demands of the late gestation conceptus and early lactation are met to a varying extent by mobilisation of the cow's body tissue reserves. The findings from the Beef CRC demonstrate that there is considerable variation in the extent to which these reserves are utilised by cows under the same pasture conditions and physiological status, and some of this variation is under genetic control. Selection for cows that are able to wean a calf annually and maintain good average body condition is likely to increase annual liveweight production. Investigation of selection strategies to achieve this is recommended.

However, the most critical work that needs to be done is to develop more effective methods of increasing adoption of management strategies that have been shown to result in the majority of cows being in good condition at calving.

5.1.6 Predicted impact of nutritional measures (CP:DMD)

The ratio CP:DMD provides a measure of the availability of rumen degradable nitrogen to metabolisable energy in the diet. The average wet season CP:DMD ratio was derived by averaging the ratio of CP:DMD determined for samples collected during November to March.

The percentage P4M for cows grazing pastures that had an average crude protein to dry matter digestibility ratio of >0.125 during the wet season was significantly higher (7.5 percentage points; $P<0.001$) than that for those cows grazing pastures ≤0.125 (**Figure 85**; **Table 87**) However, the relationship between the average dry season crude protein to dry matter digestibility ratio and percentage P4M was not significant.

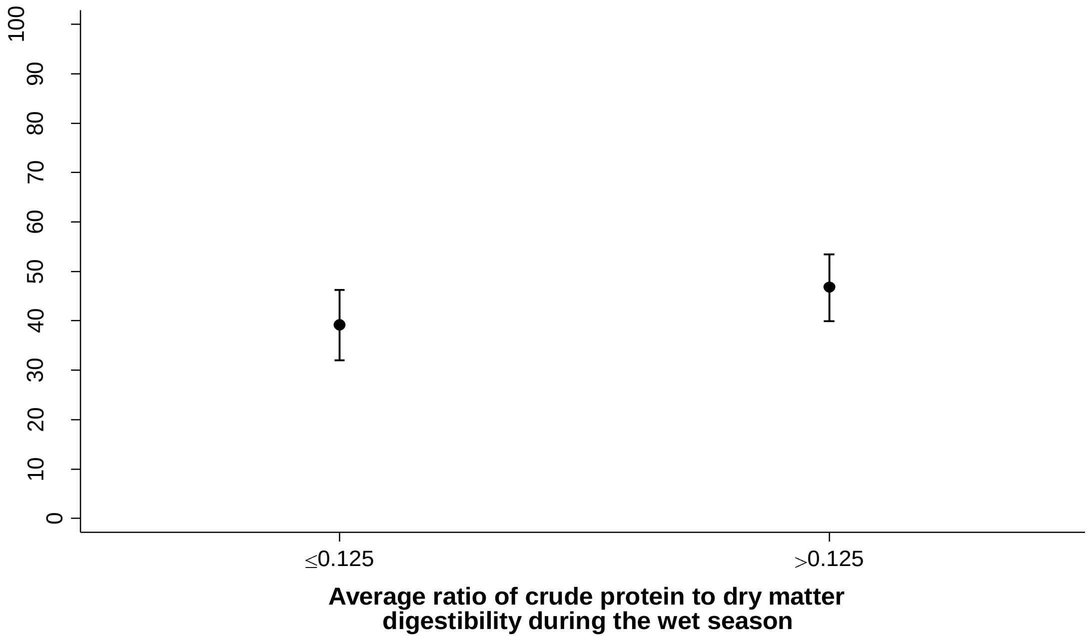


Figure 85: Predicted percentage P4M by average crude protein to dry matter digestibility category during the wet season based on marginal means generated from

the multivariable model and adjusted for all other factors in the model. Bars represent 95% confidence interval.

Table 87: Predicted percentage P4M by average wet season crude protein to dry matter digestibility ratio category, based on marginal means generated from the multivariable model and adjusted for all other factors in the model.

Average Wet season CP:DMD category	Mean percentage P4M	95% Confidence interval	
		Lower	Upper
≤0.125	39.2[A]	32.0	46.3
>0.125	46.7[B]	39.9	53.5

* Means sharing a common superscript are significantly different (P<0.05).
Note: A CP:DMD ratio ≤0.125 is equivalent to DMD:CP >8:1 and a CP:DMD ratio >0.125 is equivalent to a DMD:CP ratio of <8:1.

5.1.6.1 Application and Further work

Various practical pasture management strategies have been developed to improve the quality of wet season nutrition in northern Australia. Using the estimated impact of wet season pasture CP:DMD on percentage P4M, economic modelling of these different strategies could determine which is likely to be the most profitable.

There is a need to do further work to determine the major factors contributing to differences in wet season pasture CP:DMD between CashCow properties within each country type.

5.1.7 Predicted impact of nutritional measures (FP:ME)

The average ratio of faecal phosphorous to estimated metabolisable energy for faecal samples collected during the wet season was used as a measure of the wet season phosphorous status of each CashCow mob. The average ratio FP:ME was derived for the wet season (November – April) for each year. The FP:ME ratio was calculated per submitted sample and averaged across all samples collected during November – April for each property.

The results presented in this section use an FP:ME ratio of 500 as a cut point. This cut point was based on an assessment of a univariable logistic regression model fitting FP:ME as the sole predictor of cow reproductive performance data collected during this project. Cows that had an average wet season faecal P to metabolisable energy ratio of ≥500 were considered to have a low risk or ‘no risk’ of P deficiency adversely affecting performance, whereas those with an average wet season faecal P to metabolisable energy ratio of <500 were considered to have a high risk of P deficiency adversely affecting performance.

The average wet season faecal P to metabolisable energy ratio category was a significant determinant of the predicted percentage P4M (*P*=0.03) and its interaction with cow age class (*P*<0.001). After adjustment for all other factors in the final model, cows that were grazing pastures with a higher proportion of phosphorous relative to metabolisable energy during the wet season were predicted to have a significantly higher (10.2 percentage points) percentage P4M (**Figure 86**; **Table 88**).

For each cow age class, those with an average wet season faecal P to metabolisable energy ratio of <500 g P/MJME had lower percentages P4M than those with an average wet season faecal P to metabolisable energy ratio of ≥500 g P/MJME across the wet season (**Figure 87**; **Table 89**). All differences were significant except for the second-lactation cows. The large difference in performance of first-lactation cows is probably due to the majority of these cows undergoing skeletal growth at the same time as the foetus is undergoing skeletal mineralisation and subsequently the high loss of P associated with lactation for periods of three to eight months. The ability of this class of animal to meet any deficiency in phosphorous by mobilisation of bone reserves is likely to be significantly less than that of older cows[67].

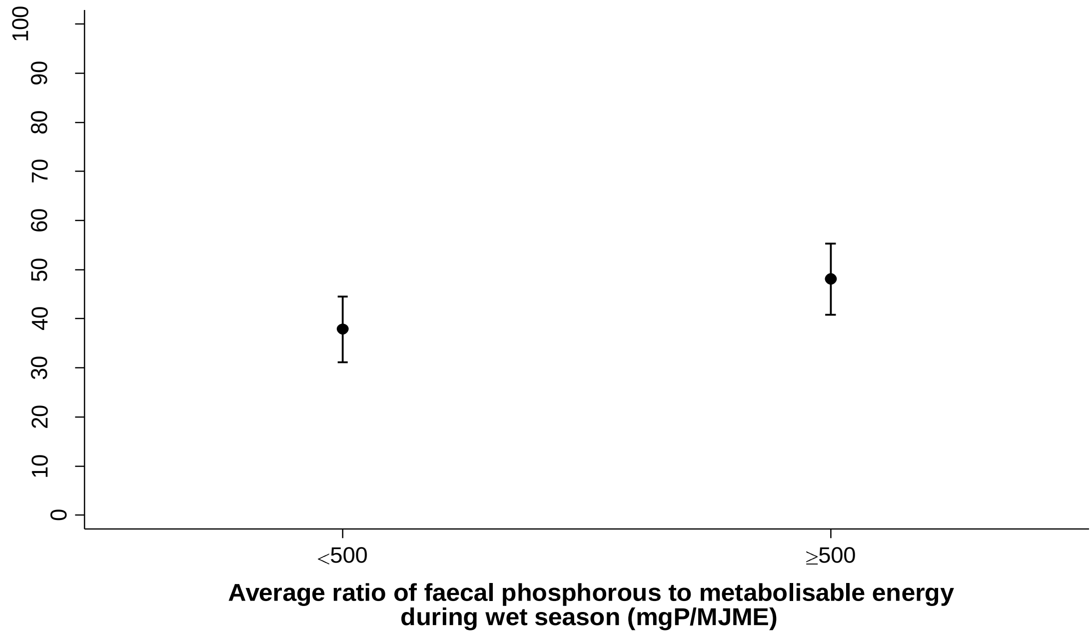


Figure 86: Predicted percentage P4M by average wet season faecal phosphorous to metabolisable energy ratio category, based on marginal means generated from the multivariable model and adjusted for all other factors in the model. Bars represent 95% confidence interval.

Table 88: Predicted percentage P4M by average wet season faecal phosphorous to metabolisable energy ratio category, based on marginal means generated from the multivariable model and adjusted for all other factors in the model.

Average wet season FP:ME category	Mean percentage P4M* (%)	95% Confidence interval	
		Lower	Upper
<500	37.8^{A}	31.1	44.6
≥500	48.1^{B}	40.9	55.3

* Means not sharing a common superscript are significantly different (P<0.05).

[67] Ternouth (1990); Miller *et al* (1997)

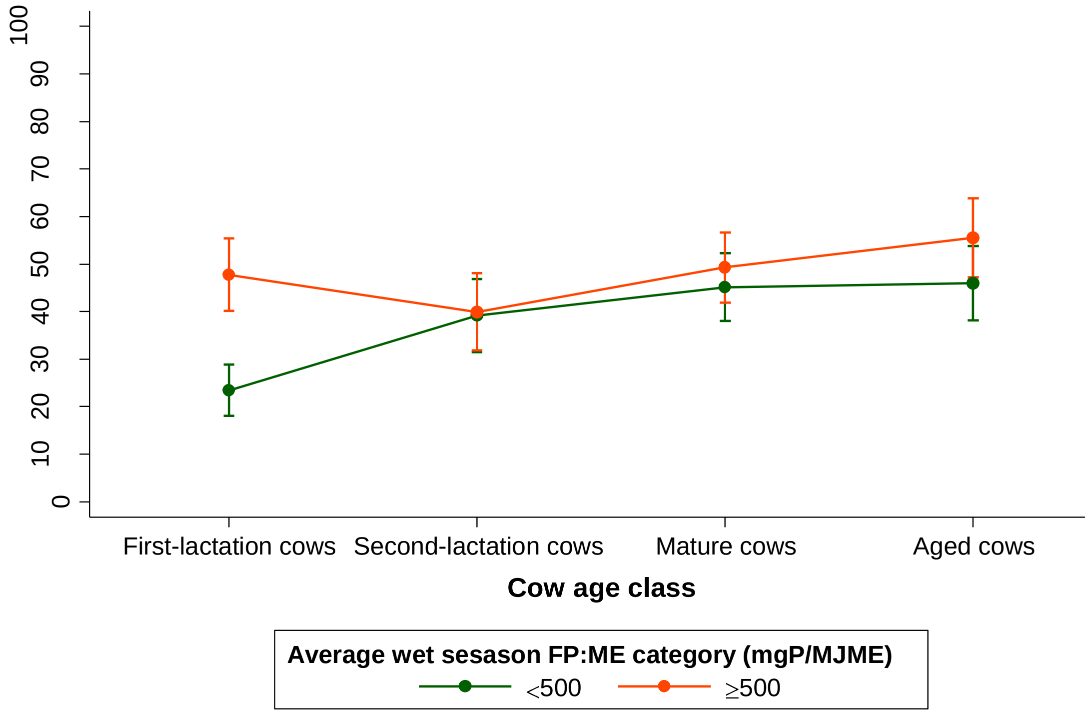


Figure 87: Percentage P4M by the predicted interaction between cow age class and average wet season faecal phosphorous to metabolisable energy ratio category based on marginal means generated from the final multivariable model. Bars represent 95% confidence interval.

Table 89: Percentage P4M by the predicted interaction between cow age class and average wet season faecal phosphorous to metabolisable energy ratio category based on marginal means generated from the final multivariable model. The lower and upper 95% confidence interval has been reported in parentheses.

Average wet season FP:ME category	**Mean percentage P4M* (%)**			
	First-lactation cows	**Second-lactation cows**	**Mature cows**	**Aged cows**
<500	23.4^{A} (18.0 - 28.8)	39.1^{A} (31.4 - 46.9)	45.1^{A} (38.0 - 52.3)	45.9^{A} (38.2 - 53.7)
≥500	47.8^{B} (40.1 - 55.4)	39.9^{A} (31.8 – 48.0)	49.3^{B} (41.9 - 56.7)	55.5^{B} (47.1 - 63.8)

* Within cow age class, means not sharing a common superscript are significantly different (P<0.05).

During the course of the Cash Cow project MLA published a manual entitled 'Phosphorous management of beef cattle in northern Australia'[68]. As this manual recommended a FP:ME threshold of 420 mg P/MJME additional categories of average wet season faecal P to metabolisable energy were investigated: ≤300, >300-420, >420-500 and >500.Preliminary assessment of the data indicated that there were no observations recorded for cows in the Southern or Central Forest where FP:ME was ≤300 mg P/MJME.

The effect of the four-level variable was then investigated by using the final model restricted

[68] Jackson *et al* (2012)

to the Northern Downs and Northern Forest. However, these revised models failed to converge until some of the other factors in the model were altered.

The effect of the four-level FP:ME variable in a multivariable model was assessed including the main effects of country type, cow age class, estimated period of calving, year, BCS at PD muster, further categorised average wet season FP:ME category, and the interaction term cow age class x average wet season FP:ME. The model was restricted to the Northern Downs and Northern Forest and omitted several variables that had been included in the final multivariable model reported above, including average wet season CP:DMD, wet season BCS change and the interactions BCS at PD muster x country type and cow age class x country type.

The findings from this additional exploratory modelling (**Figure 88**; **Table 90**) were consistent with the final model output described above. Both the main effect of average wet season faecal phosphorous to metabolisable energy ratio category during the wet season and its interaction with cow age class were significantly associated with percentage P4M (*P*<0.001). Generally, across cow age classes, the percentage P4M progressively increased as the average wet season faecal phosphorous to metabolisable energy ratio increased (**Table 91**).

In mature and aged cows, the mean percentage P4M was significantly lower when the average wet season faecal phosphorous to metabolisable energy ratio was ≤300 mg P/MJME compared to when it was >300-420 mg P/MJME (*P*<0.05) (**Table 91**). However, first-lactation cows were predicted to have a significantly higher mean percentage P4M than second-lactation cows (3.2 percentage points; *P*=0.04). In first-lactation, mature, and aged cows, when the average wet season faecal phosphorous to metabolisable energy ratio was >420-500 mg P/MJME the mean percentage P4M was not significantly different compared to when it was >500 mg P/MJME (*P*>0.05). However, in second-lactation cows a significant difference between these two categories of average wet season faecal phosphorous to metabolisable energy ratio was predicted (*P*<0.05).

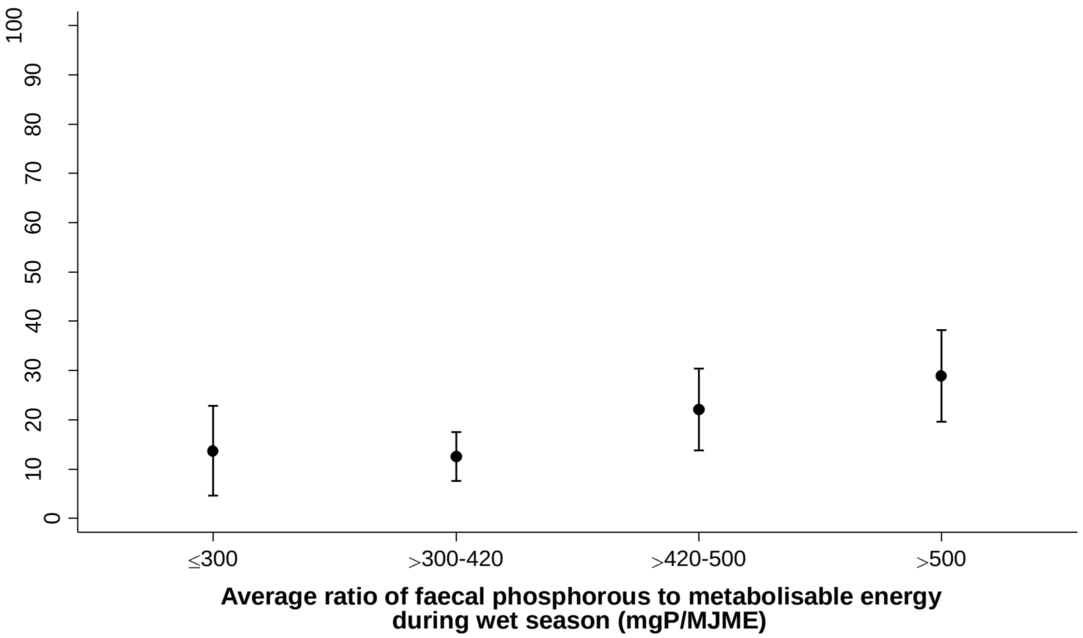


Figure 88: Predicted percentage P4M by average wet season faecal phosphorous to metabolisable energy category, based on marginal means generated from an additional exploratory model and adjusted for all other factors in the model. Bars represent 95%

confidence interval.

Table 90: Predicted percentage P4M by average wet season faecal phosphorous to metabolisable energy category, based on marginal means generated from an additional exploratory model and adjusted for all other factors in the model.

Average wet season FP:ME category	Mean percentage P4M * (%)	95% Confidence interval	
		Lower	Upper
≤300	13.7^{AB}	4.6	22.9
>300-420	12.6^{A}	7.7	17.5
>420-500	22.1^{B}	13.8	30.4
>500	29.0^{C}	19.7	38.3

* Means not sharing a common superscript are significantly different (P<0.05).

Table 91: Predicted percentage P4M by cow age class and average wet season faecal phosphorous to metabolisable energy category, based on marginal means generated from an additional exploratory model and adjusted for all other factors in the model. The lower and upper 95% confidence intervals have been reported in parentheses.

FP:ME category	Mean percentage P4M* (%)			
	First-lactation cows	Second-lactation cows	Mature cows	Aged cows
≤300	5.1^{A} (2.5-7.8)	ID$^{\#}$	14.1^{A} (8.6-19.6)	14.9^{A} (8.9-20.9)
>300-420	4.7^{A} (2.6-6.8)	14.2^{A} (8.2-20.2)	19.4^{B} (12.3-26.4)	18.0^{B} (11.2-24.8)
>420-500	17.8^{B} (10.5-25)	14.5^{A} (5.8-23.2)	30.2^{C} (20.2-40.3)	29.1^{C} (16.9-41.3)
>500	21.7^{B} (13.2-30.2)	27.9^{B} (18-37.8)	29.7^{C} (20.2-39.3)	37.8^{C} (25.9-49.8)

Note: Within cow age class, means not sharing a common superscript are significantly different (P<0.05).
Insufficient data for analysis.

5.1.7.1 Application and future work

Although there is some ongoing debate about the use of faecal P to ME ratio as a measure of the wet season phosphorous status of breeding cattle in northern Australia, the above findings provide strong evidence of a biological association between this measure and reproductive performance of cattle.

These results are consistent with previous research, which found that first-lactation cows were at greatest risk of P deficiency adversely affecting performance[69]. Similarly, the Cash Cow findings for mature and aged cows are consistent with the findings of previous research conducted in far northern Australia[70].

It is important to recognise that the faecal P to ME ratio categories used in the Cash Cow analysis describe the risk of P deficiency adversely affecting performance; they do not define the likely response to P supplementation. Unfortunately, no single measure of the P status of cattle has been shown to reliably predict the response of cattle to P supplementation. This is especially true in areas considered to be marginally P deficient. Although the use of wet and dry season P supplementation was included in the univariable analysis they were not found to significantly affect percentage P4M. However, the Cash Cow findings indicate that where the risk of P deficiency adversely affecting performance is high then strategies such as P supplementation of first-lactation cows and lactating older cows should be considered, along with other strategies such as weaning according to body condition score and improved pasture management.

5.1.8 Predicted impact of changes in body condition score

Data for the variable change in body condition score were derived by subtracting the BCS of the weaning/branding muster (WD) of the current year from the BCS at the pregnancy diagnosis muster of the previous year (PD) for each cow. The change in BCS between the PD and WD muster was found to be a significant predictor of P4M (P<0.001). It must be noted that only lactating cows were included in this analysis and thus this predicted impact is independent of the well recognised impact of weaning.

Cows that gained condition between the PD and WD musters were predicted to have a significantly higher percentage P4M than those cows that either maintained or lost condition between the PD and WD musters (8.0 percentage points; P<0.001) (**Figure 89**; **Table 92**). This difference in performance is independent of all other major factors identified, including BCS at the PD muster and its interaction with country type (**Figure 90**).

Cows in the Northern Forest, except for cows in poor condition (BCS 1-2), were more likely to lose condition between the PD and WD muster than cows in the other country types (**Figure 91**). Cows in poor to fair condition in the Northern Forest were much less likely to gain condition between the two musters than those cows in the other country types. Overall, these findings highlight the severity of the nutritional challenge cows are under in the Northern Forest and the impact this is likely to have on reproductive performance of these cows.

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[69] Miller *et al* (1997)
[70] Miller *et al* (1997)

Figure 89: Predicted percentage P4M by change in body condition score category between previous PD muster and the WD muster, based on marginal means generated from the final multivariable model. Bars represent 95% confidence interval.

Table 92: Predicted percentage P4M by change in body condition score category between previous PD muster and the WD muster, based on marginal means generated from the final multivariable model.

Change in body condition score between PD and WD musters	Mean percentage P4M* (%)	95% Confidence interval	
		Lower	Upper
Maintained or Lost condition	38.9^{A}	38.9	45.6
Gained condition	47.0^{B}	39.9	54.1

* Means not sharing a common superscript are significantly different (P<0.05).

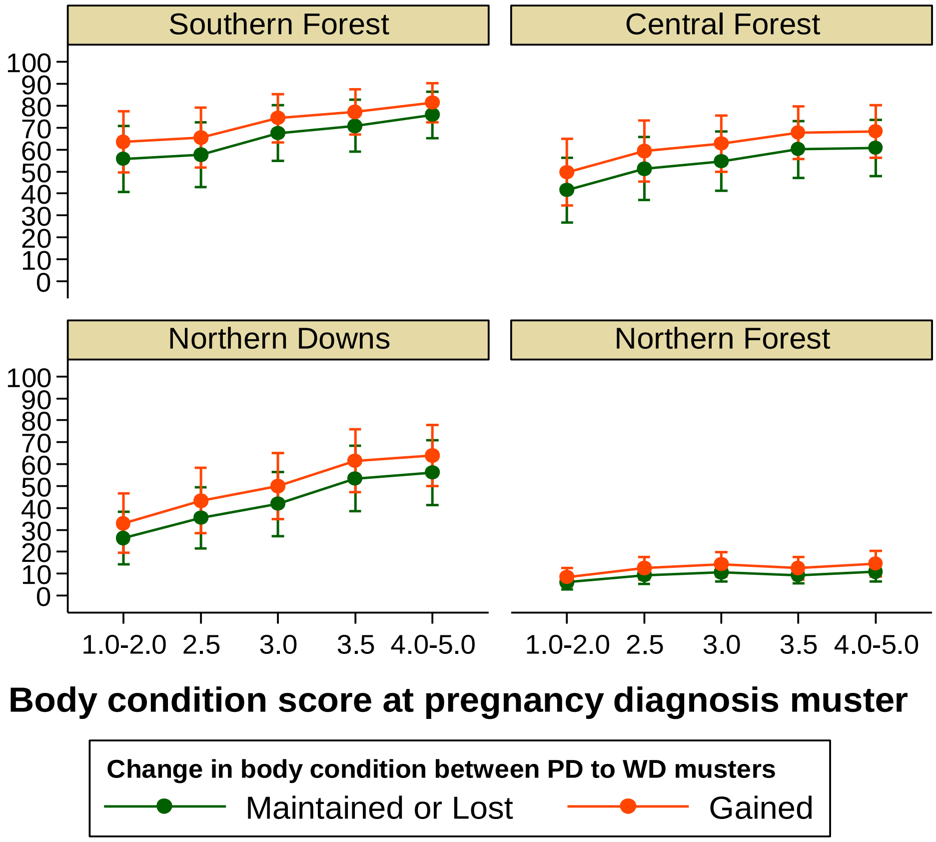

Figure 90: Predicted percentage P4M by the interaction between BCS at the PD muster and country type for each change in body condition score between previous PD muster and the WD muster category, based on marginal means generated from the final multivariable model. Bars represent 95% confidence interval.

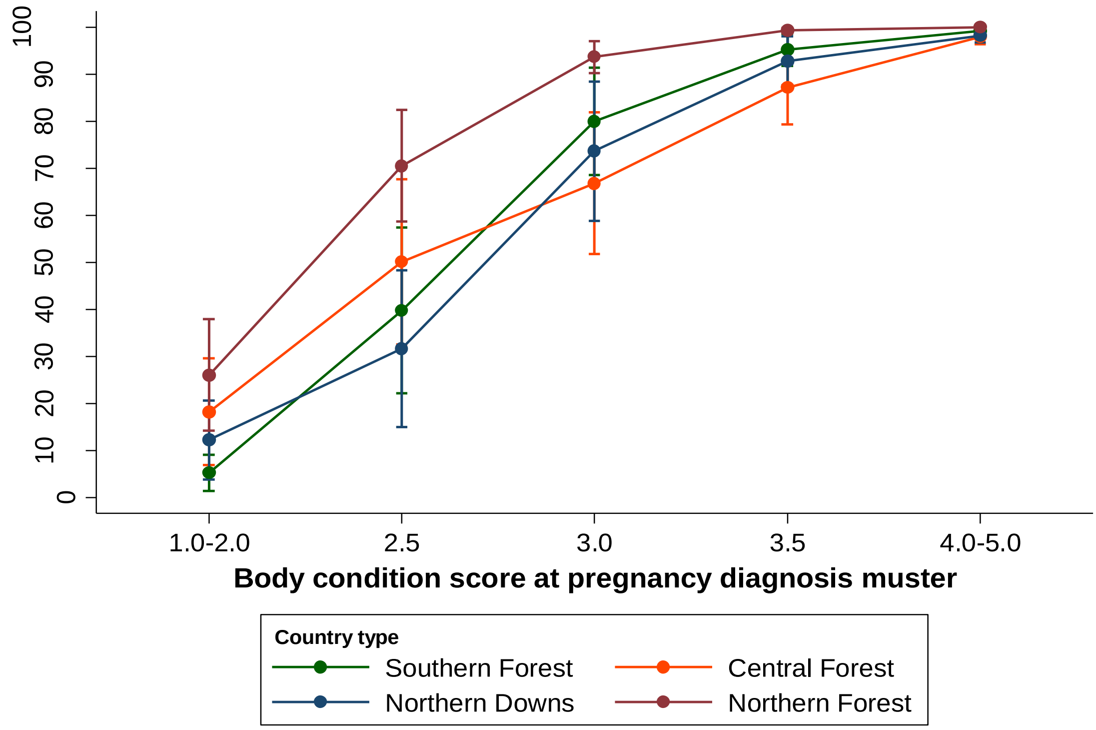

Figure 91: Predicted percentage of females losing body condition between the PD muster in the previous year and the first annual WD muster by body condition score at the PD muster and country-type, based on marginal means generated from the logistic regression model with BCS at PD muster, country type, and their interaction included as factors. Bars represent 95% confidence interval.

5.1.8.1 Application and further work

This finding highlights the critical importance of cow nutritional status both prior to and after calving. It also demonstrates the potential impact on P4M of improving the condition of cows that are lower than good condition at the time of the PD muster. Further, this finding supports the use of strategic supplementation of cows to ensure they calve in good condition.

The major challenge for the future is to increase adoption of practical, cost-effective strategies to reduce the proportion of cows in the Northern Forest losing condition between the PD and WD musters.

5.1.9 Predicted impact of selected factors not included in the model

5.1.9.1 Predicted impact of hip height

Hip height, which was measured at a cow's first PD muster, was found to be significantly associated with P4M and was eligible to be retained in the final model. However, due to only a subset of hip height measurements being collected in mobs with > 300 cattle, retaining hip height in the final model resulted in a reduction of seven properties and 8,384 animal-records contributing observations to the final model. Thus, hip height was not retained in the final model.

Although there was not a significant difference in the percentage P4M between moderate and short height females (2.8 percentage points; *P*=0.58), there was a significant difference between the performance of moderate and tall females (3.0

percentage points; *P*=0.01) (**Figure 92**; **Table 93**). Short females were observed as having a higher percentage P4M compared to tall cows, although this was not statistically significant (4.7 percentage points; *P*=0.16). This finding is independent of genotype and the other major factors described above.

This finding highlights the need to achieve a balance between selection for growth and fertility. The tools already exist for producers to achieve this. Selection of bulls for satisfactory growth and high fertility based on estimated breeding values for these two traits has been shown to be effective.

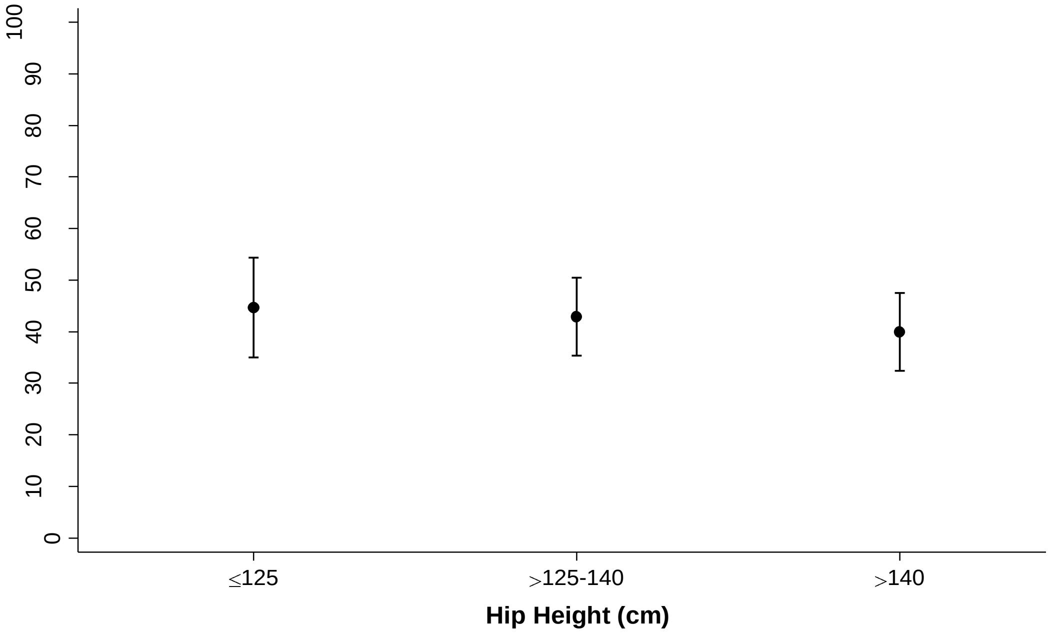

Figure 92: Predicted percentage P4M by hip height category, based on marginal means generated from final multivariable model and adjusted for all other factors in the model.

Table 93: Predicted percentage P4M by hip height category (lower quartile ≤ 125cm; interquartile range 125-140 cm and upper quartile >140 cm).

Hip height	Mean percentge P4M (%)	95% Confidence interval	
		Lower	Upper
<125 cm (lower quartile) **"Short cows"**	45.8	38.2	53.5
125-140 cm (interquartile range) **"Moderate height cows"**	43.4	36.1	50.8
>140 cm (upper quartile) **"Tall cows"**	41.0	33.7	48.3

5.1.9.2 Level of tropical adaptation

Genotype as a predictor of P4M in lactating cows was not identified as a significant factor in the final model when using two categories: ≤75% and >75% *Bos indicus*. In order to explore genotype using three genotype categories (<50% *B.indicus*, 50-75% *B. indicus* and >75% *B. indicus*), the final model was restricted to those country types that contained all three levels of genotype. This meant that the Northern Forest was omitted from the model.

The findings from this additional exploratory model revealed that genotype category was a significant predictor of P4M (*P*<0.001). Cows that were <50% *Bos indicus* were predicted to have significantly higher percentage P4M compared to either 50-75% *Bos indicus* or >75% *Bos indicus* (*P*<0.05) (**Figure 93**; **Table 94**).

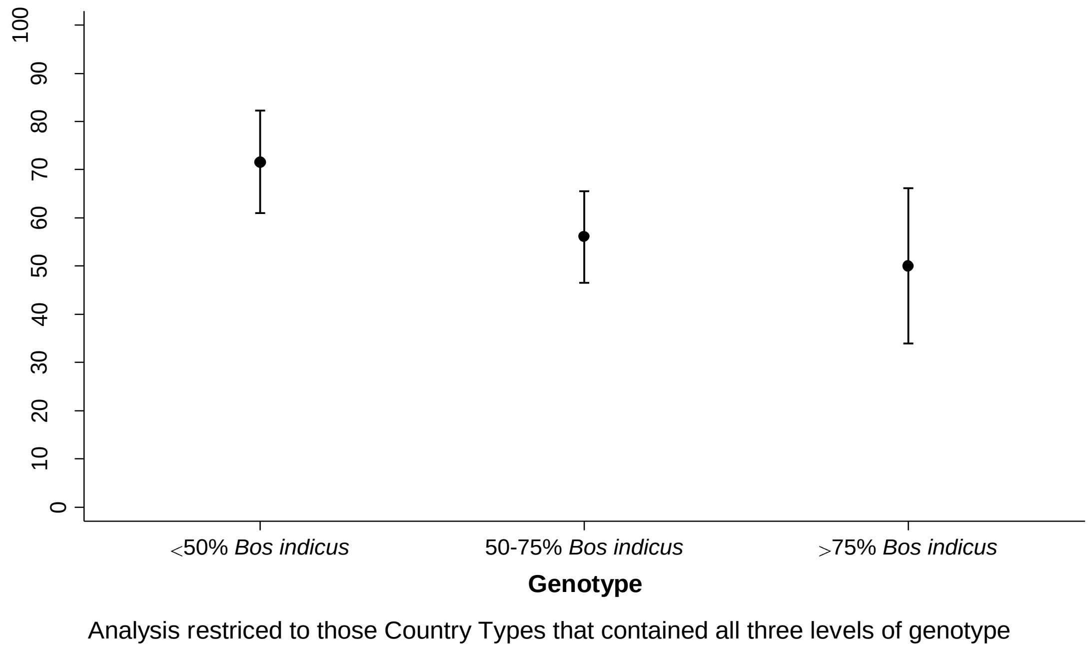

Figure 93: Predicted percentage P4M for each genotype category, based on marginal means generated from the final multivariable model and adjusted for all other factors in the model.

Table 94: Predicted percentage P4M for each genotype category.

Genotype	**Mean percentage P4M* (%)**	**95% Confidence interval**	
		Lower	**Upper**
<50% *B. indicus*	68.3^{A}	56.2	80.3
50-75% *B. indicus*	52.9^{B}	42.7	63.0
>75% *B. indicus*	51.1^{B}	33.9	68.4

*****Means not sharing a common superscript are significantly different (P<0.05).

5.1.9.3 Infectious diseases

As the monitoring of infectious diseases was only conducted in the first and third years of the main study, risk factors relating to infectious disease monitoring could not be included in development of the multivariable models. Their impact on performance was investigated using final models that were restricted to 2009 and 2011 data. The impact of infectious disease factors on the percentage P4M was assessed by individually adding the infectious disease risk factors to the final model.

In mobs with a high bovine viral diarrhoea virus (BVDV) seroprevalence (>80% seropositive) the mean percentage P4M was 23% lower (P<0.05) than in mobs with a low seroprevalence (<20% seropositive) (**Table 95**). In mobs with a moderate or high prevalence of recent infection, P4M was not predicted to be significantly lower than in mobs with a low level of recent infection. This may appear at first to be counterintuitive, as studies have shown that infection around the time of mating can significantly reduce pregnancy rate[71]. In some cases it was clear from the serological test results that at the time cows were sampled they were in the midst of an outbreak of BVDV; there was a high proportion of samples with an AGID result ≥3, but often the seroprevalence was only 50 to 60%. However, if this outbreak of infection did not coincide with the peak period of mating then a lower P4M would not be expected. It must be recognised that the interval between when cows were being mated and when blood sampling took place (either at first annual branding/weaning muster or pregnancy diagnosis muster) varied greatly, but often was many months afterwards.

Further, it is important to remember that although the majority (~88%) of susceptible cattle exposed to BVDV will have an AGID test results of ≥3 at 5weeks post-exposure only about 20% of these will still have this result at 7months post-exposure[72].Thus, in mobs where there has been widespread BVDV infection around the time of mating sufficient to adversely affect the percentage of cows conceiving early after calving, few of these females will show evidence of recent infection if tested about 6-7months later, but all will be seropositive. In the majority of CashCow mobs (72%) with a high BVDV seroprevalence, there was some evidence of recent infection (>10% of AGID test results ≥3) indicating that a persistently infected animal was likely to be present in the mob. As most mixing of cattle from different internal and external sources takes place around the time of joining this is also the time when a naïve mob is most likely to be exposed to a persistently infected animal(s).

None of the other infectious diseases (including vibriosis) investigated were predicted to significantly impact on P4M. This was somewhat surprising given the reported impacts of vibriosis on heifer pregnancy rates. However, it should be noted that the impact of vibriosis on heifer pregnancy rate could not be investigated because the heifers were only examined once. Further, there is some evidence that vaginal mucous antibodies to *C fetus veneralis* persist for variable periods[73] and it is possible that some cows may have been infected during the previous mating prior to being sampled and found to be positive. Rather than this reflecting a risk of vibriosis adversely affecting performance, it more likely indicates that these cows were immune to infection.

Table 95: Predicted percentage P4M by BVDV seroprevalence category (p=0.03).

BVDV seroprevalence*	Mean percentage P4M (%)	95% Confidence interval	
		Lower	Upper
Low	57.3 ^{A}	43.8	70.9
Moderate	43.2 ^{AB}	26.2	60.1
High	34.3 ^{B}	17.0	51.6

*Seroprevalence category defined as Low: <20%; Moderate: 20-80%; High: >80% seropositive

[71] McGowan *et al* (1993)
[72] McGowan and Kirkland (1993)
[73] Hum (1994)

5.1.10 Variance explained by the model

The fixed effect component of the full statistical model accounted for or explained 23% of the total variance in percentage P4M. Adding the fixed effects to the model also explained ~53% of the variance at the property level that had been estimated in the intercept-only model (**Table 96**). However, there is still a relatively large amount of unexplained variance in percentage P4M at the property level, and this is due to un-measured explanatory factors (factors other than those that were included in the model).

Table 96: Variance estimates from an intercept-only model for percentage P4M that included a random effect coding for property and the full model that included the same random effect.

	Null model	Full model
Level 1 variance	3.29	3.29
Property level variance	1.88	0.89
Fixed effect variance (Full model only)		1.25
Total variance		5.43
% of total Variance explained by fixed effects		23.0%
% of property level variance explained by full model		52.7%
% of unexplained variance at the property level		21.3%
Intra-class correlation (ICC)	0.36	0.21

5.2 Factors affecting annual pregnancy rate

This section presents the findings from the final multivariable model used to identify important explanatory variables that influence the outcome “annual pregnancy rate”. For each factor (variable) and interaction term included in the final multivariable model, the following section provides the predicted mean annual pregnancy rate of cows at the referent level for all other factors in the model. Referent levels used are displayed in **Appendix XIV**.

Note that the performance by country type and cow age class reported in this section will be different to that presented in the descriptive summaries of performance presented in Section 4.5 , as the mean performance is predicted from the multivariable model and takes into account the impacts of all other major factors included in the final model. Producers looking for typical measures of performance and what is commercially achievable for comparison with their own herd’s performance should use the summary data presented in **Section 4.5** .

The purpose of the multivariable modelling process is to identify the major drivers of annual pregnancy rate and to explain the effect of each factor after adjustment for all other factors in the model. All candidate factors were initially considered for inclusion in the multivariable model building process, and all factors with significant and biologically plausible associations with the outcome were retained in the final model. It is important to be aware that when comparing the predicted difference(s) between annual pregnancy rate of cows for each factor the absolute difference is expressed in terms of percentage points increase or decrease i.e., the difference between 50% and 55% is 5 percentage points.

For each annual production cycle that a breeding female was enrolled in the study, the outcome variable indicated pregnancy status based on a conception date threshold of September 1. Animals that were mated and conceived prior to September 1 were assigned a value of 1 for the outcome variable and animals that did not conceive or that conceived after September 1 were assigned a value of 0 (zero) for that year.

Note that the outcome of annual pregnancy status (0=not pregnant, 1=pregnant) used in this analysis refers to pregnancies where conception occurred in the 12 months ending at September 1 in the current year. This means that those animals that calved in the second half of the previous year and then conceived later in the same year, would be classified as outcome=1 in the current analysis.

A description of the model building process is provided in Section **3.5.5** .

The full model presented in the remainder of this section involved 32,382 animal records derived from 24,736 unique animals and from 55 properties. Animal records that were missing data for any of the variables included in the final model resulted in that row of data being omitted from the model and this explains why a number of animals and properties have not contributed data to the final model.

The average number of records per animal was 1.3. There were 229 cows that had three animal records each, 7188 cows that had two animal records each and 17319 (70% of all animals) that had only a single record each in the dataset.

The following sections outline the effects in the final model. Note that factors that are not in the final model were screened out because they were either non-significant, or explained by a closely-related variable. A full list of variables available at the commencement of the analysis is presented in **Appendix XIV**.

The final multivariable model for annual pregnancy status contained the following terms:

Main effects:

- Cow age class (first-lactation, mature cow, aged cow)
- Previous pregnancy outcome expressed as predicted window when the cow calved (October-November, December-January, February-March, April-June, July-September), cows that were known to have calved but that had an unknown calving window (Pregnant), cows that failed to get pregnant in the previous season (Empty), and cows that were diagnosed as pregnant in the previous season but failed to rear a calf in the current year (FTR = failed to rear)
- Year (2009, 2010, 2011)
- DMD at the dry period (≤55, >55)
- PME ratio in the previous wet (<500, ≥500)
- CP/DMD in the previous wet (≤0.125, >0.125)
- Country type (Southern Forest, Central Forest, Northern Downs, Northern Forest)
- BCS at wet-dry muster (1 - 2, 2.5, 3, 3.5, 4 - 5)

Interaction terms:

- PME in previous wet x CP/DMD in previous wet
- Country-type x PME in previous wet
- Previous pregnancy outcome x cow age class
- BCS at wet-dry muster x cow age class
- Country type x CP/DMD in previous wet
- Previous pregnancy outcome x BCS at wet-dry muster

Table 97 provides a summary of the number of mobs and animals that contributed data to the final multivariable model with annual pregnancy status as the outcome. These counts are relevant for all the following predicted marginal means generated from the multivariable model.

The following pages provide predicted annual pregnancy rates expressed as a percentage and 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 are adjusted for the effects of all other variables in the model. Pair-wise statistical comparisons have been conducted to generate p-values for comparisons between different levels within each variable or interaction term from the final model.

Table 97: Number of cows and mobs which contributed data to the final multivariable model.

Region	Number of mobs	No. of unique animals within a mob			Total number of animals within region
	(n)	median	min	max	(n)
Southern Forest	12	221	145	569	3,213
Central Forest	13	260	103	824	4,469
Northern Downs	11	473	133	3,960	8,286
Northern Forest	19	335	54	2,616	8,768
Total	55	304	54	3,960	24,736

5.2.1 Predicted annual pregnancy percentage by country type

The mean predicted annual percentage pregnant for the Northern Forest was significantly lower (p=0.007) than that in the Southern Forest (**Figure 94**; **Table 98**). All other comparisons were not different (p>0.05).

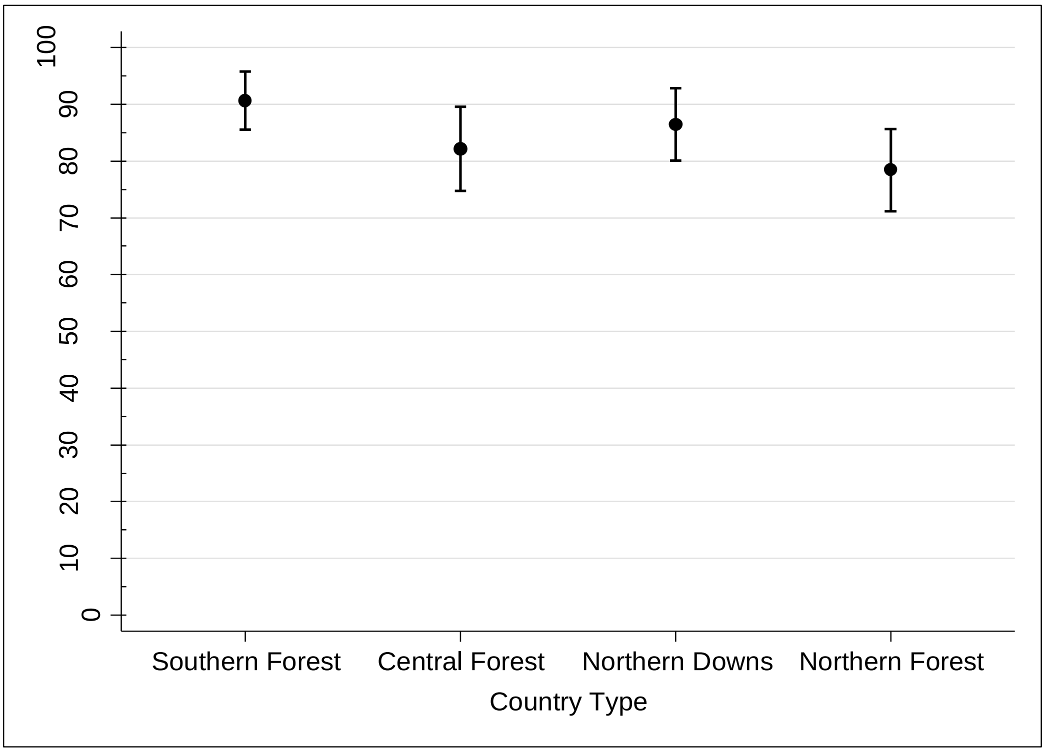

Figure 94: Predicted annual pregnancy percentage by country type, based on marginal means generated from the final multivariable model. Bars represent 95% confidence interval.

Table 98: Predicted annual pregnancy percentage by country type, based on marginal means generated from final multivariable model and adjusted for all other factors in the model.

Country type	Mean annual percentage Pregnant (%)	95% Confidence interval	
		Lower	Upper
Southern Forest	90.7	85.6	95.8
Central Forest	82.2	74.8	89.6
Northern Downs	86.4	80.1	92.8
Northern Forest	78.4	71.2	85.7

The predicted percentage pregnancy estimates are used to compare the effects of different levels of country-type after adjustment for all other variables in the model.

It is important to note the distinction between the estimates in **Table 98** and those in Section **4.5.2** , such as **Table 25**.

Table 25 provides descriptive summary statistics of annual pregnancy rate (expressed as percentage pregnancy) by country type. The descriptive summaries are not dependent on any other variables and they represent unadjusted or crude summary measures of performance. The 75th percentile may be used as a benchmark target for any measure because it separates the best 25% of mobs for each measure from the remainder (the lower 75% of the mobs). Producers looking for typical measures of performance and for targets to compare their own performance to should use the summaries presented in Section **4.5** .

The marginal means in **Table 98** are dependent on the other variables included in the final model. The purpose of the multivariable modelling process is to identify the major drivers for each outcome and to explain the effect each variable has on the outcome after adjustment for all other variables in the model.

In this case, the results indicate that adjusted for all the other variables included in the final model, the highest annual pregnancy rate was observed in the Southern Forest and the lowest in Northern Forest. Using follow-up tests to compare country types, the only comparison that was significantly different ($p<0.05$) was the difference between the Northern Forest and Southern Forest (difference of 12 percentage points in annual pregnancy rate). All other comparisons between country-type marginal means were not different ($p>0.05$).

The dependency on other variables in the final model means that if additional variables had been included in the final model then the predicted marginal means generated using the final model may have different numeric values.

The model building process used to develop the final models ensured that all candidate variables were considered for inclusion and that all variables with significant and biologically plausible associations with the outcome were retained in the final model. This approach ensured the final model contained all those variables that are likely to be major (significant) drivers of the outcome. Other variables may be considered and discarded because they are not major drivers.

5.2.1.1 Application and further work

The fact that predicted annual pregnancy rates for the different country types are all relatively high may be due in part to the fact that annual pregnancy rate may not be the most effective measure for distinguishing good from suboptimal performance because a number of cows may get pregnant but at less desirable times leading to out of season calving. The findings are consistent with the hypothesis that most cows do eventually become pregnant.

When adjusted for all the variables in the final model the findings suggest that 10-22% of cows are not getting pregnant. If these animals have chronic infertility or may be delivering calves that also have reduced annual pregnancy rates then identification of these cows for culling and replacement may offer an important strategy for increasing fertility.

This model does not assess the time taken for cows to become pregnant and therefore does not allow assessment of issues such as cows calving out of season with associated risks for cow and calf mortality and low weaning rates.

Identification of possible strategies to increase annual pregnancy rate in the Northern Forest is recommended. In addition, even though the mean predicted pregnancy rates for the other three country types were not statistically different the 95% confidence intervals for the mean pregnancy rate for the Central Forest includes values lower than 80% which suggests that there may be opportunities for exploring options to increase annual pregnancy rate in Central Forest as well.

5.2.2 Predicted annual pregnancy percentage by year

When all other factors in the model were taken into account, project year had a significant effect on annual pregnancy rate.

The highest annual pregnancy rate when adjusted for all other factors in the model was in 2009 and pregnancy rate dropped each year over the course of the project (**Figure 95**; **Table 99**). Comparisons of the annual pregnancy rate between years indicated that all three comparisons were statistically significant ($p<0.05$).

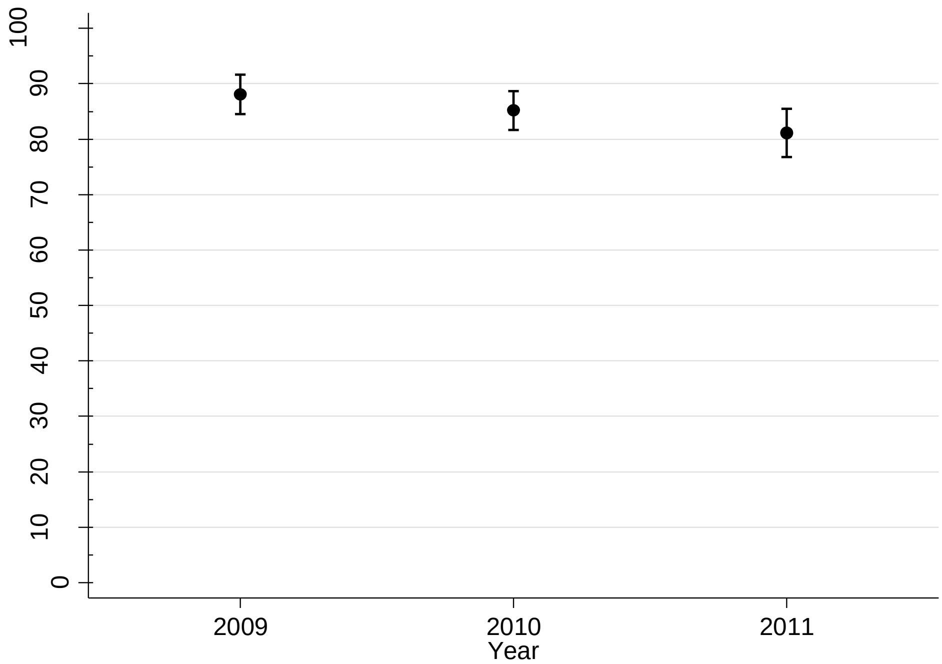

Figure 95: Predicted annual pregnancy (%) by year based on marginal means generated from the final multivariable model. Bars represent 95% confidence interval.

Table 99: Predicted annual pregnancy (%) by year based on marginal means generated from the final multivariable model.

Year	Mean annual percent pregnant	95% Confidence interval	
		Lower	Upper
2009	88.1	84.5	91.6
2010	85.2	81.7	88.7
2011	81.2	76.8	85.5

5.2.2.1 Application and further work

This finding highlights the critical importance of analysing herd performance over multiple years to provide an accurate estimate of performance measures and to adjust for the effects of year when identifying key drivers of performance.

The effects of year are likely to be related to unmeasured effects of changes in climate, pasture availability and quality, as well as other factors such as management that may change over time. Even though approximately 180 risk factors were examined, with many of these representing things that may change from year to year, the continued significance of year effects in the final model demonstrates that further work is required to better understand underlying factors that may be contributing to year effects.

5.2.3 Predicted impact of cow age class

Adjusted for other variables in the final model, there was a significant association between cow age class and annual pregnancy rate.

Mature cows had a significantly higher predicted annual pregnancy rate than both first-lactation cows ($p<0.001$) and aged cows ($p=0.001$) (**Figure 96**; **Table 100**).

There was no difference in predicted annual pregnancy rates between first-lactation cows and aged cows ($p=0.2$).

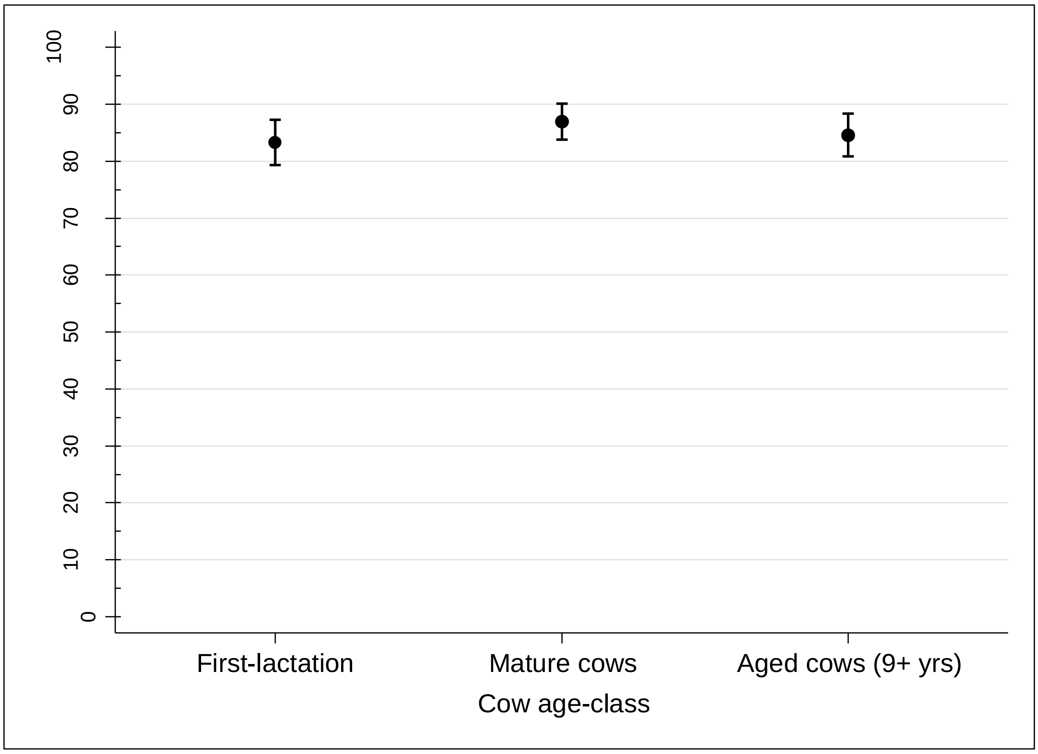

Figure 96: Predicted annual pregnancy (%) by cow age class based on marginal means generated from the final multivariable model. Bars represent 95% confidence interval.

Table 100: Predicted annual pregnancy (%) by cow age class based on marginal means generated from the final multivariable model.

Cow age class	Mean annual percentage pregnant	95% Confidence interval	
		Lower	Upper
First-lactation	83.3	79.3	87.3
Mature cow	87.0	83.8	90.1
Aged cow	84.6	80.8	88.3

5.2.3.1 Application and Further work

The reduction in annual pregnancy rate for aged cows is statistically significant but relatively small in absolute percentage point terms (<3%). It is consistent with an age-associated decline in reproductive performance and may be one factor contributing to a decision to cull aged cows.

There is a need to refine the recommendations on age at culling by country type to achieve a balance between reproductive performance and risk of mortality.

5.2.4 Predicted annual pregnancy percentage by reproductive outcome in the previous year

Data for the variable 'cow reproductive outcome' were derived from a combination of pregnancy testing performed in the previous year and examination of cow lactation status in the current year. The categories for cow reproductive outcome include:

- Predicted month of calving in two-three month intervals beginning with July-September from the previous year and moving progressively forward to February-March and April-June, which are in the current year. Cows were assigned to these intervals based on foetal ageing from the pregnancy diagnosis round performed in the previous year.
- The **Pregnant** category denotes animals that calved between the last mustering round of the previous year and the first round of the current year but where there were no data on predicted month of calving so their month of calving was unknown. This category is likely to include animals that were not pregnancy tested the previous year (and therefore had no predicted calving date recorded), or that were misclassified as empty, either through error or because they conceived late in the previous year so they were not detectably pregnant at the previous year's pregnancy diagnosis round. Some of these animals may have calved after June in the current year. The Pregnant category is therefore a catch-all category for animals known to have calved in the current year but where there is no predicted calving date.
- The **Empty** category indicates animals that were diagnosed empty at the pregnancy diagnosis round in the previous year and that were recorded as dry at both rounds in the current year.

- The **FTR** category (Failed to Rear) indicates those animals that were tested pregnant the previous year and that lost the calf between pregnancy diagnosis the previous year and the first round (wet/dry) in the current year.

These categories also express lactation status. Animals in the Empty and FTR categories are not lactating in the current year and all other animals are lactating in the current year.

Figure 97 and **Table 101** show the main effect of cow reproductive history. **Figure 98** and **Table 102** show the effects of the interaction between cow age class and cow reproductive history; both terms were associated with a significant effect on annual pregnancy ($p<0.05$).

There was a progressive decline in mean annual percentage pregnant as the predicted month of calving for the previous pregnancy moved forward in time, and the lowest annual percentage pregnant was observed in those cows that were predicted to calve between April and June in the current year, except in the case of first-lactation cows. Generally cows calving in April-June would be expected to have the least time to resume cycling, conceive after calving and be detected pregnant during the current year. It is not clear why first lactation cows calving in April-June do not show the same reduction relative to those animals calving in February-March as is apparent in the two older age-groups of cows. It may be that first-lactation cows are treated differently to older cows in some way (early weaning at the first annual mustering round and possibly some form of nutritional supplementation).

Cows classified as pregnant in the previous year, but with an unknown predicted date of calving, had annual percentage pregnant in the current year that were similar to cows predicted to calve from February to June. These animals may have been assigned to pregnant in the previous year because they were identified in the first round of the current year as lactating. Many of these cows may have conceived late in the previous year and this would be consistent with their pregnancy rate in the current year being similar to other cows that were predicted to calve later in the season. Cows that were classified as empty in the previous year had the highest annual pregnancy percentage in the current year and this may reflect the fact that these cows had no adverse effects associated with pregnancy and lactation in the period leading up to mating. Cows that were classified as failed-to-rear also had a relatively high percentage pregnant in the current year but not as high as those animals classified as empty. It may be that some of these animals carried a pregnancy to term or near term and then lost the calf, incurring some adverse effects of pregnancy and possibly lactation on the likelihood of conceiving in a timely manner in the current year.

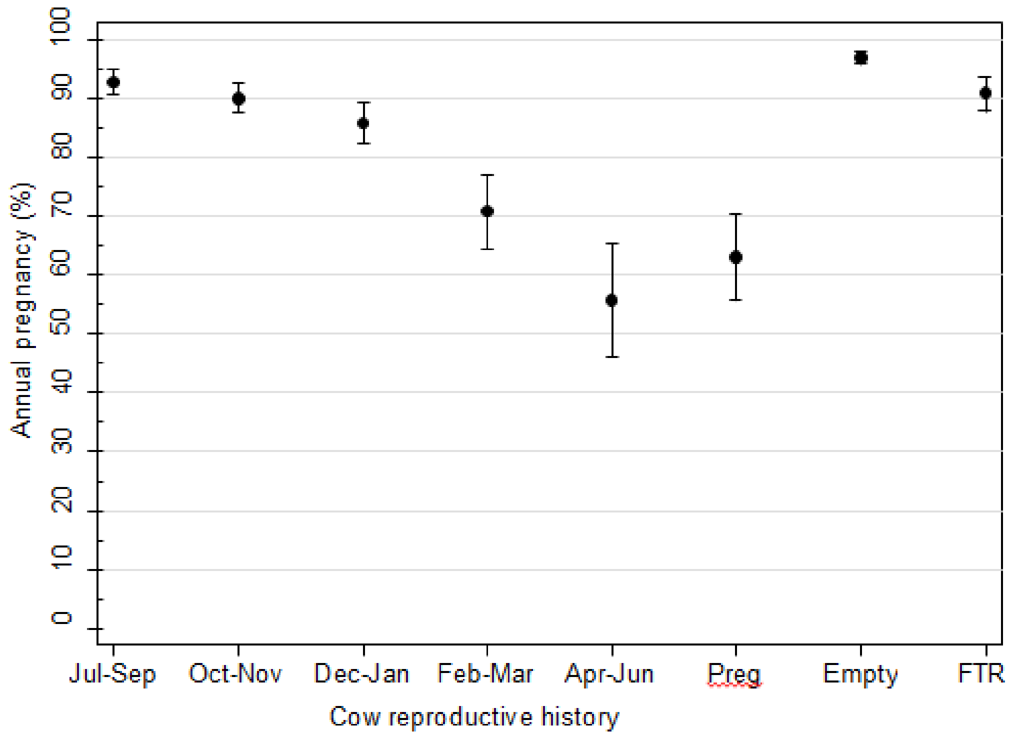

Figure 97: Predicted annual pregnancy percentage in the current year by cow reproductive outcome in the previous year based on marginal means generated from the final multivariable model. Bars represent 95% confidence interval.

Table 101: Predicted annual pregnancy (%) by cow reproductive outcome in the previous year based on marginal means generated from the final multivariable model.

Previous reproductive history	Mean annual percent pregnant	95% Confidence interval Lower (%)	Upper (%)
Jul-Sep	92.7	90.7	94.8
Oct-Nov	90.0	87.5	92.5
Dec-Jan	85.8	82.4	89.2
Feb-Mar	70.7	64.5	76.9
Apr-Jun	55.8	46.2	65.4
Pregnant	63.0	55.6	70.3
Empty	96.8	95.8	97.9
Failed to rear	90.8	87.9	93.7

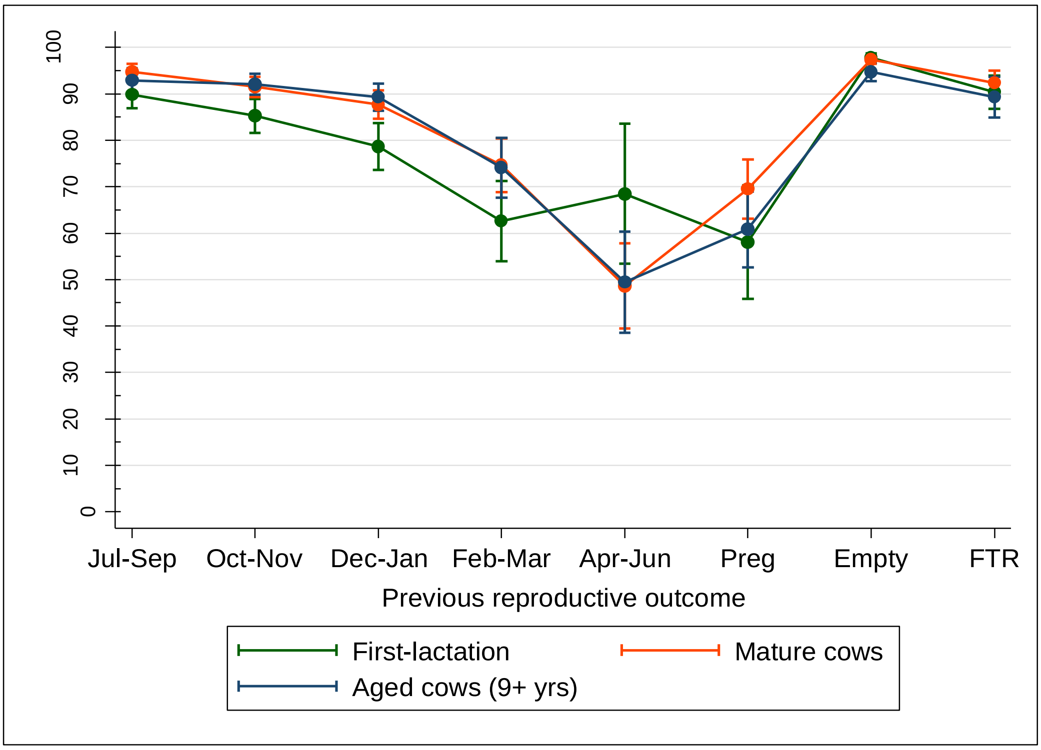

Figure 98: Predicted annual pregnancy percentage by cow age class and cow reproductive outcome from the previous year, based on marginal means generated from the final multivariable model. Bars represent 95% confidence interval.

Table 102: Predicted annual pregnancy percentage by cow age class and cow reproductive outcome from the previous year, based on marginal means generated from the final multivariable model.

Previous reproductive outcome	Cow age class	Mean annual percent pregnant (%)	95% Confidence interval	
			Lower (%)	Upper (%)
Jul-Sep	First-lactation	89.8	86.9	92.7
Jul-Sep	Mature cow	94.8	93.1	96.4
Jul-Sep	Aged cow	92.9	90.2	95.6
Oct-Nov	First-lactation	85.2	81.6	88.9
Oct-Nov	Mature cow	91.5	89.3	93.7
Oct-Nov	Aged cow	92.1	89.8	94.4
Dec-Jan	First-lactation	78.7	73.7	83.7
Dec-Jan	Mature cow	87.6	84.6	90.7
Dec-Jan	Aged cow	89.3	86.4	92.2
Feb-Mar	First-lactation	62.6	53.9	71.2
Feb-Mar	Mature cow	74.6	68.8	80.4
Feb-Mar	Aged cow	74.1	67.7	80.5
Apr-Jun	First-lactation	68.5	53.4	83.6
Apr-Jun	Mature cow	48.7	39.5	57.9
Apr-Jun	Aged cow	49.4	38.5	60.3
Pregnant	First-lactation	58.1	45.9	70.3
Pregnant	Mature cow	69.5	63.2	75.9
Pregnant	Aged cow	60.9	52.7	69.0
Empty	First-lactation	97.7	96.8	98.7
Empty	Mature cow	97.4	96.5	98.3
Empty	Aged cow	94.7	92.7	96.7
FTR	First-lactation	90.4	86.8	93.9
FTR	Mature cow	92.4	89.7	95.1
FTR	Aged cow	89.3	84.9	93.6

5.2.4.1 Application and further work

The findings are consistent with the general preference for having cows calve between November and February. Cows that calve within this window have a relatively high likelihood of getting pregnant again in the period prior to September.

Cows that calve after February in the current year have a progressively lower likelihood of getting pregnant in the same year as the month of calving advances.

Cows that calve prior to November of the previous year have a high likelihood of getting pregnant prior to September of the following year but may not necessarily calve in the ideal window.

Implementation of management strategies to increase the proportion of cows calving in the optimum period, November to February, will result in improvements in annual pregnancy rate. These findings are consistent with those for the effect of calving period on P4M. The reader is referred to **Section 5.1.4** .

Development of practical management strategies that enable increased proportions of females to calve during the optimum period is crucial, as this will enable much more effective matching of energy, protein, and phosphorous needs for late gestation and early lactation with pasture growth and quality. There is a need to identify the factors that contributed to the higher than expected annual pregnancy rate in first-lactation females calving in April-June.

5.2.5 Predicted annual pregnancy percentage by body condition score at the wet/dry muster

Cows in the lowest category of BCS (score 1.0 to 2.0) at the wet/dry muster had the lowest percentage annual pregnancy. There was a progressive and significant increase in percentage annual pregnancy with each successive improvement in BCS up to BCS=3.5 ($p<0.05$). There was then a significant decline in percentage annual pregnancy from BCS=3.5 to BCS=4.0-5.0 ($p=0.006$) (**Figure 99**; **Table 103**).

With respect to the interaction between BCS and cow age class, the highest mean annual percentage pregnant was in mature cows and particularly in mature cows with BCS between 3 and 3.5. There was a small but significant reduction in annual percentage pregnant for cows in the highest category for BCS at the wet-dry muster. Mature cows performed better on most occasions than both aged cows and first-lactation cows, except for those cows in the highest BCS where there was no effect of cow age class (**Figure 100**; **Table 104**).

With respect to the interaction between BCS and cow reproductive history in the past year, regardless of the period when cows last calved, cows in poorer condition at the subsequent wet/dry muster had lower annual percentage pregnant. The exception was those that had calved in April-June – this may be due to management interventions such as weaning of very young calves at the first annual weaning muster (wet/dry muster) (**Figure 101**; **Table 105**).

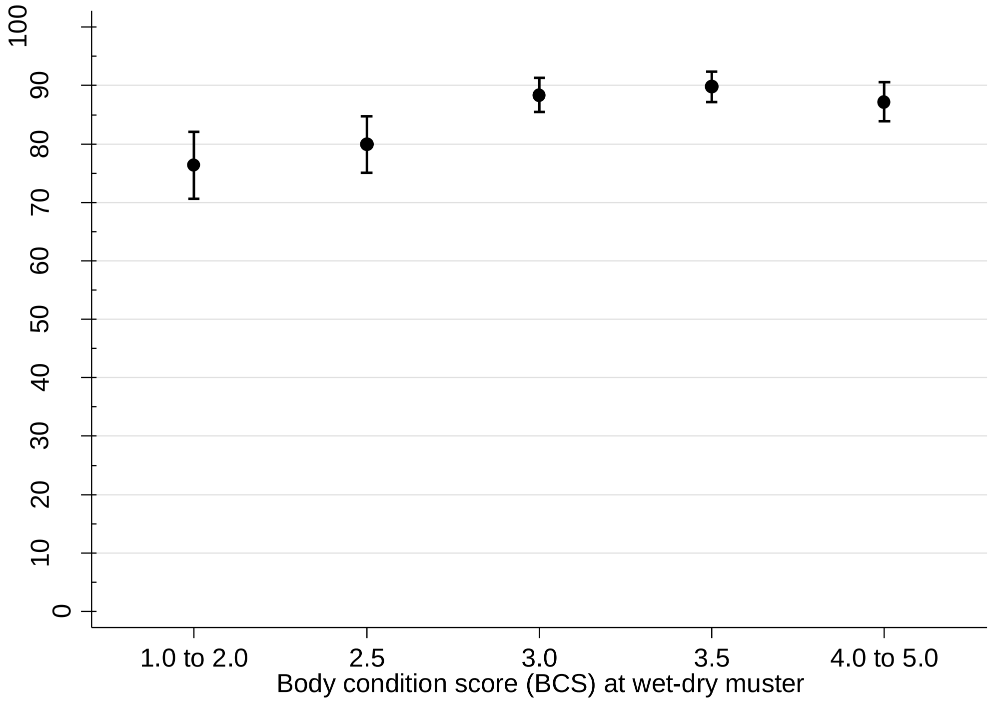

Figure 99: Predicted annual pregnancy percentage by body condition score at the wet dry muster based on marginal means generated from the final multivariable model. Bars represent 95% confidence interval.

Table 103: Predicted annual pregnancy (%) by body condition score category at the wet dry muster based on marginal means generated from the final multivariable model.

Body condition score at wet/dry muster	Mean annual percentage pregnant	95% Confidence interval Lower	Upper
1 to 2	76.3	70.6	82.1
2.5	79.9	75.1	84.7
3	88.4	85.5	91.3
3.5	89.8	87.2	92.4
4 to 5	87.2	83.9	90.5

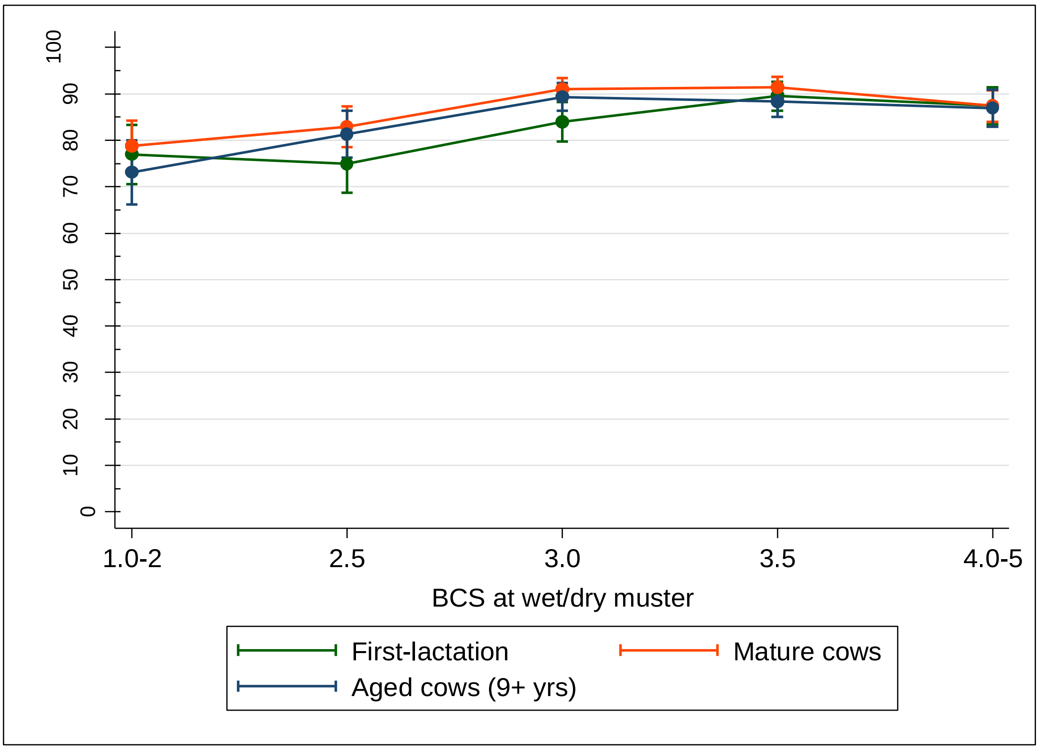

Figure 100: Predicted annual pregnancy percentage by the interaction between cow age class and body condition score category at the wet dry muster based on marginal means generated from the final multivariable model. Bars represent 95% confidence interval.

Table 104: Predicted annual pregnancy percentage by the interaction between cow age class and body condition score category at the wet dry muster based on marginal means generated from the final multivariable model.

BCS at wet/dry	Cow age class	Mean annual percent pregnant (%)	95% Confidence interval Lower (%)	Upper (%)
1 to 2	First-lactation	76.9	70.6	83.3
1 to 2	Mature cow	78.7	73.3	84.2
1 to 2	Aged cow	73.1	66.2	80.1
2.5	First-lactation	74.9	68.7	81.1
2.5	Mature cow	82.9	78.6	87.3
2.5	Aged cow	81.3	76.3	86.4
3	First-lactation	84.0	79.8	88.3
3	Mature cow	91.0	88.6	93.4
3	Aged cow	89.3	86.3	92.3
3.5	First-lactation	89.5	86.4	92.6
3.5	Mature cow	91.4	89.1	93.7
3.5	Aged cow	88.3	85.0	91.6
4 to 5	First-lactation	87.4	83.5	91.4
4 to 5	Mature cow	87.4	84.0	90.8
4 to 5	Aged cow	86.9	82.9	90.9

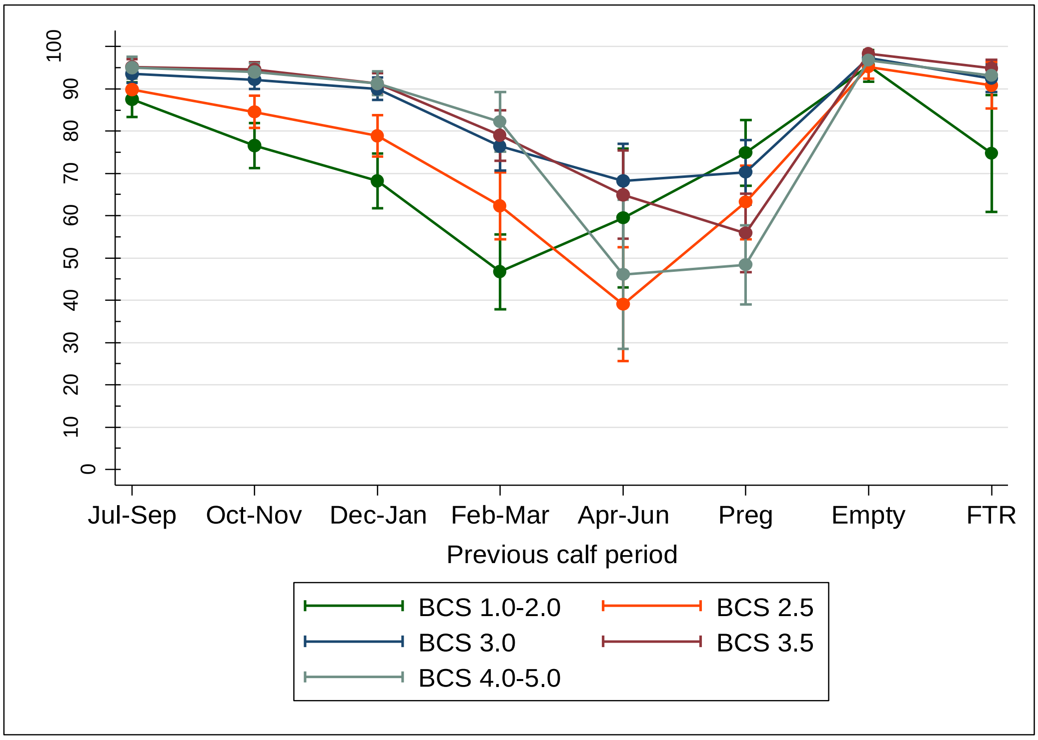

Figure 101: Predicted annual pregnancy percentage by the interaction between cow reproductive outcome from the previous year and body condition score category at the wet dry muster based on marginal means generated from the final multivariable model. Bars represent 95% confidence interval.

Table 105: Predicted annual pregnancy percentage by the interaction between cow reproductive outcome from the previous year and body condition score category at the wet dry muster based on marginal means generated from the final multivariable model.

Previous reproductive outcome	Body condition score at wet/dry muster	Mean annual percent pregnant (%)	95% Confidence interval Lower (%)	95% Confidence interval Upper (%)
Jul-Sep	BCS 1.0-2.0	87.5	83.4	91.6
Jul-Sep	BCS 2.5	89.9	86.8	92.9
Jul-Sep	BCS 3.0	93.5	91.5	95.6
Jul-Sep	BCS 3.5	95.2	93.3	97.1
Jul-Sep	BCS 4.0-5.0	95.0	92.4	97.6
Oct-Nov	BCS 1.0-2.0	76.6	71.3	82.0
Oct-Nov	BCS 2.5	84.5	80.7	88.3
Oct-Nov	BCS 3.0	92.1	90.0	94.2
Oct-Nov	BCS 3.5	94.6	93.0	96.3
Oct-Nov	BCS 4.0-5.0	94.1	92.0	96.1
Dec-Jan	BCS 1.0-2.0	68.3	61.8	74.8
Dec-Jan	BCS 2.5	78.9	74.1	83.8
Dec-Jan	BCS 3.0	90.0	87.3	92.7
Dec-Jan	BCS 3.5	91.2	88.7	93.7
Dec-Jan	BCS 4.0-5.0	91.3	88.6	94.1
Feb-Mar	BCS 1.0-2.0	46.7	37.8	55.6
Feb-Mar	BCS 2.5	62.3	54.3	70.2
Feb-Mar	BCS 3.0	76.5	70.7	82.3
Feb-Mar	BCS 3.5	79.0	73.0	84.9
Feb-Mar	BCS 4.0-5.0	82.2	75.2	89.3
Apr-Jun	BCS 1.0-2.0	59.5	43.1	75.9
Apr-Jun	BCS 2.5	39.1	25.6	52.5
Apr-Jun	BCS 3.0	68.2	59.4	77.0
Apr-Jun	BCS 3.5	65.0	54.5	75.5

Apr-Jun	BCS 4.0-5.0	46.1	28.5	63.7
Pregnant	BCS 1.0-2.0	74.8	67.1	82.6
Pregnant	BCS 2.5	63.1	54.5	71.8
Pregnant	BCS 3.0	70.2	62.6	77.9
Pregnant	BCS 3.5	55.9	46.6	65.2
Pregnant	BCS 4.0-5.0	48.3	39.0	57.7
Empty	BCS 1.0-2.0	95.5	91.8	99.2
Empty	BCS 2.5	95.1	92.4	97.9
Empty	BCS 3.0	97.4	96.4	98.3
Empty	BCS 3.5	98.4	97.8	99.0
Empty	BCS 4.0-5.0	96.7	95.6	97.8
Fail to rear	BCS 1.0-2.0	74.7	60.9	88.6
Fail to rear	BCS 2.5	90.8	85.3	96.3
Fail to rear	BCS 3.0	92.5	89.3	95.7
Fail to rear	BCS 3.5	94.9	93.0	96.8
Fail to rear	BCS 4.0-5.0	93.2	91.0	95.4

5.2.5.1 Application and further work

This finding confirms the critical importance of making decisions on timing of weaning based on cow body condition. It must be noted that this analysis does not take into account risk of cow mortality. Cows calving in the late dry season (July-September) have an increased risk of mortality.

Economic modelling is needed to assess the benefits of restricting the calving period to a four to six month period (Nov- Feb or Oct-Mar). Restricting the calving period could be achieved using a range of different strategies.

5.2.6 Predicted impact of nutritional factors

Annual pregnancy rate was significantly higher in cows grazing pasture during the dry season with an average dry matter digestibility greater than 55% (**Figure 102**; **Table 106**).

The annual percentage pregnant was highest in cows grazing pastures during the wet season with an average CP:DMD ratio >0.125 and a faecal P:ME ≥ 500 and lowest in those grazing pastures with an average CP:DMD ratio >0.125 and a faecal P:ME ratio of < 500 (**Figure 103**; **Table 107**). This difference was highly significant. Cows grazing pastures with an adequate to high protein content are likely to have increased daily milk yields and thus increased loss of phosphorous. When wet season pastures are low in phosphorous, this could lead to reduced reproductive performance, as observed in this study.

When wet season P:ME was high, there was no difference in annual pregnancy rate between the four country types (**Figure 104**; **Table 108**). However, when wet season P:ME was low, cows in the Northern Forest had significantly lower annual pregnancy rate than any other country type. Annual pregnancy rate for cows in the Central Forest was also significantly lower than those in the Southern Forest when P:ME was low. These findings reflect the importance of wet season P:ME in the Northern Forest in particular.

When CP:DMD is adequate or better, there was relatively little difference between country types with respect to annual pregnancy rate, with only one of the comparisons returning a significant p-value (Northern Downs vs Central Forest) (**Figure 105**; **Table 109**). There appeared to be more variation between country types when CP:DMD was inadequate, with Northern Forest in particular having an annual pregnancy rate that was significantly lower than all other country types except Northern Downs.

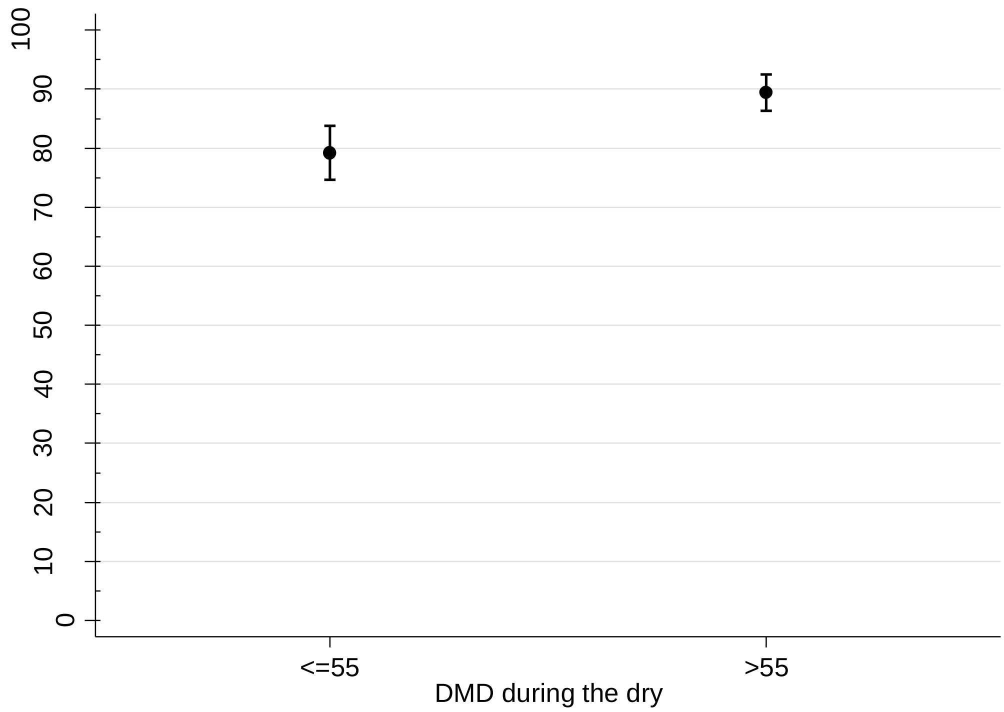

Figure 102: Predicted annual pregnancy percentage by average dry season dry matter digestibility (DMD) category, based on marginal means generated from the final multivariable model. Bars represent 95% confidence interval.

Table 106: Predicted annual pregnancy (%) by average dry season dry matter digestibility (DMD) category based on marginal means generated from the final multivariable model.

DMD in the dry season*	Mean annual percentage pregnant	95% Confidence interval	
		Lower	Upper
≤ 55%	79.2	74.6	83.8
> 55%	89.4	86.3	92.5

*measured immediately prior to the annual pregnancy diagnosis muster

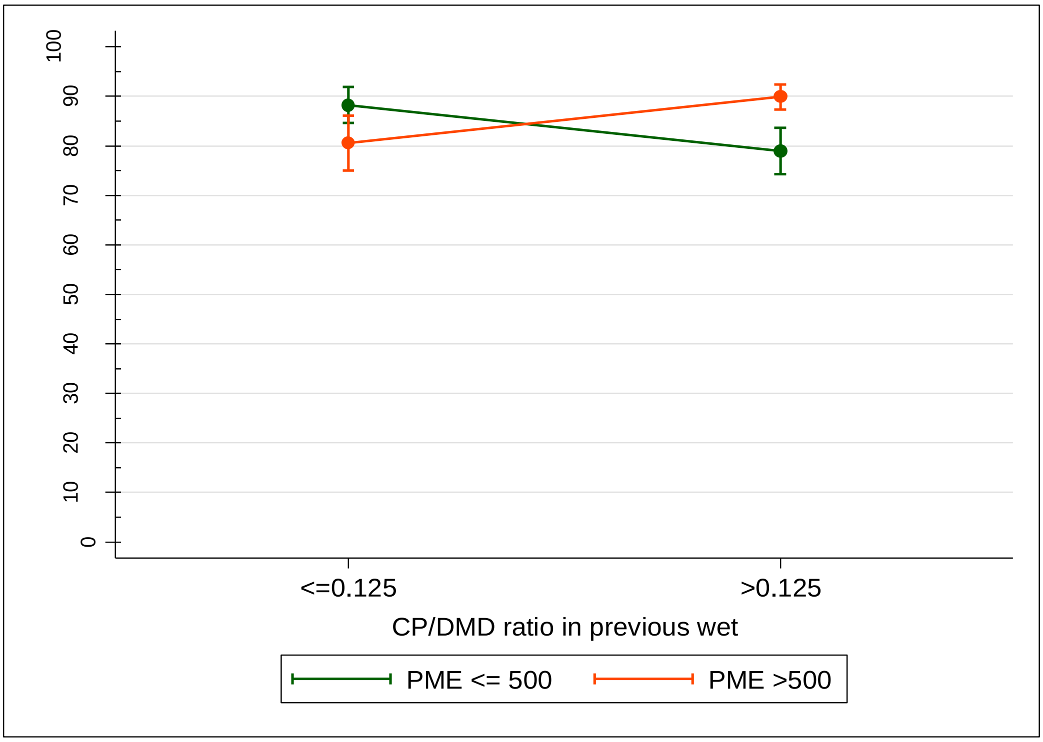

Figure 103: Predicted annual pregnancy percentage by the interaction between average wet season crude protein to dry matter digestibility ratio (CP:DMD) and faecal phosphorous to metabolisable energy ratio (P:ME), based on marginal means generated from the final multivariable model. Bars represent 95% confidence interval.

Table 107: Predicted mean annual pregnancy rate by average wet season crude protein to dry matter digestibility ratio (CP:DMD) and faecal phosphorous to metabolisable energy ratio (P:ME) based on marginal means generated from the final multivariable model.

CP:DMD in the previous wet season	P:ME in the previous wet season	Mean annual percent pregnant	95% Confidence interval	
			Lower (%)	Upper (%)
≤ 0.125	< 500	88.3	84.6	91.9
≤ 0.125	≥ 500	80.6	75.1	86.1
> 0.125	< 500	78.9	74.2	83.7
> 0.125	≥ 500	89.9	87.3	92.5

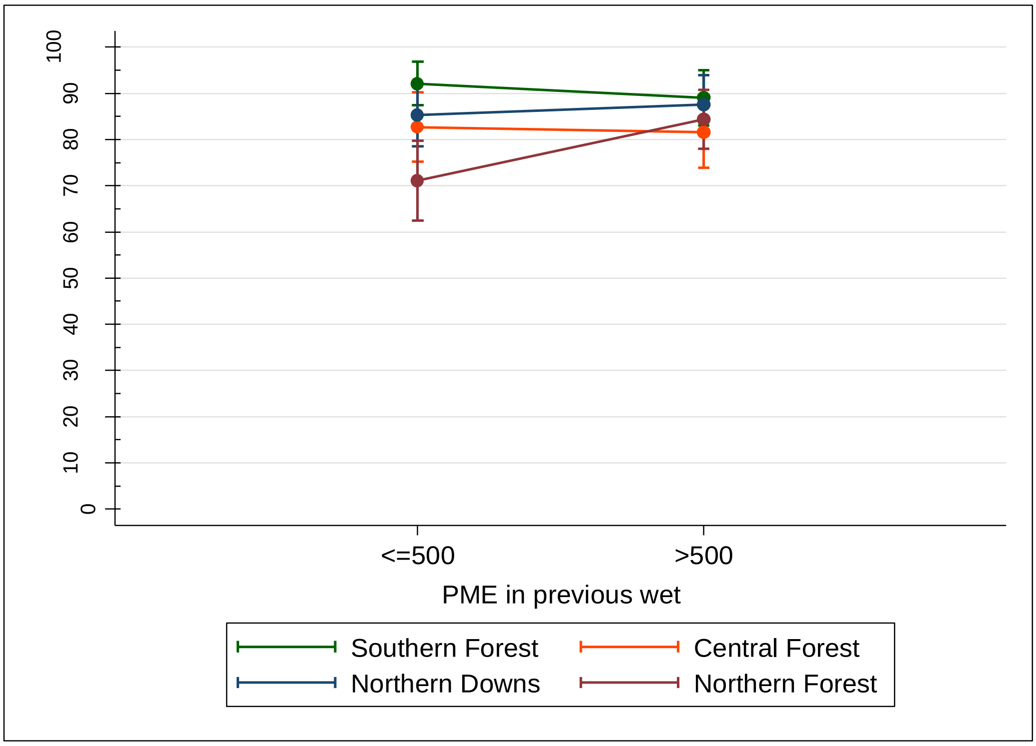

Figure 104: Predicted annual pregnancy percentage by the interaction between average faecal phosphorous to metabolisable energy ratio (P:ME) and country-type, based on marginal means generated from the final multivariable model. Bars represent 95% confidence interval.

Table 108: Predicted annual pregnancy (%) by average wet season faecal phosphorous to metabolisable energy ratio (P:ME) and country type based on marginal means generated from the final multivariable model.

P:ME in the previous wet season	Country type	Mean annual percent pregnant	95% Confidence interval	
			Lower (%)	Upper (%)
< 500	Southern Forest	92.1	87.4	96.8
< 500	Central Forest	82.7	75.2	90.2
< 500	Northern Downs	85.3	78.5	92.1
< 500	Northern Forest	71.1	62.5	79.7
≥ 500	Southern Forest	89.0	83.0	95.0
≥ 500	Central Forest	81.6	73.9	89.4
≥ 500	Northern Downs	87.5	81.1	93.9
≥ 500	Northern forest	84.3	77.9	90.7

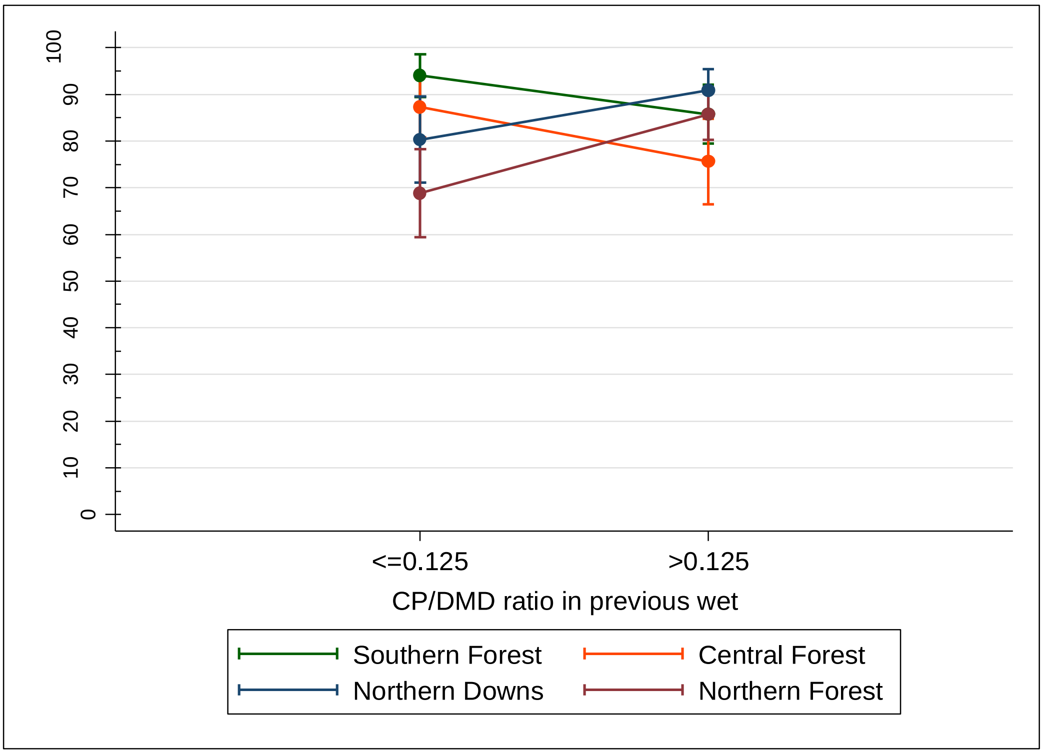

Figure 105: Predicted annual pregnancy percentage by the interaction between average wet season crude protein to dry matter digestibility ratio (CP:DMD) and country-type, based on marginal means generated from the final multivariable model. Bars represent 95% confidence interval.

Table 109: Predicted annual pregnancy (%) by average wet season crude protein to dry matter digestibility ratio (CP:DMD) and country type based on marginal means generated from the final multivariable model.

CP:DMD in the previous wet season	Country-type	Mean annual percent pregnant	95% Confidence interval	
			Lower (%)	Upper (%)
≤ 0.125	Southern Forest	94.0	89.4	98.6
≤ 0.125	Central Forest	87.3	80.8	93.8
≤ 0.125	Northern Downs	80.3	71.1	89.6
≤ 0.125	Northern Forest	68.9	59.5	78.3
> 0.125	Southern Forest	85.7	79.4	92.1
> 0.125	Central Forest	75.6	66.4	84.8
> 0.125	Northern Downs	90.9	86.3	95.4
> 0.125	Northern Forest	85.7	80.3	91.0

5.2.6.1 Application and further work

These findings clearly demonstrate the importance of nutritional status on the likelihood of cows becoming pregnant within 12 months. The findings of the interaction between CP:DMD and P:ME are particularly applicable to the first-lactation cow, which is the animal most at risk of phosphorous deficiency.

Faecal NIRS and wet chemistry testing provide broad estimates of quality of nutrition but do not fully explain the differences in performance between country types. Development of more sensitive measures of nutritional status would enable more accurate assessment of the impact of different management strategies and more importantly enable better prediction of when to implement these.

5.2.7 Predicted impact of selected factors not included in the model

This section examines the effect of selected explanatory factors that were not included in the final multivariable statistical model for annual pregnancy status. See Section **3.5.5** for additional description of the model building process.

The effects of these variables were assessed by adding them one at a time to the final multivariable model. This allowed reporting of the effects of a particular factor after adjustment for the effects of all other factors included in the multivariable model. These findings are presented mainly for interest.

Table 110: Predicted annual pregnancy (%) by proportion of paddock within <2.5km of water around time of calving based on marginal means generated from the final multivariable model, with proportion of paddock within <2.5km of water forced into the model.

Proportion of paddock within <2.5km of water around the time of calving	Annual percentage pregnant	95% Confidence interval	
		Lower (%)	Upper (%)
<40%	66.2	56.8	75.5
40-68%	70.6	62.6	78.5
69-88%	78.1	71.7	84.6
89-99%	80.4	74.8	86.0
100%	81.7	76.5	86.9

The proportion of the paddock within <2.5km of water around time of calving (**Table 110**) showed a possible trend in that there was a progressive increase in the predicted annual pregnancy percentage as the proportion of a paddock less than 2.5 km from water around the time of calving increased. The fact that this variable was not retained in the final multivariable model suggests that some caution should be used in interpreting this result. There may be some level of confounding between this variable and other variables in the final model that may explain some of the apparent effects of this variable. Further work is required to assess the effects of this variable.

A relatively large number of other variables were considered for inclusion and not retained in the final multivariable model. Each of these variables was forced into the final multivariable model one at a time as described above and in all cases the findings suggested either no apparent effect or confounding with other variables. These results are not presented in this report.

5.2.8 Variance explained by the model

The fixed effect component of the full statistical model accounted for or explained 27% of the total variance in the outcome “annual pregnancy rate”. Adding the fixed effects to the model also explained 28% of the variance at the property level that had been estimated in the intercept only model (**Table 111**).

There was significant evidence for clustering at the property level.

The residual intra-class correlation estimate from the intercept only model was 0.24 and is an estimate of the correlation between values of two randomly-drawn observations from the same property. It can also be interpreted as the proportion of the overall variation in the outcome (in this case annual pregnancy) that is attributable to property level effects.

In the full model it is the proportion of the overall residual variation in the outcome – **that is not explained by the fixed effects in the model** – that is attributable to property level effects. The measure of this in the full model (0.18) indicates that there is still a relatively large amount of variance in pregnancy that is at the property level and that is due to un-measured explanatory factors (factors other than those that are included in the model).

Table 111: Variance estimates from an intercept only model for annual pregnancy rate that included a random effect coding for property and the full model that included the same random effect.

	Null model#	**Full model**
Level 1 variance	3.29	3.29
Property level variance	1.03	0.74
Fixed effect variance (Full model only)		1.50
Total variance	4.32	5.53
% of total variance explained by fixed effects part of the full model		27.1
% of property level variance explained by full model		28.1
% of total variance at property level		13.4
Intra-class correlation (ICC)	0.24	0.18

Intercept only model variance was estimated on the same dataset as used in the final multivariable model to allow direct comparison between the null and full models.

5.3 Factors affecting the percentage of foetal/calf losses

This section presents the findings from the final multivariable model used to identify important explanatory variables that influence the outcome, "percentage foetal/calf loss". For each factor (variable) and interaction term included in the final multivariable model, the following section provides the predicted mean percentage foetal/calf loss at the referent level for all other factors in the model. Referent levels used are displayed in Appendix XV.

Note that the performance by country type and cow age class reported in this section will be different to that presented in the descriptive summaries of performance presented in Section 4.5 , as the mean performance is predicted from the multivariable model and takes into account the impacts of all other major factors included in the final model. Producers looking for typical measures of performance and what is commercially achievable for comparison with their own herd's performance should use the summary data presented in Section **4.5** .

The purpose of the multivariable modelling process is to identify the major drivers of foetal/calf loss and to explain the effect of each factor after adjustment for all other factors in the model. All candidate factors were initially considered for inclusion in the multivariable model building process, and all factors with significant and biologically plausible associations with the outcome were retained in the final model. It is important to be aware that when comparing the predicted difference(s) between percentage foetal/calf loss of cows for each factor, the absolute difference is expressed in terms of percentage points increase or decrease i.e., the difference between 50% and 55% is 5 percentage points.

Loss or survival to weaning from a confirmed pregnancy was able to be determined if a heifer or cow was diagnosed as pregnant in one year, and lactation status was assessed beyond the expected calving date the following year. Cows lactating beyond expected calving date were considered to have weaned a calf. Observations were excluded if not supported by the measurements for risk factors used in the analysis. In the final model, 23,166 animal records derived from 55 mobs (median of 333 animals/mob; range of 59-1,936) were used (**Table 112**). By definition, foetal and calf loss as it was derived for this analysis excluded cow mortality, which should be added in a full explanation of foetal/calf loss.

Table 112: Numbers of heifers and cows, and mobs, which contributed data to the final multivariable model.

Country type	Mobs	Animals within a mob			Animals within country type
		Median	Minimum	Maximum	
Southern Forest	15	287	72	1,036	5,588
Central Forest	12	423	72	1,111	5,460
Northern Downs	10	495	291	1,936	6,705
Northern Forest	18	267	59	688	5,413
Total	55	333	59	1,936	23,166

As 68.7% of animals in the model had only one observation (mean 1.3, range 1 – 3) and country type was included as a fixed effect, three-level models to estimate variance at the country type, property, and animal level could not be run. Instead, models were run with one level of random effects, property, and variance estimated at this level in both the full and the null model using the same observations as the full model.

The significance of the differences between levels within a factor was assessed using p-values for pairwise odds ratios and the magnitude of the differences quantified by marginal means expressed as percentages and associated confidence intervals.

Alternative valid models that were able to explain similar levels of variance in foetal/calf loss were investigated. Selection of the final model was on the basis of having the most biologically-plausible outcomes, and included factors that provided the best opportunity for intervention to reduce losses. The final model included wet season P:ME ratio (in preference to a combination of leptospirosis vaccination and wild dog activity) and body condition score at the PD muster (in preference to dry season CP:DMD ratio).

The following sections outline the effects in the final model. Note that factors that are not in the final model were screened out because they were either non-significant, or explained by a closely-related variable. A full list of variables available at the commencement of the analysis is presented in **Appendix XV**.

The final multivariable model percentage foetal/calf loss contained the following terms:

Main effects:

- Lactated in the previous year – yes, no
- Hip height - <125cm, 125 to140 cm, >140cm
- BCS at pregnancy diagnosis muster – Score 1-2, 2.5, 3, 3.5, 4-5
- Cow age class – First-lactation, Mature, Aged
- Mustered -1 to +2 months from expected calving - yes, no
- Days in calving month with THI >79 - <15 days, ≥15 days
- P:ME ratio during the wet season - <500mgP/MJME, ≥500mgP/MJME
- Mustering efficiency - ≤90%, >90%
- Country type – Southern Forest, Central Forest, Northern Downs, Northern Forest

Interaction terms:

- Mustering within two months of calving x cow age class
- BCS at pregnancy diagnosis muster x average wet season P:ME ratio
- Days in calving month with THI >79 x country type
- Average wet season P:ME ratio x country type

5.3.1 Predicted impact of lactation

Confirmed pregnancy to weaning loss was 3.6 percentage points higher in cows that lactated than those that did not lactate in the previous year (P<0.001;**Figure 106**;**Table 113**). Those that did not rear a calf in the previous year included cows diagnosed non-pregnant and those that lost a foetus or calf before lactation assessment after being diagnosed pregnant. As, by definition, all first-lactation cows did not have a previous reproductive cycle and were thus analysed as being non-lactating, an interaction term was added to the final model to confirm this effect is not solely due to heifers. The effect was significant and losses were 7.6 percentage points lower in second-lactation and aged cows if they lactated in the previous year.

This indicates that foetal/calf loss is at least lowly repeatable. This research has not shown why foetal/calf loss is repeatable in some cows, though published research does suggest problems, such as teat and udder abnormalities and calf vigour at birth are contributors.

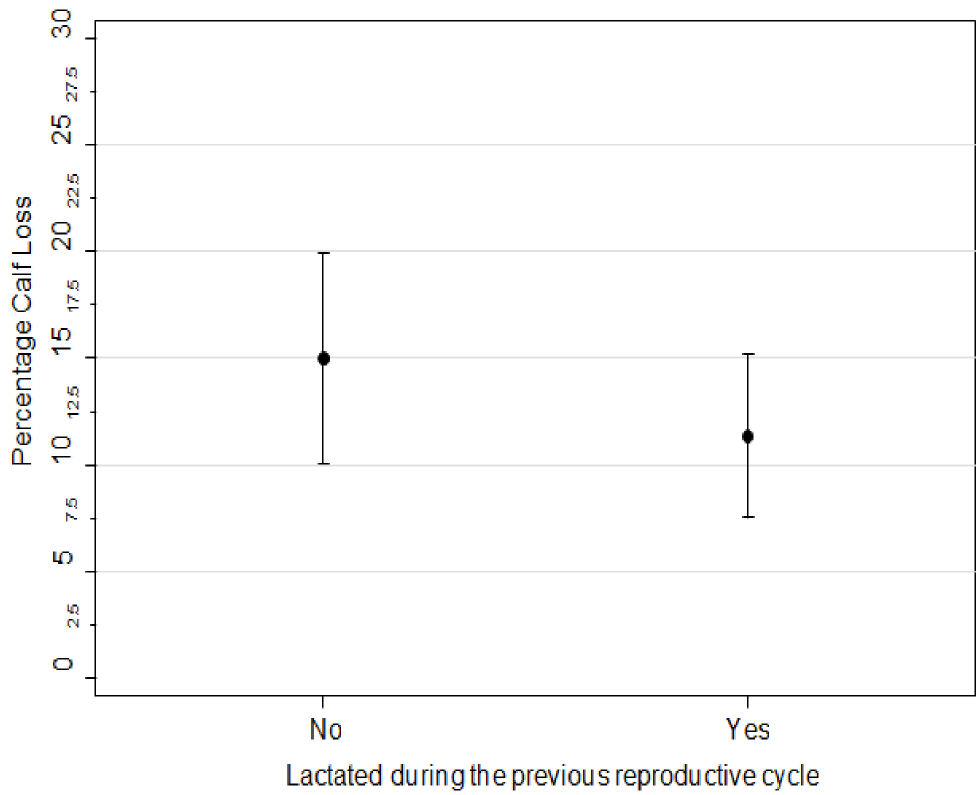

Figure 106: Predicted probabilities and 95% confidence intervals of foetal/calf loss by previous lactation category.

Table 113: Predicted percentage foetal/calf loss by lactation history category.

Lactated previous reproductive cycle	Mean loss (%)	95% Confidence interval	
		Lower	Upper
No	14.97	10.02	19.92
Yes	11.38	7.54	15.23

5.3.1.1 Application and Further work

Cows that fail to rear calves to weaning are often excellent candidates for sales. They are likely to be in forward body condition due to lactation failure. These cows have a high pregnancy rate because of no lactation anoestrus and good body condition. Whether to retain or sell depends on whether there is evidence for a cause of previous foetal or calf loss that is likely to be a recurring problem, and the relative expected future profitability of the cow as a function of her current weight, body condition, age, and expected time of next calving.

If the causes of repeated foetal/calf loss could be better identified, they could be better targeted in selection, as long as research supports the hypothesis that the cause and the problem are both repeatable and heritable.

5.3.2 Predicted impact of female hip height

Tall cows lost on average 3.7 percentage points more pregnancies before weaning than short cows, with moderate-height cows intermediate (**Figure 107**; **Table 114**). The difference between tall cows and others was significant (P<0.01), but was not significant between short and medium height cows. The reason for tall cows losing more calves is not readily apparent, though one hypothesis is that cows of large mature size have proportionately-greater energy partitioning to maintenance and growth and away from pregnancy and lactation than shorter cows. Growth differences due to different frame sizes occur by about 4.5 years of age, which is approximately when skeletal maturation occurs. Regardless of mature size, cows continue to gain weight at the same body condition score to at least eight years of age. If the hypothesis is true, tall cows may have lower milk production, which in some cows may result in insufficient milk to ensure calf survival.

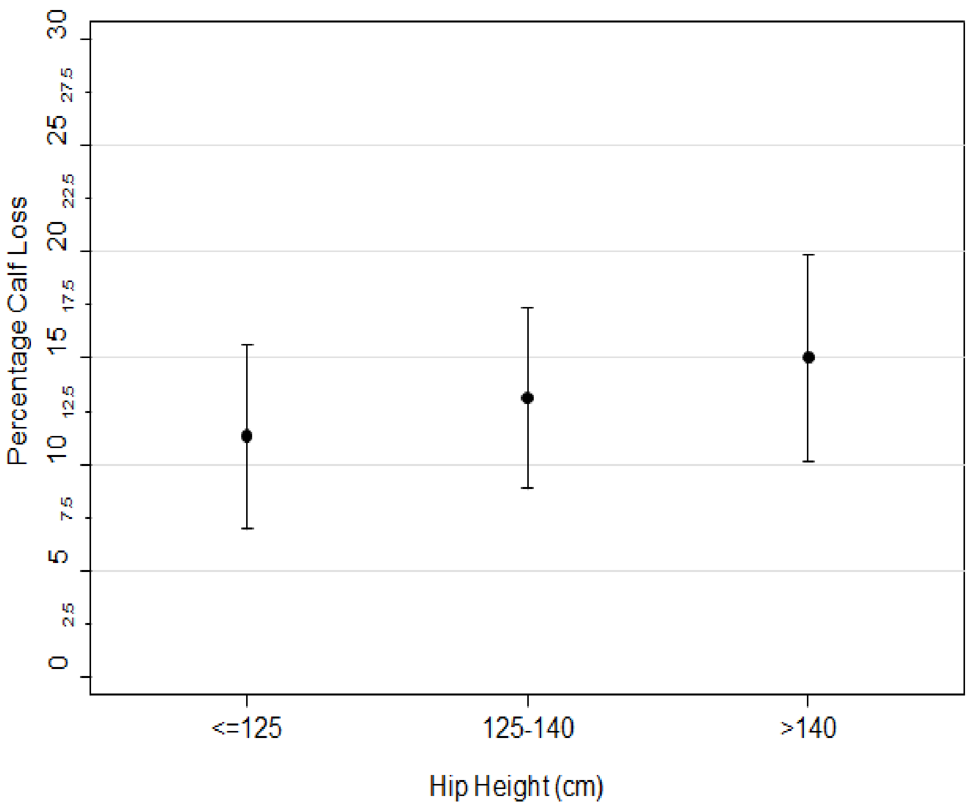

Figure 107: Predicted probabilities and 95% confidence intervals of foetal/calf loss by hip height category.

Table 114: Predicted percentage foetal/calf loss by hip height category.

Hip Height	Mean loss (%)	95% Confidence interval	
		Lower	Upper
≤ 125 cm	11.31	6.99	15.63
125 - 140 cm	13.12	8.87	17.37
> 140 cm	15.02	10.16	19.88

5.3.2.1 Application and Further work

This outcome suggests selection of cows that are tall when mature may contribute to reproduction inefficiency. However, it may be partially countered by improving the nutrition of tall cows during lactation, and or to select against large mature size cows that appear to have lactation insufficiency.

The proportion of foetal/calf loss that is attributable to taller cows is not insignificant and warrants further investigation to determine the primary mechanism, to subsequently enable development of appropriate genetic and/or management practices to control the problem.

5.3.3 Predicted impact of BCS x FP:ME interaction

In situations where the risk of phosphorous deficiency was low (≥500 mg/kg ME), overall foetal/calf loss was 3.4 percentage points lower than where the risk of phosphorous deficiency was high (P<0.001;**Figure 108**; **Table 115**). This effect occurred in cows with body condition scores <2.5, 3 and >3.5. The lower loss in cows with body condition score <2.5 at the previous PD muster in situations with low risk of phosphorous deficiency may reflect the exclusion of loss due to cow mortality in this analysis.

Where phosphorous was <500 mg/kg ME, cows with a body condition score of >3 at the PD muster had 3 percentage points lower foetal/calf loss than cows in lower body condition (P<0.05). Where phosphorous was ≥500 mg/kg ME, cows with a body condition score of >3.5 had on average 9 percentage points lower foetal/calf loss than cows in body condition scores of 2.5-3.5 (P<0.05).

These data do not indicate the cause of loss, but as both body condition score and phosphorous adequacy are related to general nutrition status of the female, it may be that poorer nutrition reduces the volume and/or quality of colostrum and milk available to the calf, increasing the risk of death due to dehydration and other neonatal diseases.

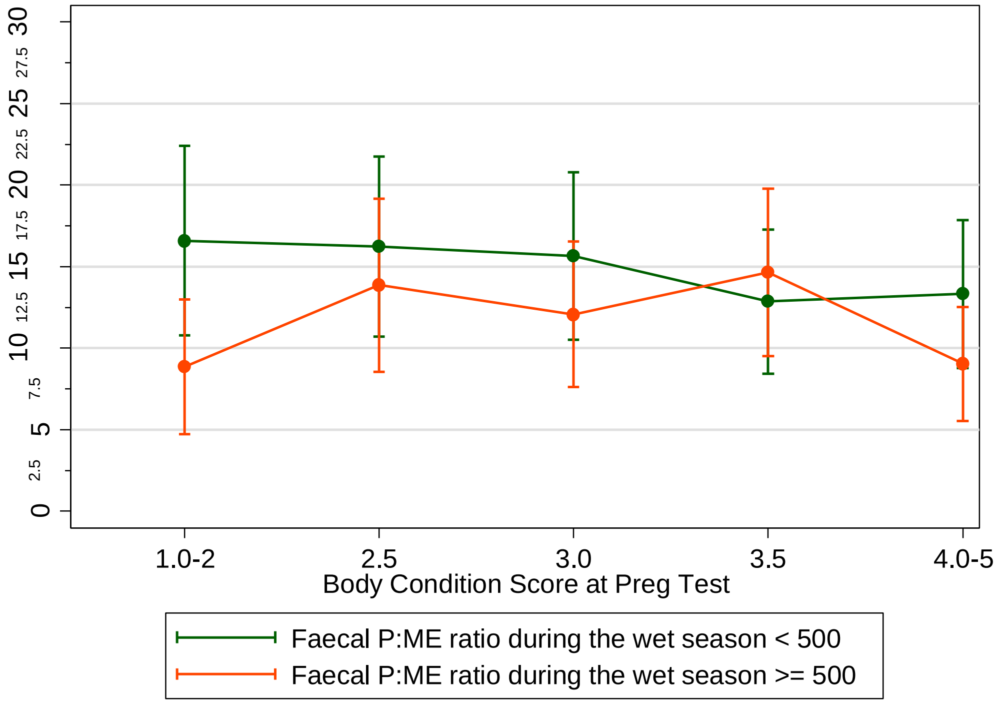

Figure 108: Predicted probabilities and 95% confidence intervals of foetal/calf loss by the interaction between body condition score at the time of the PD muster and the average wet season faecal phosphorous to metabolisable energy ratio.

Table 115: Predicted percentage foetal/calf loss by body condition score at the time of the PD muster and the average wet season faecal phosphorous to metabolisable energy ratio.

BCS at PD muster	Wet season Faecal P:ME	Mean loss (%)	95% Confidence interval	
			Lower	Upper
1 - 2	< 500	16.59	10.79	22.40
1 - 2	≥ 500	8.85	4.71	13.00
2.5	< 500	16.23	10.69	21.76
2.5	≥ 500	13.86	8.56	19.16
3.0	< 500	15.66	10.52	20.79
3.0	≥ 500	12.07	7.62	16.52
3.5	< 500	12.85	8.42	17.29
3.5	≥ 500	14.64	9.51	19.77
4 - 5	< 500	13.32	8.78	17.85
4 - 5	≥ 500	9.03	5.54	12.53

5.3.3.1 Application and Further work

Foetal/calf loss can be reduced by at least 3 percentage points if cow nutrition is sustained at an adequate level, as reflected by a body condition score above 3 at time of calving. Reducing the risk of phosphorous deficiency, weaning management, and control of calving time are all important elements in cow nutritional effects on calf survival.

If the mode of effect of cow condition and phosphorous adequacy were better understood, then more effective strategies could be developed to reduce their impact on calf survival. For example, if the effect is a function of lactation yields then research should focus on how to ensure neonates receive an adequate amount of colostrum and milk in the critical first few weeks of life rather than on body condition or P:ME ratios *per se*.

5.3.4 Predicted impact of mustering efficiency

Losses in situations where mustering efficiency is <90% were 9 percentage points higher (2.2 times more likely; P=0.029; **Figure 109**; **Table 116**) than where mustering efficiency was >90%. It is unclear whether this is related specifically to the mustering process or whether this factor is a surrogate for the class of country and/or prevailing weather that causes low mustering efficiency, or if it is a reflection of management overall.

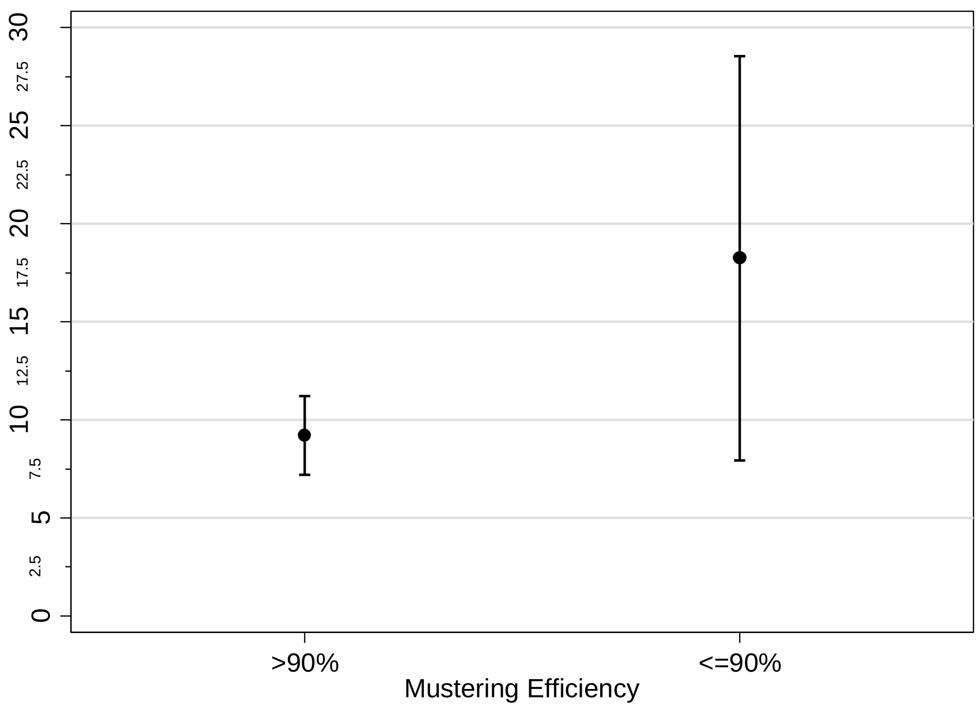

Figure 109: Predicted probabilities and 95% confidence intervals of foetal/calf loss by mustering efficiency category.

Table 116: Predicted percentage foetal/calf loss by mustering efficiency category.

Mustering	Mean loss	95% Confidence interval

efficiency	(%)	Lower	Upper
>90%	9.20	7.21	11.20
<=90%	18.24	7.93	28.56

5.3.4.1 Application and Further work

Increasing levels of cattle control that enable higher levels of husbandry—such as effective fencing, good paddock design, appropriate segregation, training of cattle, and selection for temperament—may substantially reduce foetal/calf loss.

The specific reasons for the dramatic effect of mustering efficiency on foetal/calf loss needs to be elucidated so that it can be effectively controlled.

5.3.5 Predicted impact of mustering within two months of calving x cow age class interaction

When cows were not mustered around calving, foetal/calf loss was only, on average, 1.3 percentage points higher in first-lactation cows than in older cows ($P<0.05$; **Figure 110**; **Table 117**). In mature cows, foetal/calf loss was increased by 2.5 percentage points if they were mustered around calving ($P=0.02$), with a similar but non-significant effect observed for aged cows. Note that mustering around calving was a cow-level effect, i.e., calculated for each cow using foetal ageing and dates of mustering. This effect could be associated with stress on cows causing abortion or premature calving, resulting in calves with low vigour and thus lower probability of survival. Mustering lactating cows with young calves can cause separation, resulting in calf dehydration and mortality. This could be a bigger problem if the cow is inexperienced, and may explain why loss from cows in their first lactation was increased by 9 percentage points when mustered around calving ($P<0.001$).

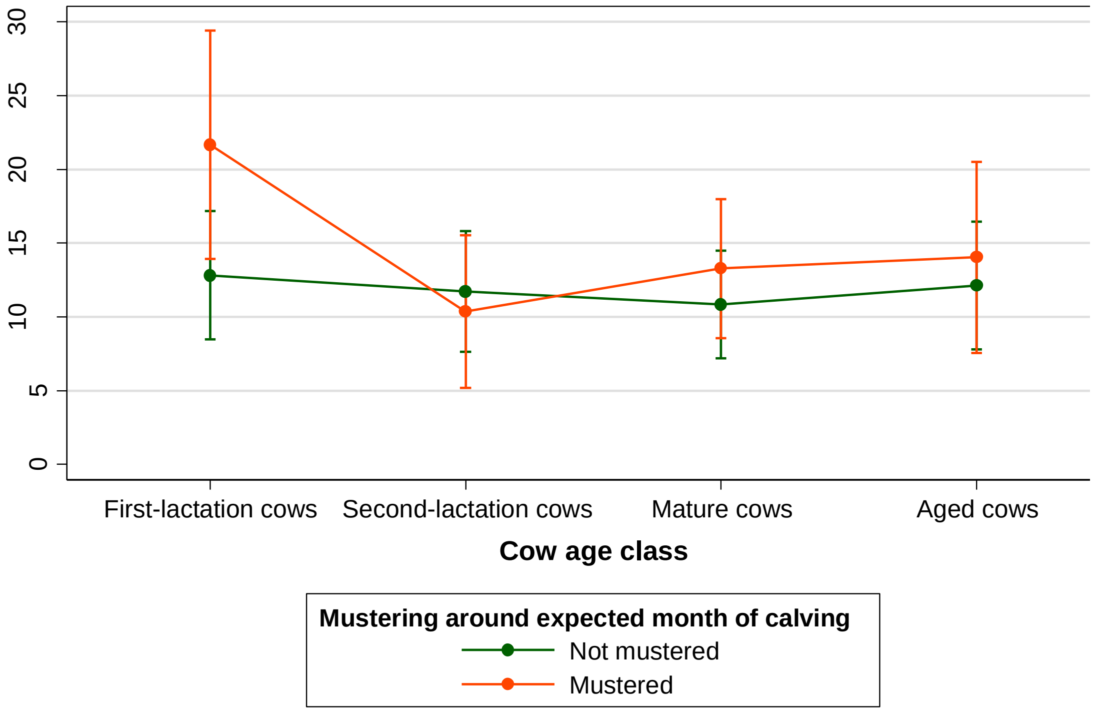

Figure 110: Predicted probabilities and 95% confidence intervals of foetal/calf loss by the interaction between mustering within two months of calving and cow age class.

Table 117: Predicted percentage foetal/calf loss by mustering within two months of calving and cow age class.

Cow age class	Mustered	Mean Loss (%)	95% Confidence interval	
			Lower	Upper
First-lactation	No	12.82	8.47	17.17
First-lactation	Yes	21.66	13.91	29.41
Second-lactation	No	11.73	7.64	15.82
Second-lactation	Yes	10.37	5.19	15.54
Mature cows	No	10.83	7.18	14.47
Mature cows	Yes	13.28	8.57	17.99
Aged cows	No	12.12	7.80	16.45
Aged cows	Yes	14.04	7.56	20.51

5.3.5.1 Application and Further work

If cows are to be mustered when they are in advanced pregnancy or with small calves, increased foetal/calf loss can be expected without intervention that targets the at-risk groups: small calves, early-lactation cows, and late-pregnant cows. This is particularly important in young cows in their first pregnancy and lactation. Use of foetal ageing data to determine when females are likely to calve enables musters to be scheduled when it is very unlikely that females will either be heavily pregnant or suckling very young calves.

Demonstration of strategies that are likely to reduce the risk of foetal/calf loss due to peri-parturient handling may assist adoption of these, and reduce the impact of this problem in the future.

5.3.6 Predicted impact of THI x country type interaction

A temperature-humidity index (THI) threshold of 79 has previously been used in published research. The threshold of >2 weeks (≥15 days) was based on an assessment of the univariable logistic regression models fitting counts of the days >79 THI as the sole predictor of cow reproductive performance.

When the temperature-humidity index exceeded 79 for at least two weeks during the month of expected calving there were no significant differences between country types (**Figure 111**; **Table 118**). However, calf losses under lower THI conditions were reduced by 3.9-6.7 percentage points ($P<0.01$), except in the Northern Forest where there was no effect of THI.

If THI was not >79 for at least two weeks in the expected calving month, foetal/calf losses were 9 percentage points higher in the Northern Forest than in either the Northern Downs or Southern Forest ($P<0.05$); losses in the Central Forest were intermediate and not significantly different from other country types.

Some of this loss may be related to direct heat load effects on the dam and/or calf. However, higher THI is also related to wet season rainfall, and calving into wet and boggy conditions may be as big a problem as heat load effects. The specific reason for the lack of effect in the Northern Forest is unclear.

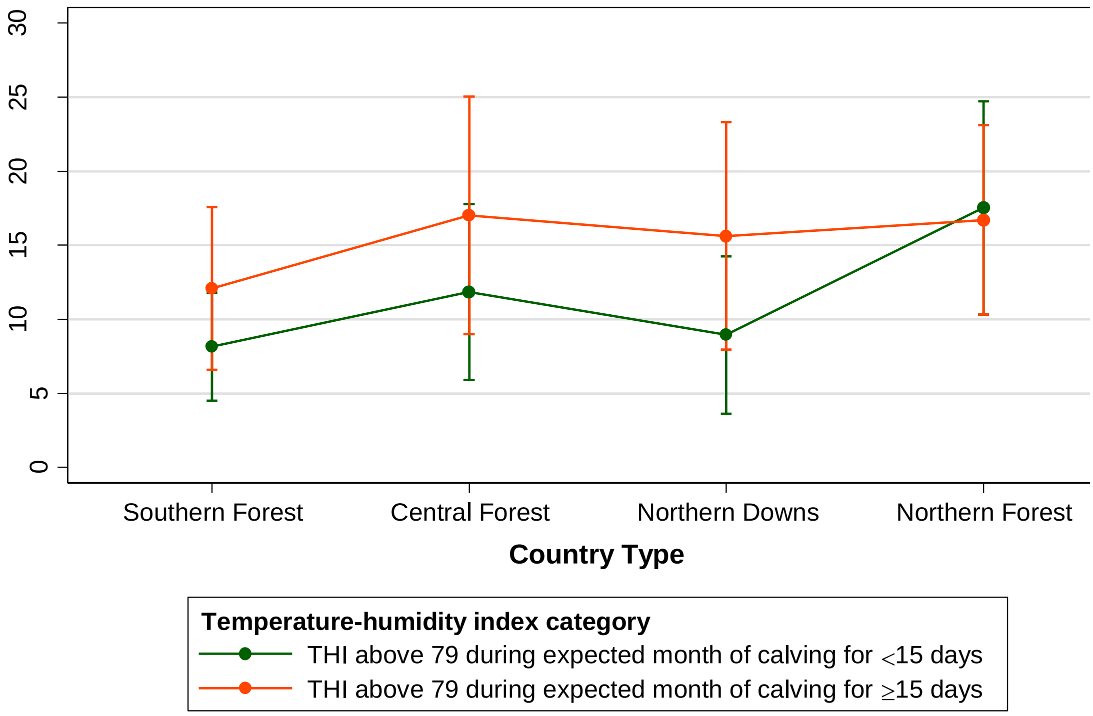

Figure 111: Predicted probabilities and 95% confidence intervals of foetal/calf loss by the interaction between temperature-humidity index category and country type.

Table 118: Predicted percentage foetal/calf loss by the interaction between temperature-humidity index category and country type.

Country Type	No days THI >79	Mean loss (%)	95% Confidence Interval	
			Upper	Lower
Southern Forest	< 15	8.16	4.50	11.82
Southern Forest	≥ 15	12.08	6.60	17.57
Central Forest	< 15	11.86	5.92	17.79
Central Forest	≥ 15	17.02	8.99	25.05
Northern Downs	< 15	8.95	3.64	14.26
Northern Downs	≥ 15	15.63	7.95	23.31
Northern Forest	< 15	17.53	10.34	24.73
Northern Forest	≥ 15	16.72	10.30	23.14

5.3.6.1 *Application and Further work*

Until the mechanism by which high THI affects foetal/calf loss is better understood it is difficult to make specific recommendations. However, providing late gestation and calving cattle with well drained paddocks with access to adequate shelter should be considered.

Given its large impact, how high THI affects foetal/calf survival needs further clarification so that methods to reduce its impact can be more definitively recommended.

5.3.7 Predicted impact of FP:ME x country type interaction

Where FP:ME ratio was low, foetal/calf loss was an average of 10 percentage points higher in the Central and Northern Forest, in comparison to that in the Southern Forest (P<0.01;**Figure 112**; **Table 119**). By contrast, where FP:ME ratio was high, there was no significant effect of country type on losses. Only in the Central Forest was there a significant difference (10.3 percentage points; P<0.001) in foetal and calf loss between mobs grazing paddocks with low or high FP:ME ratios.

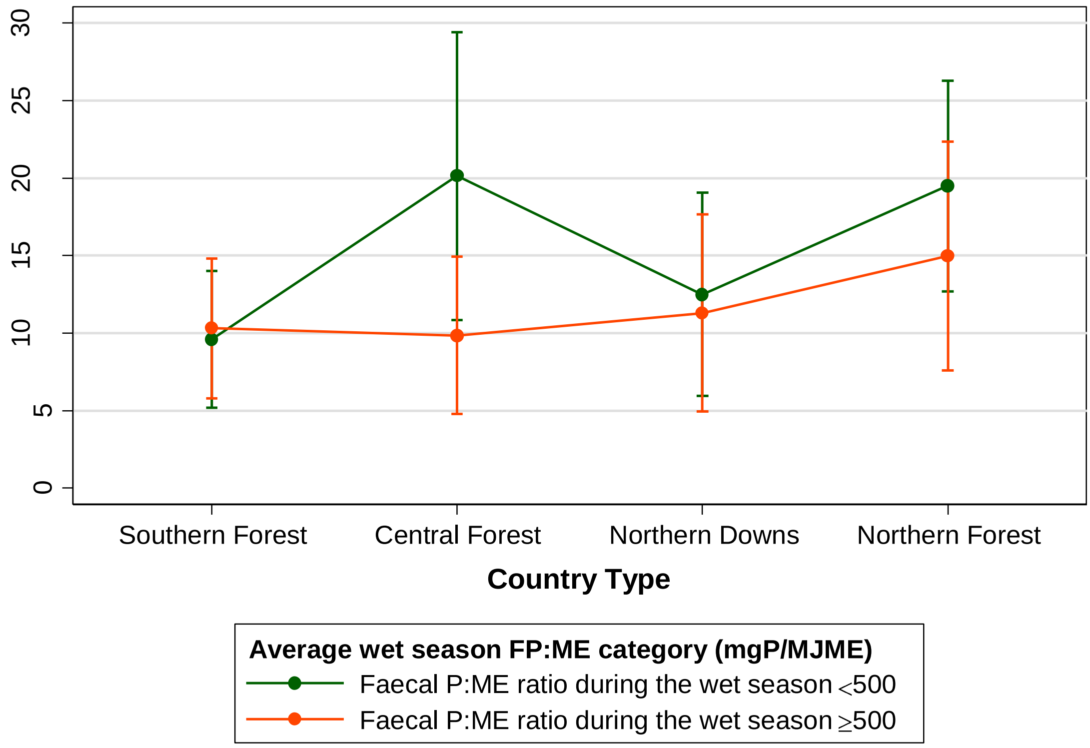

Figure 112: Predicted probabilities and 95% confidence intervals of foetal/calf loss by the interaction between average wet season faecal phosphorous to metabolisable energy ratio category and country type.

Table 119: Predicted percentage foetal/calf loss by average wet season faecal phosphorous to metabolisable energy ratio category and country type.

Country Type	Wet season Faecal PME	Mean loss (%)	95% Confidence interval	
			Lower	Upper
Southern Forest	< 500	9.61	5.20	14.02
Southern Forest	≥ 500	10.30	5.78	14.83
Central Forest	< 500	20.14	10.86	29.42
Central Forest	≥ 500	9.86	4.80	14.92
Northern Downs	< 500	12.50	5.94	19.06
Northern Downs	≥ 500	11.30	4.96	17.65
Northern Forest	< 500	19.50	12.70	26.30
Northern Forest	≥ 500	14.98	7.59	22.37

5.3.7.1 Application and Further work

These results partially reinforce the association between phosphorous status and foetal/calf loss as described in its interaction with body condition score. The higher loss in the Central Forest with low P:ME ratios and in the Northern Forest is a non-specific effect, presumably related to environmental conditions and features of management that differ between country types.

As previously stated, future research may show the impact of phosphorous adequacy as part of nutrition effects studies on milk yields and delivery of calves, thus survival of calves.

5.3.8 Predicted impact of selected factors not included in the model

5.3.8.1 Wild dogs

Back fitting the final model showed that where property owners/mangers considered wild dogs were adversely impacting on herd productivity, whether control was being attempted or not, foetal/calf loss was predicted to be 5-7% higher than where wild dogs were not considered to be adversely affecting productivity (**Figure 113**; **Table 120**). For mobs where wild dogs were considered to be adversely affecting herd productivity there was no significant difference in percentage foetal/calf loss between properties using baiting to control wild dogs versus those using trapping or shooting. Because prevalence of wild dogs and likelihood of baiting are associated, baiting is usually presumed to reduce calf predation. However, baiting has been reported to be associated with increased calf predation, presumably because of the subsequent disruption of social and other wild dog behaviours[74]. These results suggest that further research is required to better understand how the impact of wild dogs can be effectively controlled.

[74] Allen (2013)

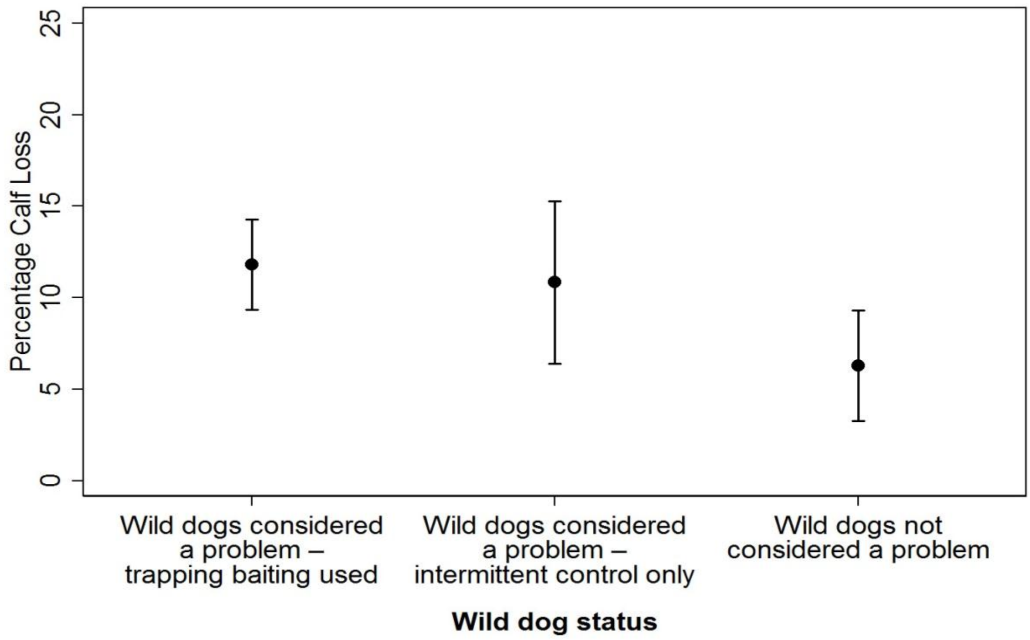

Figure 113: Predicted percentage foetal/calf loss and 95% confidence intervals for each wild dog category.

Table 120: Predicted percentage foetal/calf loss for each wild dog category.

Wild dog Category	**Foetal/Calf Loss (%)**	**95% Confidence interval**	
		Lower	**Upper**
Wild dogs considered a problem – baiting used	11.81	9.33	14.29
Wild dogs considered a problem - intermittent control only	10.84	6.40	15.28
Wild dogs not considered a problem	6.29	3.27	9.31

5.3.8.2 Average CP:DMD during the dry season

Back fitting the final model also demonstrated that inadequate average dietary protein status (CP:DMD of <0.125) during the dry season was associated with about 4.2 percentage points higher loss compared to that for females with an adequate dietary protein status. This finding is consistent with work in the US, which demonstrated that cows experiencing marked dietary protein deficiency in the last trimester produced lower volumes of poorer quality colostrum and gave birth to calves that had reduced vigour[75, 76]. The effect was dramatic in the Northern Forest, where much of the response may have been caused by variations in seasonal conditions, and that higher CP:DMD ratios could have been due to early rain, which

[75] Bull *et al* (1974)
[76] Stalker *et al* (2006)

dramatically improved both CP and DMD. This possibility is supported by such conditions having large effects on cow survival, unlike dry licks. This analysis did not include foetal/calf losses due to missing cows, so when nutritional conditions improve dramatically, there may be equally dramatic effects on cow and calf survival.

5.3.8.3 Infectious diseases

The findings below were all generated by back fitting the final model i.e., the impact of all the factors in the model have been accounted for and the outcome is the impact of the specific factor tested.

5.3.8.4 Bovine Viral Diarrhoea Virus (BVDV)

In mobs where there was a high prevalence of recent BVDV infection detected at either the time of pregnancy diagnosis or at the wet/dry muster there was a significantly higher percentage of foetal/calf loss than in mobs with a low prevalence of recent infection (**Table 121**). It should be noted that at the time of sampling many of the cattle in these mobs would have been pregnant, and hence evidence of recent infection with BVDV would strongly indicate an increased risk of in-utero infection with BVDV. There was little difference in percentage foetal/calf loss between the low and moderate categories of recent BVDV infection. Some caution should be applied in interpreting these findings due to the wide confidence intervals, but nonetheless they are very consistent with the published reports of the effect of in-utero BVDV infection.

Table 121: Predicted mean percentage foetal/calf loss between pregnancy diagnosis and weaning by category of recent BVDV infection (p=0.001).

Prevalence* of recent BVDV	Mean loss (%)	95% Confidence interval	
		Lower	**Upper**
Low	11.45^{A}	6.51	16.39
Moderate	12.08^{A}	7.00	17.16
High	20.84^{B}	12.49	29.19

* Mob prevalence of recent BVDV infection defined as Low: <10%; Moderate: 10-30% and High: >30% AGID test result ≥3. Means not sharing a common superscript are significantly different (P<0.05).

5.3.8.5 Neopsorosis

N.caninum infection was not associated with percentage foetal/calf loss although numerically mobs with a moderate to high seroprevalence had a higher predicted mean percentage foetal/calf loss than those with either nil or a low seroprevalence (**Table 122**). These finding are consistent with the findings of the study conducted by Kirkland *et al*[77], but sharply contrast with studies of the impact of *N.caninum* infection of dairy cattle on the Atherton tableland in northern Australia[78] and elsewhere in the world. The reason for this difference is not apparent, but one could speculate that because wild dogs have been shown to be a carrier of this organism[79] and are common across the beef breeding regions of northern Australia, that exposure of

[77] Kirkland *et al* (2012)
[78] Landmann *et al* (2011)
[79] King *et al* (2012)

young heifers to pastures contaminated with faeces from wild dogs may result in them becoming immune to infection[80].

Table 122: Predicted mean percentage foetal/calf loss between pregnancy diagnosis and weaning by *N.caninum* seroprevalence category (p=0.502).

***N.caninum* seroprevalence* category**	**Mean loss (%)**	**95% Confidence interval**	
		Lower	**Upper**
Nil	12.55 ^{A}	3.43	21.17
Low	12.03 ^{A}	5.94	18.12
Mod-High	15.94 ^{A}	6.96	24.91

* Mob prevalence of recent *N.caninum* infection defined as Nil: 0%; Low: 0-20%; Moderate to High: ≥20%. Means not sharing a common superscript are significantly different (P<0.05).

5.3.8.6 Leptospirosis

There was no evidence that either *L.hardjo* or *L.pomona* infection was significantly associated with foetal/calf loss in this study. However, it must be recognised that the observed seroprevalence and prevalence of recent infection with these serovars was generally very low. There was a trend for higher loss (± 6 percentage points) in mobs that had evidence of a moderate to high prevalence of recent infection with *L.pomona.* Further, backfitting of vaccination against leptospirosis to the final model showed a reduction in foetal/calf loss of 3.4 percentage points.

5.3.8.7 Vibriosis

Generally vibriosis is associated with conception failure and delayed conception, although an abortion rate of 5 to 10% (usually between the 5th to 7th months of gestation) has been reported. Because vibriosis is usually associated with embryo loss prior to foetal ageing, it was a little surprising to find that in mobs where the prevalence of samples positive for antibodies to *C.fetus* sp*.veneralis* was high, percentage foetal/calf loss was significantly higher than in mobs where the prevalence was low to moderate (p=0.02; **Table 123**). However, in mobs with a high prevalence of *C.fetus* sp*.veneralis* infection it is quite possible that some bulls are also infected with the other common venereal infection, *Tritrichomonas fetus,* which also is reported to cause abortions. Therefore, a high prevalence of *C.fetus* sp*.veneralis* infection may be a proxy for widespread venereal disease in a mob. Unfortunately, although sampling of bulls for venereal infections was originally included in the design of CashCow, logistical reasons prevented this from being done. A newly developed PCR for *T.fetus* was used to test pooled vaginal mucus samples from each mob sampled in 2009, but only one out of 121 mobs tested was positive with two others categorised as suspect.

[80] Williams *et al* (2009)

Table 123: Predicted mean percentage foetal/calf loss between pregnancy diagnosis and weaning by prevalence of *C.fetus* sp*.veneralis*.

Prevalence* of ***C.fetus*** **sp*.veneralis***	Mean loss (%)	95% Confidence interval	
		Lower	Lower
Low to moderate	12.92 ^{A}	8.41	17.44
High	19.91 ^{B}	10.79	29.02

*****high: ≥30% of females with vaginal mucus antibody. Means not sharing a common superscript are significantly different (P<0.05).

5.3.8.8 Other factors

The findings of investigation of the impact of other factors were:

- Proportion of the paddock grazed within 2.5 km of water. Only a low overall proportion of paddocks were outside this level.
- No disease vaccination variable had a significant effect.
- Herd size did not significantly affect loss, but the trend was for herds greater than1000 to have lower losses.
- Genotype, which could vary between *Bos indicus* and *Bos Taurus,* was not associated with foetal or calf loss.
- Month of calving between July of one year and June of the next did not have a significant effect. However, back fitting this variable showed a trend for highest loss when calving occurred in April-June, and lowest loss when calving in October-November (range of effect was 3.4%).

5.3.9 Variance explained by the model

Fixed effects in the selected model for analysis explained 7.6% of the variation in foetal and calf loss between pregnancy diagnosis and weaning (**Table 124**). The unexplained variance at the property level was 13.0%.

Table 124: Variance estimates from an intercept only model for percentage foetal/calf loss that included a random effect coding for property and the full model that included the same random effect.

	Null Model	Full Model
Level 1 variance	3.29	3.29
Property Level Variance	0.74	0.49
Fixed Effect Variance (Full model only)	n/a	0.31
Total Variance	4.03	4.09
Total unexplained variance	4.03	3.78
% Total Variance explained by fixed effects	n/a	7.63
% Property Level Variance explained by full model	n/a	33.89
% Total variance at the Property Level	18.45	12.02
% Unexplained variance at the Property Level	18.45	13.01

A possible causal pathway for foetal/calf loss was constructed (**Figure 114**). Even though many variables had large and significant effects on foetal/calf loss, they were not necessarily explanatory, and further clarification of these variable effects is required before they can be efficiently controlled. The overall level of loss, especially in the Northern Forest, and the substantial impact of many controllable variables indicate the opportunity to reduce losses through strategic changes in management and genetics.

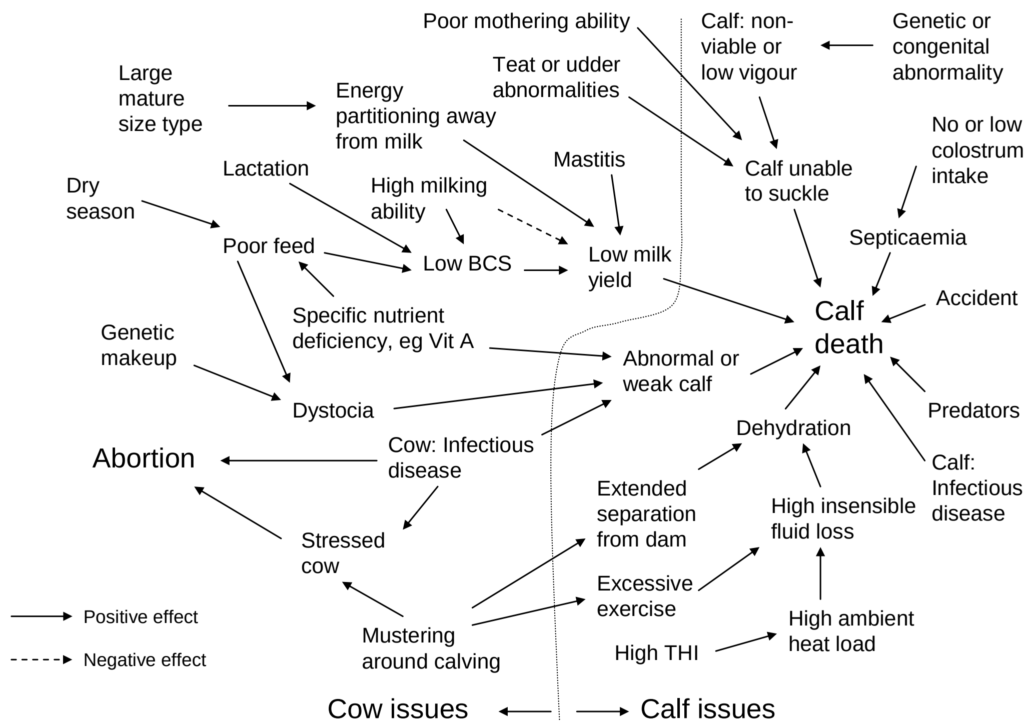

Figure 114: Possible causal pathway for foetal and calf loss in northern Australia.

5.4 Factors affecting percentage of pregnant cows missing

This section presents the findings from the final multivariable model used to identify important explanatory variables that influence the outcome "annual percentage of pregnant cows missing". For each factor (variable) and interaction term included in the final multivariable model, the following section provides the predicted mean annual percentage of pregnant cows missing at the referent level for all other factors in the model. Referent levels used are displayed in **Appendix XVI**.

Note that the performance by country type and cow age class reported in this section will be different to that presented in the descriptive summaries of performance presented in Section 4.5 , as the mean performance is predicted from the multivariable model and takes into account the impacts of all other major factors included in the final model. Producers looking for typical measures of performance and what is commercially achievable for comparison with their own herd's performance should use the summary data presented in Section **4.5** .

The purpose of the multivariable modelling process is to identify the major drivers of annual percentage of pregnant cows missing and to explain the effect of each factor after adjustment for all other factors in the model. All candidate factors were initially considered for inclusion in the multivariable model building process, and all factors with significant and biologically plausible associations with the outcome were retained in the final model. It is important to be aware that when comparing the predicted difference(s) between annual percentage of pregnant cows missing for each factor the absolute difference is expressed in terms of percentage points increase or decrease i.e., the difference between 50% and 55% is 5 percentage points.

Missing cows were defined as those females that had been enrolled in the study (meaning that they had at least some records in the dataset) and that at some stage, without any record of being culled, did not contribute any further data at any of the future musters. Animals that were known to have died (46/1618; 2.78%) were classified as missing from when they were known to have died.

Animals classified as missing were considered to provide an indirect estimate of mortality, given that many extensive beef properties are not able to observe cattle in order to accurately determine mortalities.

The outcome "annual percentage of pregnant cows missing" is likely to be an over-estimate of mortality as it includes cows that lost their lifetime traceability due to loss of their NLIS tag, or were un-reportedly relocated within the property and not sold before the end of the project.

The dataset used in this Poisson regression analysis was restricted to those properties where a record of all NLIS tag transfers during the project period was supplied in order to be confident that animal transfers were not contributing to a bias in the percentage of cows missing. The dataset was also restricted to animals that were pregnant at the pregnancy diagnosis muster because of the high risk that empty cows would be culled for commercial reasons and therefore lost from follow-up. This outcome, percentage of pregnant cows missing, was a binary outcome with 0=not missing throughout annual production cycle and 1=became missing during annual production cycle. An individual animal was only recorded as missing if it was recorded as being retained at a pregnancy diagnosis muster and then was missing for a minimum of two consecutive musters and if it did not turn up again at any subsequent muster. Therefore, animals observed as going missing during 2011 were excluded from the analysis due to insufficient musters taking place to confidently ascribe an animal missing rather than miss-mustered.

A description of the model building process is provided in Section **3.5.5** .

The data contributing to the final model represented 21,554 observations (animal years) from 20,340 individual pregnant cows recorded across 52 properties. Animal records that were missing data for any of the factors included in the final model were omitted from the model. **Table 125** provides a summary of the number of properties and animal records contributing to the model within different country types. Note that factors that are not in the final model were screened out because they were either non-significant, or explained by a closely-related variable. A full list of variables available at the commencement of the analysis is presented in **Appendix XVI**.

Table 125: Number of cows and properties that contributed data to the final multivariable model.

Country Type	**Number of properties** (n)	**Total number of unique animals within country type** (n)	**Total number of animals within country type** (n)
Southern Forest	12	3,216	3,591
Central Forest	13	4,557	4,957
Northern Downs	10	8,494	8,888
Northern Forest	17	4,073	4,118
Total	52	20,340	21,554

The final multivariable model for annual percentage of pregnant cows missing contained the following terms:

Main effects:

- Country type (Southern Forest, Central Forest, Northern Downs, Northern Forest)
- Body condition score at the pregnancy diagnosis muster (1-2, 2.5, 3.0, 3.5, 4-5)
- Estimated period of calving expressed as a predicted window when a cow calved (October-November, December-January, February-March, April-June, July-September)
- Available dry season biomass (<200kg/ha, ≥2000kg/ha)
- Days to follow up rain after wet season onset (<30 days, ≥30 days)

Interaction terms:

- BCS at pregnancy diagnosis muster x available dry season biomass

The following sections provide the predicted incidence rates for cows going missing per year, expressed as a percentage and generated as marginal means from the final multivariable model for each of the explanatory variables (factors) in the final model. The marginal means for any one variable are adjusted for the effects of all other variables in the model. Pair-wise statistical comparisons have been conducted to generate p-values for comparisons between different levels within each variable or interaction term from the final model.

The overall percentage of pregnant cows missing was 10.9% (8.7–13.1%) per year, which is of considerable concern given it is an estimate of cow mortality. As reported in Section 4.2, using a restricted dataset the overall incidence of NLIS tag replacement, a proxy for tag loss, for northern Australia was estimated as 2.6% per year. As the percentage of cows missing due to unrecorded NLIS tag loss and cattle remaining on the properties but in other management groups could not be determined, an upper estimate of cow mortality on these collaborating northern Australian properties is approximately 8% per year.

Risk factor levels that were significantly different are thought to be equated to differences in cow mortality as there was no evidence that tag loss or cattle movement differed significantly between levels of any risk factor.

5.4.1 Predicted impact of country type

After all other factors in the model were considered, the percentage of pregnant cows missing was significantly associated with country type (*P*=0.02). The percentage of pregnant cows missing was significantly higher in the Northern Forest than either the Southern Forest or Northern Downs (7.1 percentage points, *P*=0.04 and 9.1 percentage points, *P*=0.01, respectively) (**Figure 115**; **Table 126**). The percentage of pregnant cows missing in the Central Forest was predicted to be 6.3 percentage points lower than those cows in the Northern Forest, although this difference was not statistically significant.

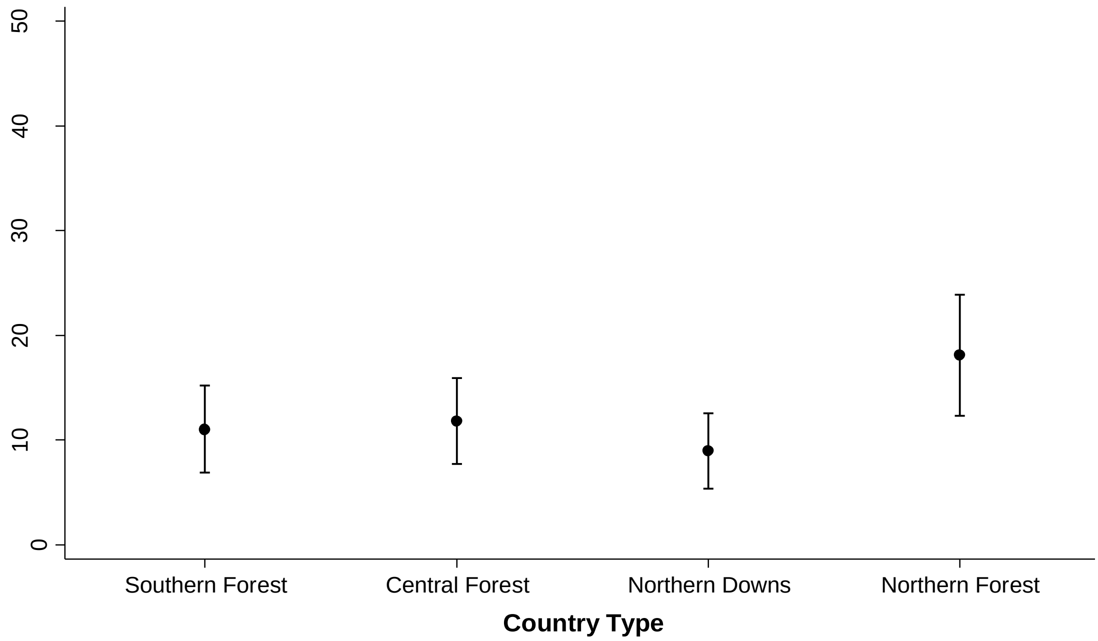

Figure 115: Predicted percentage of pregnant cows missing (missing per 100 pregnant cows per year) by country type, based on the marginal means generated from the multivariable model and adjusted for all other factors in the model. Bars represent 95% confidence interval.

Table 126: Predicted percentage of pregnant cows missing (missing per 100 pregnant cows per year) by country type, based on the marginal means generated from the multivariable model and adjusted for all other factors in the model.

Country Type	Mean percentage pregnant cows missing * (%)	95% Confidence interval	
		Lower	Upper
Southern Forest	11.0^{A}	6.8	15.2
Central Forest	11.8^{AB}	7.7	15.9
Northern Downs	8.9^{A}	5.3	12.5
Northern Forest	18.1^{B}	12.3	23.9

* Means not sharing a common superscript are significantly different (P<0.05).

5.4.1.1 Application and Further work

The high percentage of pregnant cows missing across the project includes tag loss, but differences between country types are more likely due to differences in mortality. This suggests that there is a significant problem with cow mortality in the Northern Forest. The specific cause is not defined by this analysis. The majority of cows in this study were <10 years of age, thus precluding the analysis from discerning increased loss without phosphorous supplementation in aged cows in the Northern Forest[81].

Targeted cow mortality research is required in the Northern Forest to confirm the level of loss, and to define strategies to counter the problem in addition to those associated with other risk factors identified in this report.

5.4.2 Predicted impact of body condition score and available dry season biomass

Five categories of body condition of pregnant cows were used as an individual-animal effect in the final model: 1-2, 2.5, 3, 3.5, 4-5 at the PD muster.

The standing available pasture biomass was visually estimated using photo standards to the nearest 500 or 1,000 kg/ha across each paddock approximately every two months throughout the year. The minimum biomass estimated across the dry season (May-November) was categorised as two levels: ≥2,000 kg/ha and < 2,000 kg/ha.

After adjustment for all other factors in the model the main effects of body condition score and available dry season biomass and their interaction were significant predictors of percentage of pregnant cows missing (P<0.001, P<0.001 and P<0.03, respectively). The main effect of minimum available dry season biomass was as expected, with a higher percentage of pregnant cows missing where pasture biomass was <2000 kg/ha during the dry season compared to where it was ≥2000 kg/ha (**Figure 116**;**Table 127**). Generally, the percentage of pregnant cows missing progressively declined as body condition scores increased between categories 1.0-2.0, 2.5 and 3.0, and then remained relatively constant for the categories 3.5 and 4.0-5.0 (**Figure 117**; **Table 128**). The significant effect of body condition score occurred

[81] Perkins *et al* (2012)

both when high and low levels of biomass were available to cows (*P*=0.03) (**Figure 118**; **Table 129**).

The magnitude of effect for body condition is not as high when compared to the report of a specific event by Fordyce *et al*.[82]. However, pregnancy rates, thus chances of lactating during the dry season, are lower in cows that have experienced poor nutrition and are in lower body condition, and this is most likely why the effect of poor body condition was less severe.

The percentage of pregnant cows missing was 4 and 9 percentage points higher in cows in body score categories 1.0-2.0 and 2.5 compared to pregnant cows in body condition score categories 3.0, 3.5, or 4.0-5.0 when ≥2000 kg/ha biomass was available. When available biomass was <2000kg/ha, the percentage of pregnant cows missing for cows in a body condition score category of either 3.0 or lower was 5-7 percentage points higher compared to when biomass was high (*P*<0.001). Additionally, the percentage of pregnant cows missing when available biomass was <2000kg/ha, was 2 and 4 percentage points higher in cows in body score categories 1.0-2.0 and 2.5 compared to cows in score 3 or better.

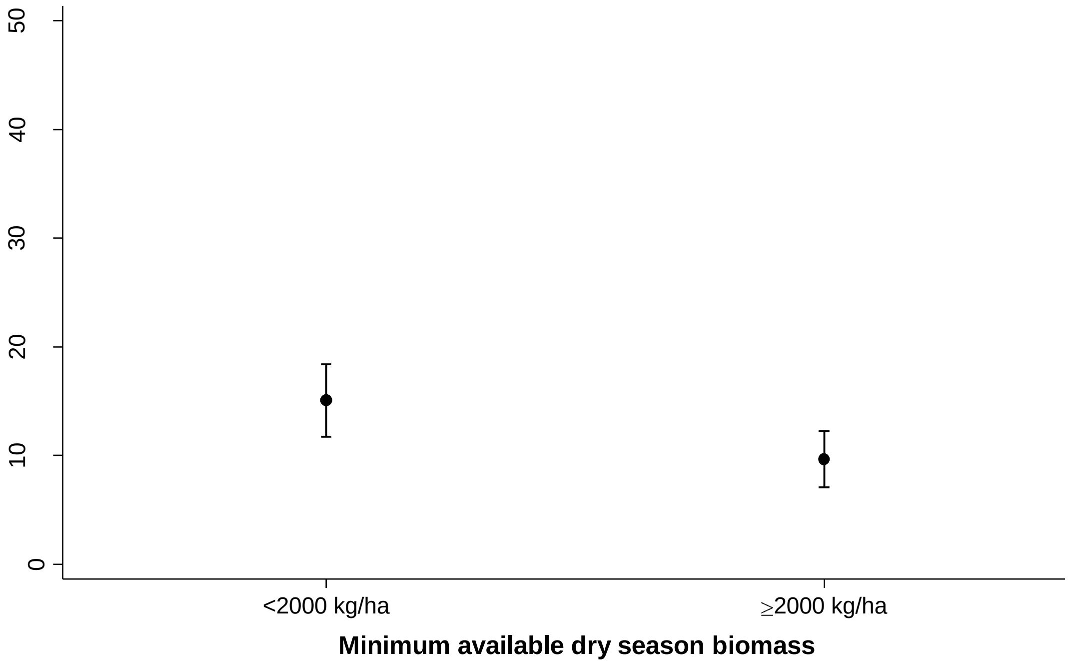

Figure 116: Predicted percentage of pregnant cows missing (missing per 100 pregnant cows per year) by minimum available dry season biomass, based on the marginal means generated from the multivariable model and adjusted for all other factors in the model. Bars represent 95% confidence interval.

[82] Fordyce *et al* (1990)

Table 127: Predicted percentage of pregnant cows missing (missing per 100 pregnant cows per year) by minimum available dry season biomass, based on the marginal means generated from the multivariable model and adjusted for all other factors in the model.

Minimum available dry season biomass	Mean percentage pregnant cows missing * (%)	95% Confidence interval	
		Lower	Upper
<2000 kg/ha	15.0[A]	11.7	18.4
≥2000 kg/ha	9.6[B]	7.0	12.2

* Means not sharing a common superscript are significantly different (P<0.05).

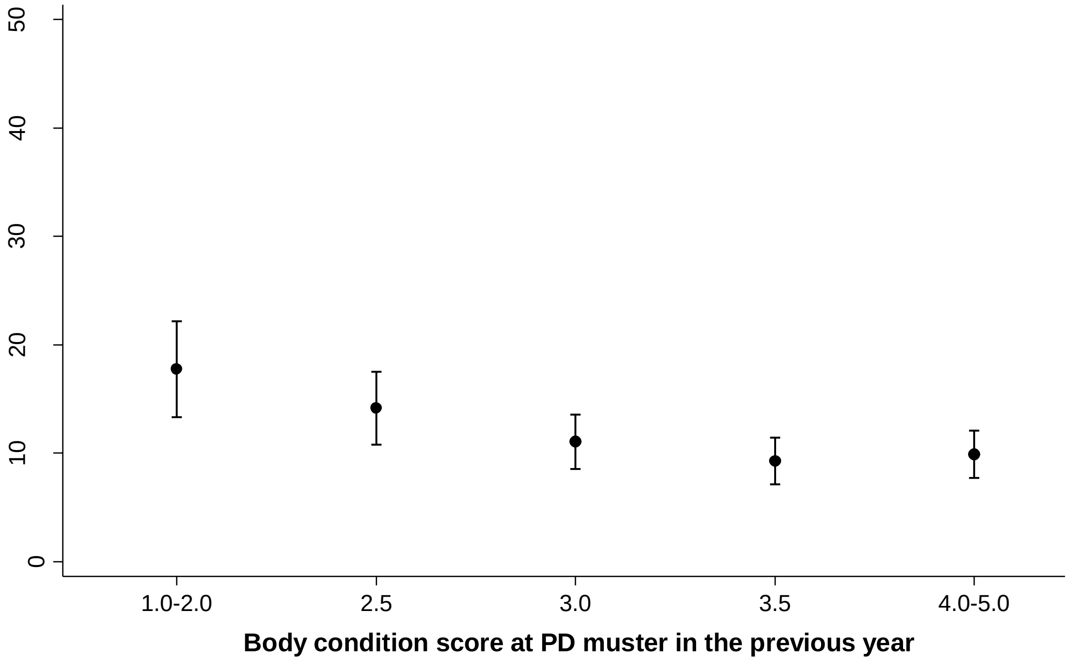

Figure 117: Predicted percentage of pregnant cows missing (missing per 100 pregnant cows per year) by body condition score at pregnancy diagnosis muster in the previous year, based on the marginal means generated from the multivariable model and adjusted for all other factors in the model. Bars represent 95% confidence interval.

Table 128: Predicted percentage of pregnant cows missing (missing per 100 pregnant cows per year) by body condition score at pregnancy diagnosis muster in the previous year, based on the marginal means generated from the multivariable model and adjusted for all other factors in the model.

Body condition score category	Mean percentage pregnant cows missing * (%)	95% Confidence interval	
		Lower	Upper
1.0-2.0	17.7^{D}	13.3	22.1
2.5	14.1^{C}	10.7	17.5
3.0	11.0^{B}	8.5	13.6
3.5	9.3^{A}	7.1	11.4
4.0-5.0	9.9^{AB}	7.7	12.1

* Means not sharing a common superscript are significantly different (P<0.05).

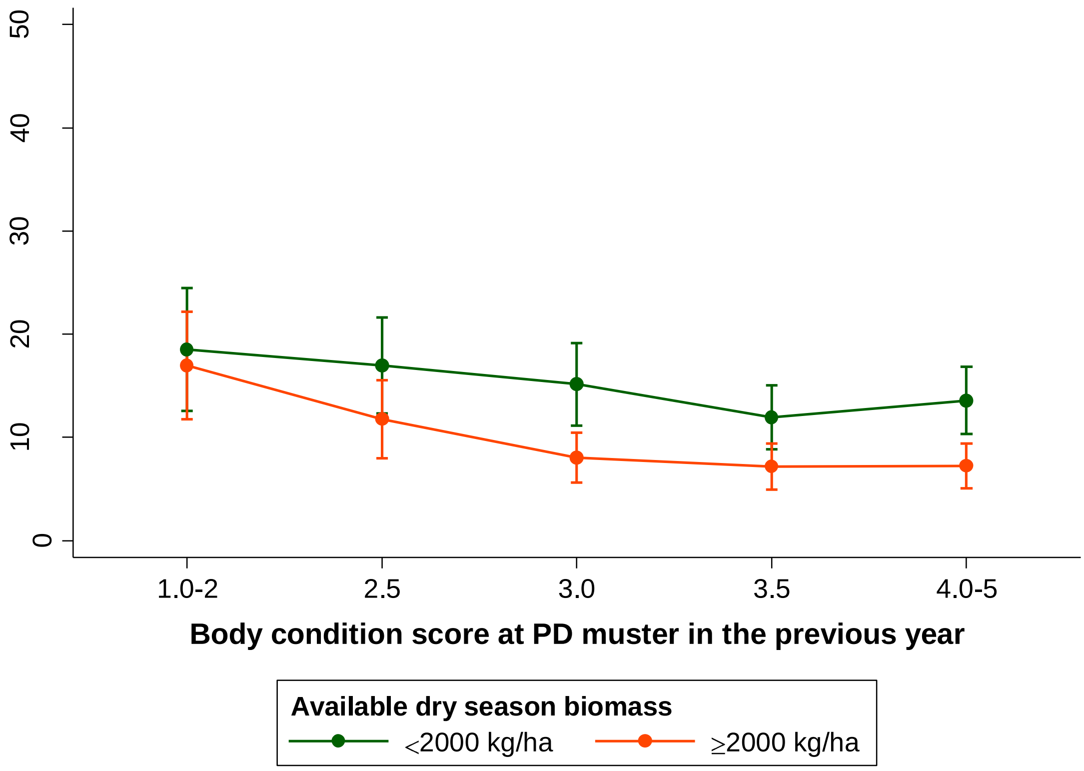

Figure 118: Predicted percentage of pregnant cows missing (missing per 100 pregnant cows per year) by the interaction between cow body condition at the pregnancy diagnosis muster in the previous year and available dry season biomass category. Bars represent 95% confidence interval.

Table 129: Predicted percentage of pregnant cows missing (missing per 100 pregnant cows per year) by the interaction between cow body condition at the pregnancy diagnosis muster in the previous year and minimum available dry season biomass. The lower and upper 95% confidence interval has been reported in parentheses.

Body condition score category	Mean percentage of pregnant cows missing* (%)	
	<2000 kg/ha	≥2000 kg/ha
1.0-2.0	18.5[A] (12.6-24.5)	17.0[C] (11.8-22.2)
2.5	17.0[A] (12.3-21.6)	11.7[B] (7.9-15.5)
3.0	15.1[AB] (11.1-19.2)	8.0[A] (5.6-10.4)
3.5	11.9[C] (8.8-15.1)	7.2[A] (4.9-9.4)
4.0-5.0	13.6[BC] (10.3-16.8)	7.2[A] (5.0-9.4)

*Within available dry season biomass category, means that are not sharing a common superscript letter are significantly different at P<0.05.

5.4.2.1 Application and Further work

The increased percentages of pregnant cows missing due to both low body condition and low available biomass in the dry season are likely to equate to increased mortality rate.

Using cow body condition category of <3 at the pregnancy diagnosis muster as part of a draft for differential management to reduce mortalities is one management strategy that could be considered.

Given the high incidence of missing pregnant cows, demonstration of systems management that conserve body condition and achieve adequate available pasture in the dry season appears well justified.

5.4.3 Predicted impact of days to follow-up rain after wet season onset

The wet season onset was defined as the date when a total of 50 mm of rainfall had fallen in 14 days or fewer, starting from any day after September 1 (but before March 31). The number of days following the wet season onset until another major rainfall event was derived assuming a major rainfall event was defined as a total of 50 mm of rainfall within 14 days. The two categories investigated were <30 days and ≥30 days between onset of wet season and follow-up rainfall. Two Central Forest and one Northern Forest property had no wet season onset in 2009-2010. Though early wet season onsets (September-November) were associated with more annual rainfall, they were also associated with longer periods to follow-up rainfall.

The percentage of pregnant cows missing was 4 percentage points higher when follow-up rainfall to the wet season onset was ≥30 days (**Figure 119**; **Table 130**).

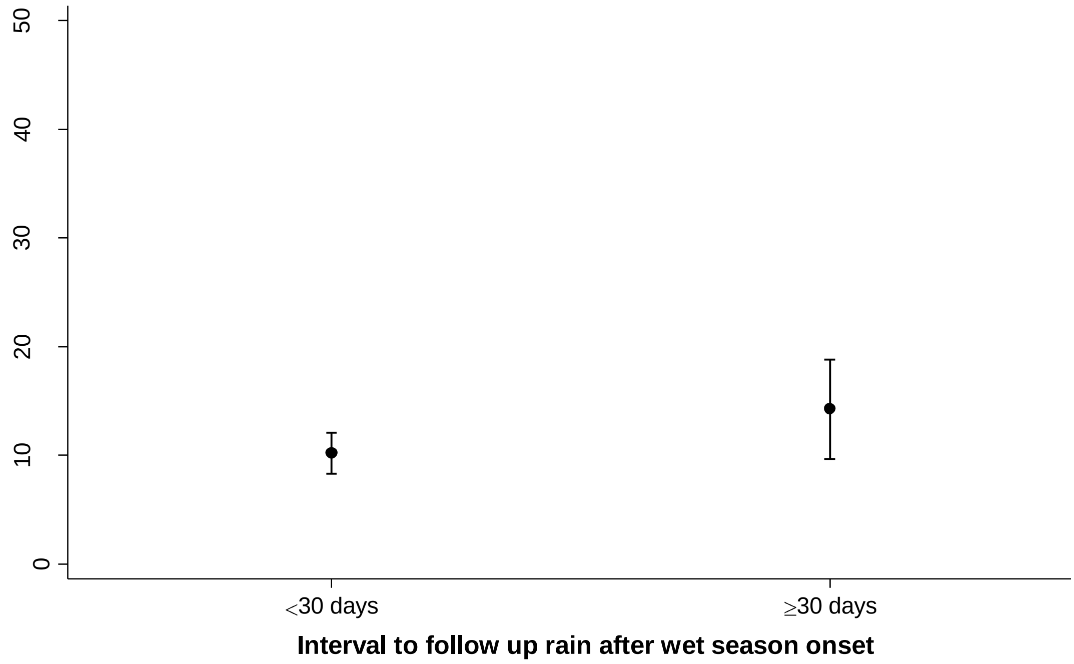

Figure 119: Predicted percentage of pregnant cows missing (missing per 100 pregnant cows per year) by interval to follow up rain after wet season onset based on the marginal means generated from the multivariable model and adjusted for all other factors in the model. Bars represent 95% confidence interval.

Table 130: Predicted percentage of pregnant cows missing (missing per 100 pregnant cows per year) by interval to follow up rain after wet season onset based on the marginal means generated from the multivariable model and adjusted for all other factors in the model.

Interval to follow up rain category	Mean percentage pregnant cows missing * (%)	95% Confidence interval	
		Lower	Upper
<30 days	10.2^{A}	8.3	12.1
≥30 days	14.2^{B}	9.7	18.8

* Means not sharing a common superscript are significantly different (P<0.05).

5.4.3.1 Application and Further work

At the onset of the wet season, feed intake drops dramatically as a variable 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. This problem is very expensive to manage as it often requires energy supplementation. Simple urea-based licks are only effective if sufficient adequate quality dry matter is available.

Given the potential significant financial benefits when done well, cost-effective application of strategies to deal with delayed follow-up rainfall needs to be investigated.

5.4.4 Predicted impact of expected month of calving

The predicted month of calving was calculated using estimated foetal age at the date of the pregnancy diagnosis muster and projected forward using an assumed gestation length of 287 days. As foetal age was recorded in months it was multiplied by 30.4 (365/12) days per month to estimate foetal age in days. The predicted months of calving were grouped into five categories: July-September, October-November, December-January, February-March and April-June. It should be noted that few calves are born during the latter two periods in most controlled mating systems.

Month of calving was not a significant effect in the model (P=0.101;**Figure 120**; **Table 131**). However, it was retained as it has previously been reported as a major effect on survival because of the dramatic effect of late pregnancy and lactation on energy requirement.

The trend in this project was the same as previously reported: a higher percentage of cows calving out-of-season (usually April-September) were missing than cows calving in the October-March period. The difference (not significant) was 1-2%.

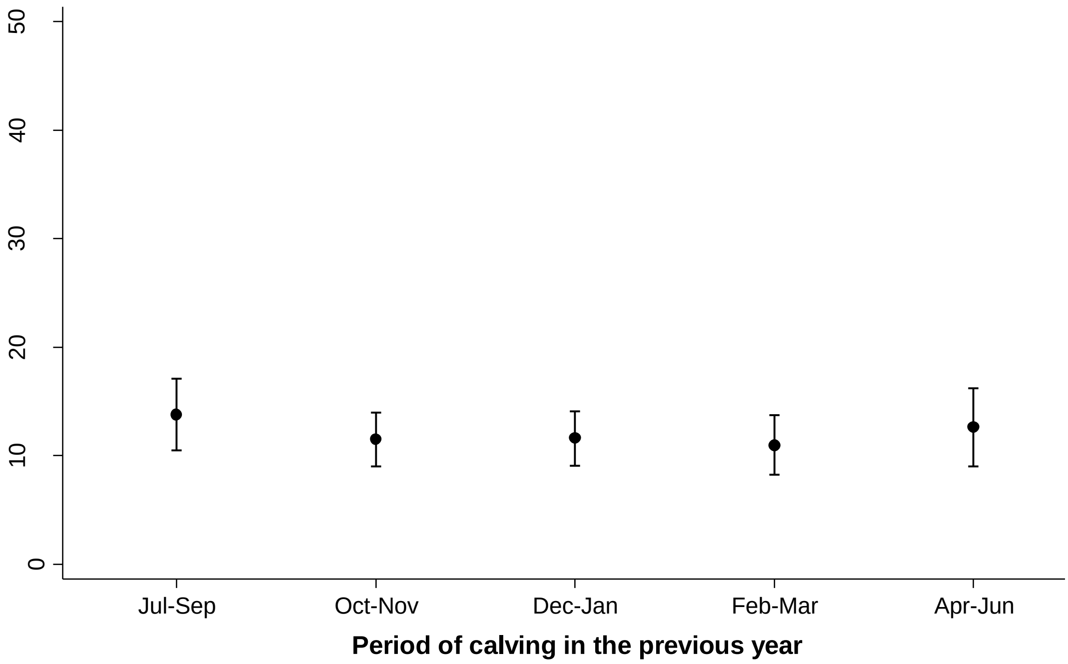

Figure 120: Predicted percentage of pregnant cows missing (missing per 100 pregnant cows per year) by period of calving in the previous year, based on the marginal means generated from the multivariable model and adjusted for all other factors in the model. Bars represent 95% confidence interval.

Table 131: Predicted percentage of pregnant cows missing (missing per 100 pregnant cows per year) by period of calving in the previous year, based on the marginal means generated from the multivariable model and adjusted for all other factors in the model.

Period of calving	Mean percentage pregnant cows missing (%)	95% Confidence interval	
		Lower	Upper
Jul-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-Jun	12.6	9.0	16.2

5.4.4.1 Application and Further work

The impact of period of calving on predicted percentage of cows missing is consistent with previous reports and supports the use of management strategies, such as foetal ageing, to identify those cows at higher risk of mortality due to out-of-season calving.

Further R&D is not indicated.

5.4.5 Variance explained by model

The fixed effect component of the full statistical model accounted for or explained 32.3% of the variance at the property level that had been estimated in the intercept only model (**Table 132**).

Table 132: Variance estimates from an intercept only model that included a random effect coding for property and the full model that included the same random effect.

	Null model#	Full model
Property level variance	0.49	0.33
% of property level variance explained by full model		32.3%

Variance estimated on the dataset from the final multivariable model to allow comparison

6 Estimation of annual liveweight produced by breeding herds

Historically, breeding herd performance has been assessed through measuring a range of parameters such as pregnancy and weaning rates, conception patterns, and calf wastage. Unfortunately, across the beef industry there is large variation in the definition and understanding of each of these parameters due to variation in both the numerators and denominators used. Part of this is due to attempts to derive annual parameters from over-lapping two-year cycles (i.e., conception-calving-conception-calving). Another reason is that routine management, such as culling, transferring, and selling, annually imposes major herd re-structures between the mating and lactation phases of reproduction.

Even when these parameters are precisely defined, it is notoriously difficult to relate the findings to business outcome, thus some difficulty in assessing the impact of risk factors affecting these parameters. It is interesting to note that typical herd modelling has consistently suggested that achieving higher than 70% weaning rate usually provides little business advantage.

The principal question for a beef producer is, “how is a breeding herd performing in relation to what is practically achievable within environmental constraints”. At a biological level, we suggest this can be answered by assessing annual net liveweight production per cow or cow-calf unit that is environmentally sustainable. However, the simplistic model of beef production from a breeding herd presented in **Figure 121** demonstrates the complexity of calculating these parameters. Our hypothesis is that liveweight production from breeding mobs/herds can be calculated from readily collected data, and used as a key performance indicator for achievable performance in northern beef herds.

Whether a beef herd is reaching achievable production will dictate the need for detailed analysis of performance, which will indicate where the problems and opportunities for improvement exist.

Data were only complete for 102, 102, and 154 mobs to estimate liveweight production, liveweight production ratio, and weaner production, respectively.

All rates used in this section were calculated as a percentage of cows retained.

Descriptive analyses were conducted to derive the distribution for each variable within country type. Inter-quartile points were derived for presentation. The economically achievable performance level was selected as the 75 percentile point in distributions within country type.

6.1 Annual net liveweight production per cow

Liveweight production is the annual net liveweight produced per cow retained. Mob-level output data from animal-level descriptive analyses are presented below. From the model (**Figure 121**), liveweight production from a breeding herd is the change in weight of a cow-calf unit over a one year period. For simplicity of calculation, the start and end point is the pregnancy diagnosis muster, which usually coincides with the final weaning round of the year. The calculation is confined to the one year period, and for each year, a new calculation is done as a different group of animals will make up the selected management group.

The concept of liveweight production is that a cow starts a period at a specific weight. One year later, if she remains alive, she may have lost or gained weight, and weaned or not weaned a calf of specified weight. Overall, it is expected that the difference between the end and start weights, plus weaner weight, makes up annual net liveweight production. The business makes money by selling the net liveweight produced either directly, or after transfer to another sector of the herd for value adding. Cow mortalities, low weaning rates, and low weaner weights will reduce net liveweight production.

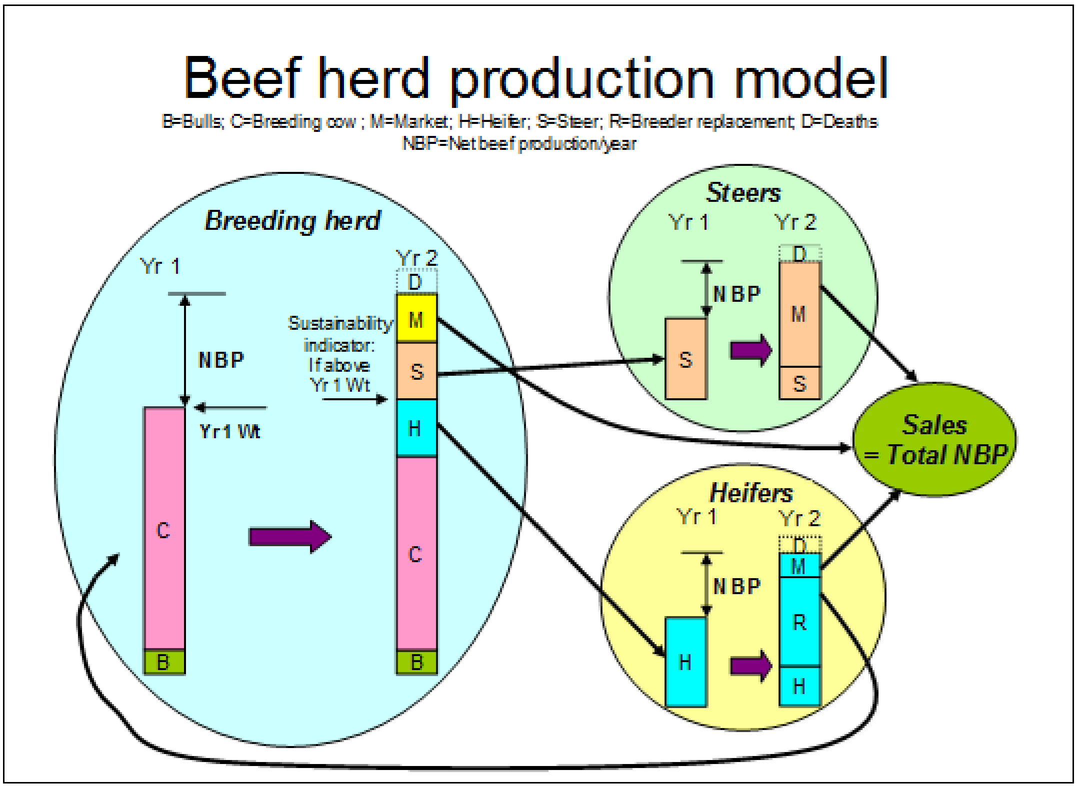

Figure 121: A framework for analysing annual liveweight production from breeding mobs and herds. B=Bulls; C=Breeding cow ; M=Market; H=Heifer; S=Steer; R=Breeder replacement; D=Deaths; LWP=Net live weight production/year.

6.1.1 Annual liveweight production

Given the above, the calculation of annual net liveweight production per cow is

EW * (1 – MR) + (WN/SN * WW) – SW

This equation reads as:

Average weight of cows at the end of the measured period, adjusted down for mortalities

+ Average weight of weaners produced

- Average weight of cows at the start of the measurement period

WN/SN	=	Lactation rate	Calculated as cows lactating / starting number of cows at the beginning of the cattle year or production cycle
WW	=	Average weight of calves weaned	In all weaner groups, a representative group of calves is weighed, thus providing an average weaning weight.
SW	=	Average weight of cows at the pregnancy diagnosis muster at the beginning of the measurement period	Representative sample of cows weighed, or an estimate of average weight derived using hip height and BCS
EW	=	Average weight of cows at the pregnancy diagnosis muster at the beginning of the next measurement period	Representative sample of cows weighed, or an estimate of average weight derived using hip height and BCS
MR	=	Cow mortality rate	Taken as equivalent to percentage pregnant cows missing between the 2 musters

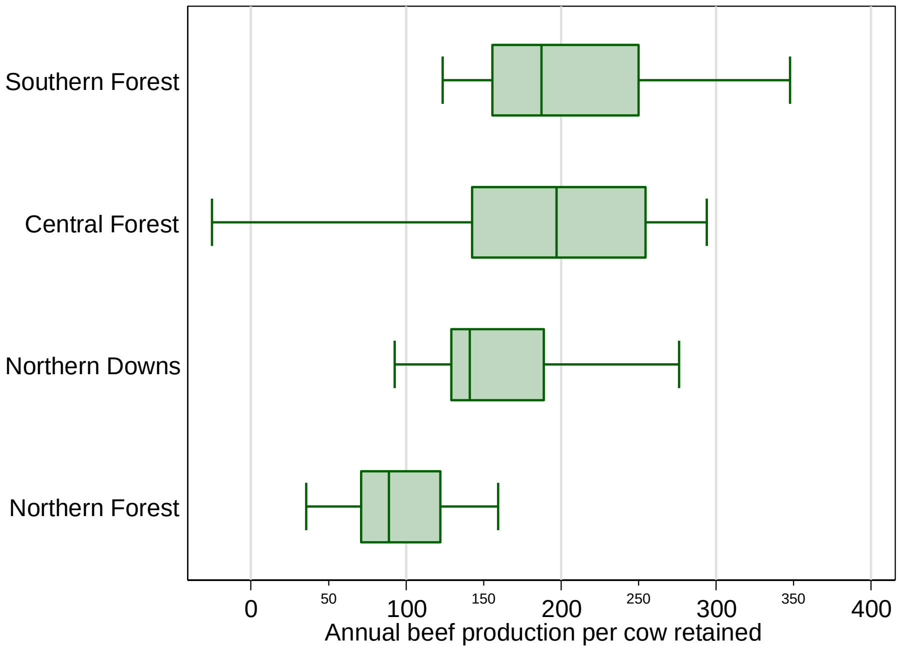

Figure 122: Liveweight production by country type.

Table 133: Descriptive summary of liveweight production for each country type.

Country-type	No of mobs	Annual Liveweight Production		
		25th percentile	Median	Achievable level
Southern Forest	28	155.6	187.5	250.3
Central Forest	28	142.7	197.3	254.9
Northern Downs	17	129.3	141.2	188.8
Northern Forest	29	70.9	88.8	122.4
Total	102	115.0	149.7	213.4

6.1.2 Explanation

The achievable annual liveweight production per cow was similar to expected achievable annual steer growth in these country types (**Figure 122**; **Table 133**). Very low levels were primarily related to substantial loss of weight by cows and low weaning rates. Outliers, for example the extreme low cases, were caused by high cow mortality rates.

6.1.3 Practical application

The suggested achievable level for annual liveweight production per cow is typically about 50 kg above the median within country type (**Table 133**), thus indicating opportunity to improve in many situations.

6.1.4 Future research

The limited number of data points for production variables and weaning rate generated in this project precluded risk factor analyses to parallel that of performance variables presented in earlier sections of this report. Much larger data sets for net annual liveweight production are required to more accurately define achievable performance against environmental factors that cannot be manipulated, and to directly relate management factors to liveweight production.

6.2 Liveweight production ratio

Liveweight production can be calculated as a function of many denominators such as hectares, cows, adult equivalents, and cost units. Our decision was to standardise the calculation against the stocking capacity in the paddock, which is most easily expressed as average liveweight of cattle in the paddock over the one year period. For some breeding mobs the data available were obtained from a sample of cattle in the paddock, but because they had been selected using a cross-sectional sampling technique they were considered representative of the mob.

Average liveweight per cow-calf unit in the paddock over one year was calculated as

(SW + EW) / 2 + WN/SN * (WW +35) / 2 * (WW - 35) / 0.9 * 365

This equation reads as:

Average cow weight over the year + Average weight due to weaners over the year

The latter is:

Lactation rate as a percentage of retained cows * average weight of weaned calves during suckling * average age of weaners (years).

The last two variables were calculated using a suckling calf growth rate of 0.9 kg/d and birth weight of 35 kg.

The equation for liveweight production ratio is therefore:

Annual net liveweight production per cow / Average liveweight of cow-calf unit over the year =

((EW * (1 – MR) + WN/SN * WW) – SW) / ((SW + EW) / 2 + WN/SN * (WW +35) / 2 * (WW - 35) / 330)

Liveweight production ratio is expressed as kg of liveweight produced / kg of liveweight in the paddock. For example, a liveweight production ratio of 0.35 equates to 35 kg net increase in liveweight for every 100 kg of cattle grazing that paddock on average over a one year period.

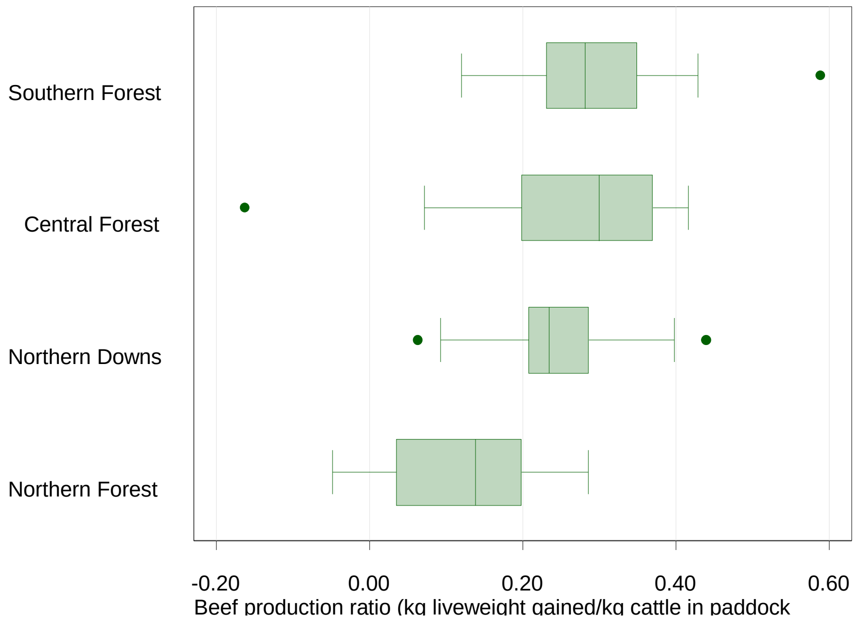

Figure 123: Liveweight production ratio by country type.

Table 134: Descriptive summary of liveweight production ratio for each country-type.

Country-type	No of mobs	Liveweight Production Ratio		
		25th percentile	Median	Achievable level
Southern Forest	28	0.23	0.28	0.35
Central Forest	28	0.20	0.30	0.37
Northern Downs	17	0.21	0.23	0.29
Northern Forest	29	0.04	0.14	0.20
Total	102	0.17	0.23	0.33

6.2.1 Explanation

Median levels for beef production ratio varied between 0.14 kg liveweight gained per kg cattle in the Northern Forest to 0.30 in the Southern Forest cow herds (**Figure 123**; **Table 134**). Substantial variation occurred in all regions, with half of herds within 0.07 kg produced/kg of cattle of the median. This indicates that those at the 25 percentile level could improve their efficiency by at least 0.07 kg/kg cattle; this is a large change.

6.2.2 Practical application

The suggested achievable level for liveweight production ratio is typically about 0.07 kg per kg cattle above the median within country type (**Table 134**).

6.2.3 Future research

Much larger data sets for cow liveweight production efficiency are required to more accurately define achievable performance against environmental factors that cannot be manipulated, and to directly relate management factors to efficiency.

6.3 Weaner production

Calculation of annual net liveweight production for breeding herds requires data that needs to be collected over a number of years. Weaner production is usually the major component of annual net liveweight production, is simpler to derive, and may be a more useful parameter to use to estimate annual liveweight production from a herd.

Weaner production is kg of weaner per cow and is calculated as follows:

WN/SN * WW

This equation reads as:

Lactation rate (which equals calves weaned/retained cows) x Average weaner weight

Lactation rate, rather than weaning rate, was used in the calculation of weaner production because

- Weaning rate is a difficult parameter to derive in a commercial situation. It relies on pregnancy diagnoses and tracking individual cows after drafting to determine their lactation status at weaning.
- Lactation rate is based on the cows consuming the available pasture and incurring on-going business costs. Cows removed from the herd, whether pregnant or not, no longer incur business costs.

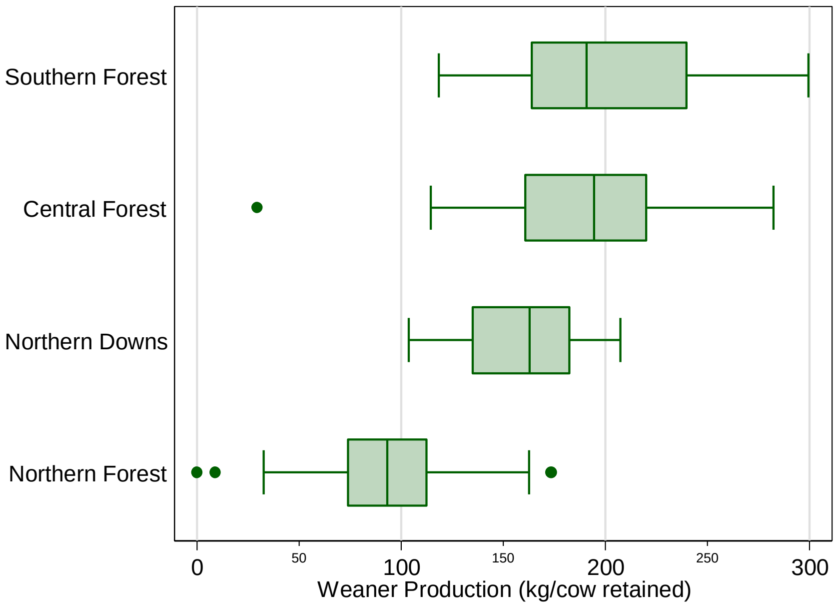

Figure 124: Weaner production by country type.

Table 135: Weaner production for each country type.

Country-type	**No of mobs**	**Weaner Production (kg/cow)**		
		25 percentile	**Median**	**Achievable level**
Southern Forest	33	164.0	191.0	240.0
Central Forest	33	160.7	194.6	220.1
Northern Downs	29	134.9	163.0	182.6
Northern Forest	59	74.0	93.3	112.4
Total	154	99.8	150.0	188.5

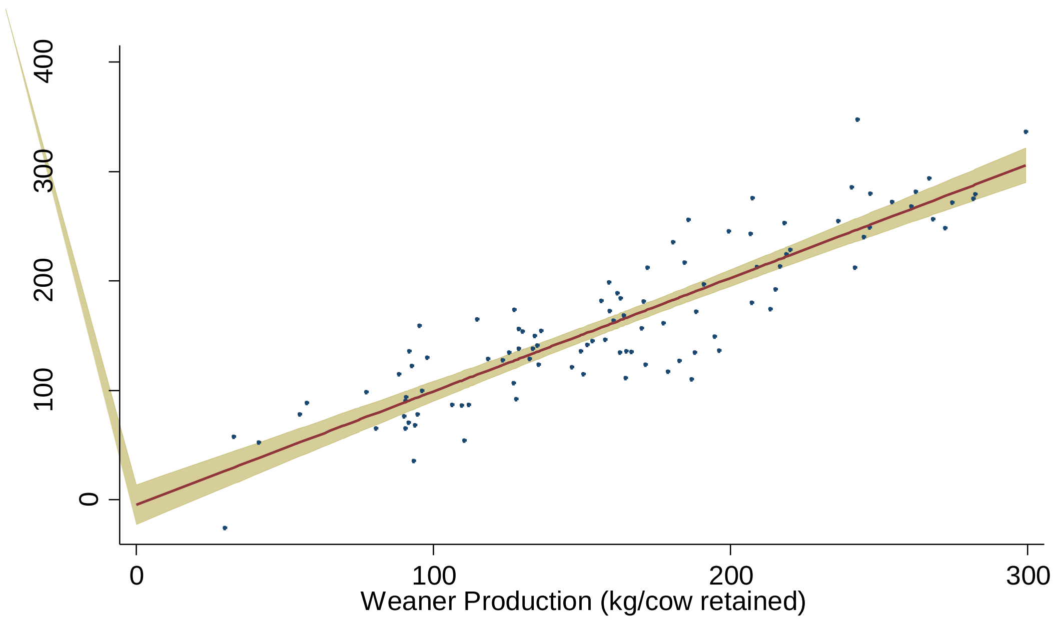

Figure 125: Relationship between liveweight production and weaner production.

6.3.1 Explanation

Median levels from available data for weaner production ranged from 93 kg/cow in the Northern Forest to 191-195 kg/cow in the Central and Southern Forest (**Figure 124**; **Table 135**). Within country type, half of the herds had annual weaner production within approximately 25 kg/cow of the median. The large variation was highlighted by weaner production for some herds being as much as 70 kg above or below the median. This suggests both substantial seasonal effects, and substantial opportunity to improve.

The coefficient of determination of 0.85 of weaner production for liveweight production ratio indicates that weaner production is a fair proxy for this variable (**Figure 125**).

To test the hypothesis that annual steer growth is indicative of achievable weaner production, annual steer liveweight gain was derived from two sources:

Owners were asked for average yearling steer growth in their situation. Data were available for 37 sites (**Table 136**).

Annual liveweight gain of steers was derived from published survey data collected across northern Australia[83]. Land units within region were classed into the four country types used. The weighted average within country type for each statistic reported (average, median, sd) The weighted average within country type for each statistic reported (average, median, sd) was based on the land type area[84]. The averages and medians were similar. Using the weighted data, the 25th and 75th percentiles were calculated as 0.67 x sd below and above the average, respectively.

Weaner and liveweight production at the 50th and 75th percentiles within country type were similar to the 25th and 50th percentiles for annual steer liveweight gain derived

[83] Bortolussi *et al* (2005)
[84] Tothill & Gilles (1992)

from Bortolussi *et al*.[85], except in the Northern Forest where the 75th percentile weaner production and liveweight production were intermediate to the estimated 50th and 75th percentiles for steer growth **Table 137**).

From a sub-set of 37 properties, average weaner production (kg) = 0.92 x average annual steer growth (kg; estimated by the owners) + 10.3 (**Figure 126**).

Table 136: Average annual steer growth for project sites as estimated by station owners.

Country Type	Number of responses	Lower 25%	Median	Upper 25%
Southern Forest	11	180	200	200
Central Forest	6	150	180	200
Northern Downs	4	155	170	190
Northern Forest	16	90	100	130

Table 137: Average annual steer growth (kg / year) derived from Bortolussi *et al*.[86]

Country Type	Lower 25%	Median	Upper 25%
Southern Forest	129	148	193
Central Forest	139	162	198
Northern Downs	116	136	171
Northern Forest	100	113	131

[85] Bortolussi *et al* (2005)
[86] Bortolussi *et al* (2005)

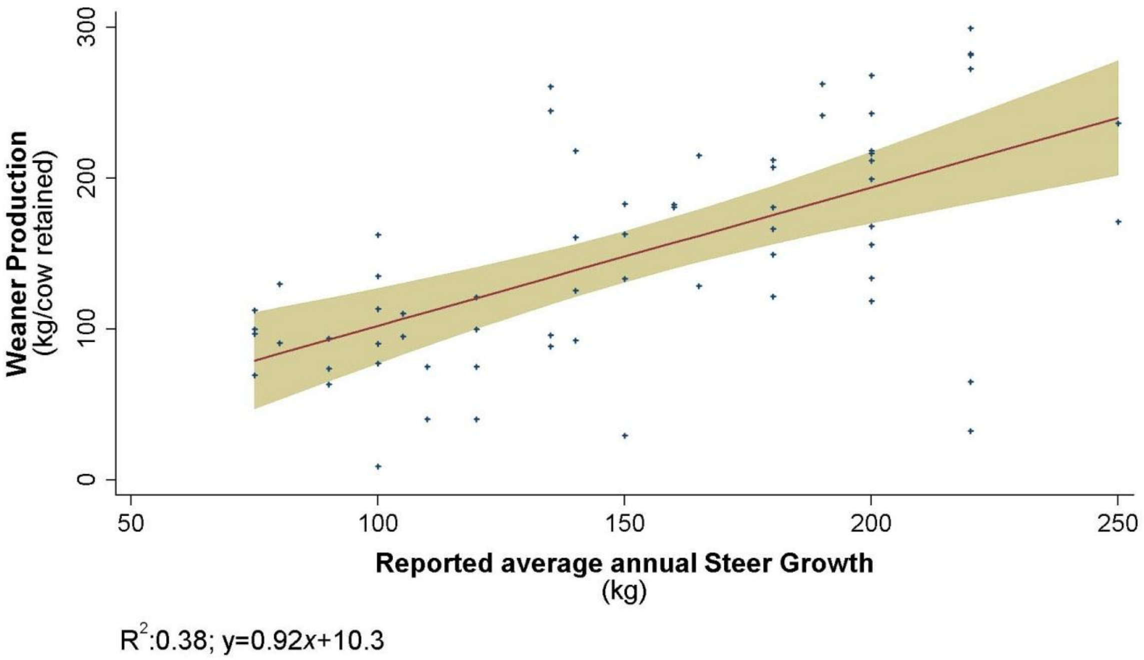

Figure 126: Weaner production as a function of annual steer growth estimated by station owners. Each point represents observed values and the shaded area shows the 95% confidence intervals.

6.3.2 Practical application

Achievable weaner production in the Southern and Central Forest is more than double that in the Northern Forest, and achievable weaner production in the Northern Downs approximately 60% higher than in the Northern Forest. Weaner production is a good indicator of liveweight production ratio, mainly because a significant component of the latter is derived from weaner production.

Steer growth may be a very useful guide to breeding cattle productivity per cow within specific situations. The reason for lower average steer growth within country type reported by others[87] in relation to that indicated in our research is unclear. The earlier research was based on a random selection of properties, whereas this project did not use random selection and the level of management on enrolled properties was considered equal to or above industry average. Differences in genotypes and management may also have contributed to the observed differences in findings.

Achievable weaner production may indicate appropriate weaning management. The very low weaner production achievable in the Northern Forest is a strong indicator that producers cannot consistently achieve high weaning rates without having low average weaning weights.

6.3.3 Future research

Research on weaning outcomes needs to include both weaner weight and weaning rate. Effective strategies will increase one without reducing the other. How these

[87] Bortolussi *et al* (2005)

interact with cow growth and mortality is also a critical element of weaning and weaner management research.

The specific relations between steer growth and cow herd production should be further explored as this is the simplest method available to set cow production targets.

6.4 Relationships between measures of reproductive performance and production

The strength of association and the impact of measures of reproductive performance (for example annual pregnancy rate, foetal/calf loss) on production (for example liveweight production) were assessed using simple linear regression models adjusted for effects at the property level (**Table 138**). The regression coefficient represents the rate of change in each measure of liveweight production per unit change in each measure of reproductive performance. For example, in **Table 138** a 6.3% increase in percent P4M is associated with a 10 kg increase in weaner production and a 7.1 kg increase in average weaner weight. The latter example shows that cow live weight changes also contribute to live weight production.

Table 138: Proportion of total variance in production (var) explained by each measure of performance and the change in performance per unit change in production derived from uni-variable analyses.

	Liveweight production ratio (kg/kg cattle/yr)		**Liveweight production (kg/cow/yr)**		**Weaner production (kg/cow/yr)**	
	var	/0.01	var	/10 kg	var	/10 kg
Pregnant 4 mths after calving	0.18	5.8%	0.43	5.7%	0.57	6.3%
Pregnant annually	0.27	2.8%	0.40	3.9%	0.61	4.5%
Pregnancy-weaning foetal/calf loss	0.16	-1.8%	0.20	-2.7%	0.34	-3.6%
Cow mortality	0.42	-0.9%	0.18	-2.1%	0.11	-3.4%
Average weaner weight	0.56	5.1kg	0.70	7.1kg	0.69	8.2kg
Cow liveweight change	0.26	5.6kg/yr	0.29	9.9kg/yr		

Overall it can be concluded that although all mob performance traits have a well-defined relationship with production, no single performance measure can be used alone to accurately predict annual production. As previously discussed, weaner production, which is relatively easy to derive, can provide a guide to liveweight production ratio, the most valuable production index (**Figure 125**).

7 Development of a cost benefit framework for assessing factors affecting reproductive performance

7.1 An analytical tool to estimate key performance indicators

To answer the question, "How is the herd performing in relation to what is practically achievable in this environment?" key performance indicators (KPIs) must be generated. A number of animal-based KPIs have been historically used, but Phil Holmes[88] suggested that operating margin is one of the best KPIs. It explains a very high percentage (82%[89]) of the variation in profitability. Most businesses do not know their KPIs, nor what is achievable. This is mainly due to the perceived large investment in time required to generate the data for accurate calculation of KPI's. Further, many beef businesses do not have standard recording systems for basic information.

To underpin future application of the outcomes from the CashCow project, and potentially to analyse the impact of identified major risk factors on collaborator businesses, we developed a mob-based herd performance recording system plus a method that takes a relatively small number of readily-measured beef business inputs to generate satisfactory estimates of KPIs. The latter is an experimental tool called the BRICK (Beef - Rough Indication Calculator of KPIs).

The herd and business performance data required for the BRICK includes:

- For the business: total income, total costs (- interest, drawings, labour; + depreciation), variable costs, labour costs, families drawing
- Calves (x gender if available) branded each year
- Date for close of the cattle year. This date may be later than the completion of the financial year

At the close of the cattle year, numbers, average weight, and average value/kg for five cattle age classes for each gender (**Table 139**). The BRICK does not allow impossible entries, such as those that generate negative mortality rates

- Date, number, average liveweight, cattle age class x gender group, and total value for each livestock transaction
- Females spayed each year within each age group

In financial calculations, the BRICK:

- Calculates cattle enterprise total business costs on a *pro rata* basis using cattle income (less purchases) and total business income
- Adjusts labour costs to a company-owned business by replacing family drawings with $60,000 for the first family and $45,000 for each other family drawing

The BRICK is an Excel spreadsheet calculator with seven sheets:

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[88] Holmes (2009)
[89] Holmes, *pers comm*

Sheet	***Function***
Notes	Description of the program and its use
Data entry	All data are entered on this one page.
Calculators	Three calculators to assist financial data management for entry
Transaction calculations	Transforms purchase and sale entries for further analyses
Livestock trading calculations	Calculates herd beef production and its value
Summary calculations	Calculates cattle and business KPIs annually
Summary of results	Summary over years of cattle and business KPIs

Some of the BRICK calculations of KPIs are expressed per 450 kg of cattle liveweight. This helps develop a rapid perception in relation to a "standard animal" (Note: this number comes from the American equivalent of 1,000 pounds). It also assists with more directly informing BREEDCOW, which uses the same standard.

7.1.1 Application of the BRICK

Examples of the outcome when the BRICK was applied to two businesses are given in **Table 139**. These examples show quite different outcomes for a full range of performance indicators. Business A was in high flux, whereas Business B was a more stable operation. Business A had a low EBIT (earnings before interest and tax) over 4 years. Further, Business A had a year where net beef production was negative because of high cow mortalities, which meant that no sensible value for operating margin could be calculated.

The most important outcome is that a calculation of many performance indicators was possible using quite simple inputs. The outputs can be used to gauge performance against what is achievable in that situation, i.e., as produced by this project, and to understand where opportunities for improvement may exist.

This outcome exemplifies the complexity in conducting and understanding beef business. If an accurate understanding of current performance is not available, then errors may be made in changing management.

If KPIs need to be expressed in another way, for example $/ha rather than $/450 kg animal, then they should be readily calculable from the information available.

If the BRICK is used to derive business performance, its output will provide a sound basis for Breedcow inputs. For example, if a Breedcow model is being established to represent a business, weaner production and variable costs should equate to BRICK outputs for the herd. Using this approach, an opportunity exists to update the "Beef CRC templates", which would improve the method of evaluating the economic effects of management strategies that influence breeding herd performance.

Table 139: Examples of key performance indicators calculated by the BRICK for two north Australian beef herds.

Performance indicator	***Expression***	***A***	***B***

Herd size	Number (450 kg equivalents)	1,618	4,656
Herd beef production	**kg liveweight produced**	**115**	**168**
Breeding cattle beef production	**/ 450 kg of cattle liveweight**	**68**	**161**
Steer beef production		152	187
Herd beef production efficiency	kg liveweight produced / kg cattle	26%	37%
Breeding cattle beef production efficiency		15%	36%
Steer beef production efficiency		34%	42%
Weaner production	kg / cow (closing number)	94	183
Average annual steer growth	kg / year	135	170
Branding rate (Cows mated)	Percentage	33%	74%
Weaning rate (Cows mated)		33%	72%
Branding rate (Cows retained)		52%	91%
Weaning rate (Cows retained)		52%	90%
Heifers as replacements		74%	86%
Average herd size change		-10%	5%
Mortality: Female calves and weaners	Percentage	0.0%	1.9%
Mortality: Yearling heifers		1.3%	1.9%
Mortality: Heifers 2-3 years		0.8%	2.3%
Mortality: Cows		5.2%	5.2%
Mortality: Spays			
Mortality: Male calves and weaners		0.0%	1.9%
Mortality: Yearling males		0.0%	2.3%
Mortality: Males 2-3 years		0.0%	5.7%
Mortality: Mature males		12.5%	8.3%
Mortality: Bulls		0.0%	1.0%
Sold: Male weaners	Percentage	43%	4%
Sold: Male yearlings		59%	3%
Sold: Males 2-3 years		19%	71%
Sold: Mature males		2%	27%
Total sales / Weaners		152%	77%
Female / Total sales		32%	48%
Income	$ / kg liveweight produced	$1.27	$1.43
Cost of production		#	$0.95
Operating margin		#	**$0.48**

Labour		$0.28	$0.30
Mortality effect on sales	$ / kg liveweight sold	-$0.17	-$0.23
Income	$ / 450 kg of cattle liveweight	$94	$241
Variable costs		$37	$4
Gross Margin		$56	$237
Overhead costs		$40	$155
EBIT		$3	$83
Labour		$41	$50
Bull costs	$ / weaner	$3	$24

not able to be calculated as net beef production was negative in one year

7.2 Cost benefit analysis for managing identified key risk factors

Analyses of the economic impacts on beef business of all the risk factors identified in this project are outside the scope of the project. However, we have developed a framework for conducting these analyses, and have provided some examples of the outcome. The process involved assessing a range of approaches to assessing the economic impact on beef breeding businesses in consultation with Dr Phil Holmes.

An analysis conducted for the recently completed Beef CRC using the Beef CRC templates[90] in BREEDCOW assessed the impacts of increasing weaning rates without altering weaning weights. Herd gross margins increased by a little over $1/AE for each percentage increase in weaning rates up to a weaning rate of approximately 70%. However, the findings from the CashCow project provide the opportunity to calculate more accurate impacts, and particularly to determine the impact in specific situations. This contrasts to the Beef CRC analysis, which is based on templates representing a broad range of situations, which may produce the correct average impact, but which may not be transferable to all situations within the zones assessed.

7.2.1 Framework for analysis

Financial analysis of a business enterprise, such as a beef breeding herd, can be considered at three levels: economics, business and accounting (**Table 140**). Economics is forward looking and aimed at testing options, but not necessarily accurately quantifying differences between options. Business analysis takes account of all business costs, returns, inputs and outputs, and is focussed on what has been achieved, and with economic analysis input, what could be achieved. Accounting reports the business financial performance from which taxation is calculated.

Based on the above, a proposed framework (**Figure 127**) to test the impact of a specific input is:

1. Conduct a business analysis using the BRICK to derive key performance indicators for breeding cows in the prevailing situation.

[90] Holmes *et al* (2011)

2. Use the changes in production parameters for breeding cows in response to risk factors from the CashCow project and other sources to derive Breedcow inputs to test the impact on whole-of-business gross margins or partial returns per cow.

An alternative strategy is to derive operating margins for each of the collaborators in the CashCow project, and then conduct analyses of variance in operating margin to test risk factors that have significant impact on herd performance.

Table 140: Inputs to be used for beef breeding business production and financial analyses.

Input	Output	Production CashCow	Business BRICK	Economic Breedcow	Accounting ATO
Animal/environment/management					
Cow enterprise	Beef	x	x	x	
Pregnancies					
Foetal/calf losses					
Weaning weight		x	x		
Cow weight change		x	x		
Cow losses		x	x		
Heifer enterprise	Beef		x	x	
Steer enterprise	Beef		x	x	
Bull enterprise	Beef		x	x	
Other enterprises			x		
Risk factors		x			
Financial					
Variable costs	Sales		x	x	x
	Gross margin		x		
Fixed & Personal costs			x		x
	Operating margin		x		
Interest, Tax					x
	Profit				x

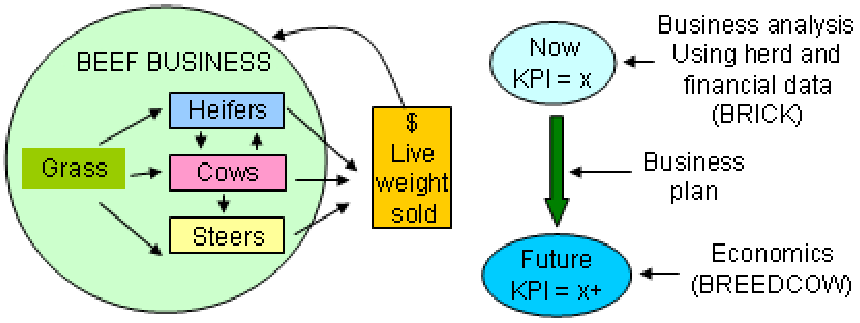

Figure 127: Framework for beef breeding business analysis (adapted from **Figure 121**).

7.2.2 BreedCow analysis

BreedCow is an excellent tool for economic analyses of applying management options in northern beef herds. The impact of each risk factor on cow production can be tested by changing the input variables it affects, while holding other inputs constant.

7.2.2.1 Input effects on production

The specific effects of key risk factors on mob performance have been presented in preceding sections. Of most value in an economic analysis are:

- Effects on weaner production, which can be used to test changes in the product of lactation rate and weaner weight
- Pregnancy rates and foetal/calf loss, which together can be used to test changes in weaning rates
- Mortality rates

7.2.2.2 Prevailing performance

Without a method of calculating actual business performance on which to conduct economic assessments, non-validated estimates input to BreedCow are used as a proxy. This will increase the error in the output from BreedCow. Therefore, accurate definition of herd production parameters requires herd-specific data. This may be available from well-recorded herds, but in most situations, performance parameters should be derived from both input and output data used in the BRICK or its equivalent. The parameters of most value in an economic analysis include those for changes in performance, plus:

- Weights, sale values and selling strategies of all stock classes
- Bull investments
- Spaying strategies
- Variable costs

7.2.2.3 Economic analyses

The CashCow project has focussed on performance of the breeding herd. Therefore, data for impacts on other variables have to be derived from other sources. This is especially so for replacement heifers and weaners.

In the analyses of percentage P4M, foetal/calf loss, and percentage pregnant cows missing (mortality), the risk factors that emerged as significant were:

- Nutritional and environmental - country type, year, body condition score, pasture digestibility and phosphorous, temperature-humidity index.
- Management - mustering around calving, mustering efficiency.
- Animal-based - age, height, previous lactation status, month of calving.

The effects of year, cow age class, country type and temperature-humidity index cannot be submitted to steady state economic analysis, as they are essentially fixed elements with no option for intervention within a business. The differences between country types are represented in the pre-existing regionally-based Beef CRC templates[91].

Management factors and previous lactation status only affected foetal/calf loss. Therefore their impacts can be assessed simply by using the analysis of Holmes[92], which concluded that a one percentage point difference in weaning rate is associated with a difference in gross margin of $0.72 per AE (450 kg of cattle managed). For example, low mustering efficiency was associated with 9 percentage points higher foetal/calf loss, thus reducing gross margins by $6.48 per AE, or $19,440 for a 3,000 AE herd.

Foetal/calf loss is 0.5-2 percentage points higher if cows are mustered around calving, but 9 percentage points higher if it is their first calf. The impact of this on herd gross margins depends on the proportion of cattle that are calving around mustering, and the age of these cows.

Cows that did not lactate in the previous year had 3.6 percentage points higher foetal/calf loss than cows that did lactate. Depending on region, these cows typically represent 5-15% of the herd as they are often those that lost their previous calf. If foetal/calf loss is 10%, the herd effect when non-lactating pregnant cows are not culled when the opportunity is available is a reduction in foetal/calf loss of 0.4 percentage points, thus a gross margin difference of $0.29 per AE or ~$800 for a 3,000 AE herd.

Other risk factors that are subject to management affect multiple variables, and therefore require more complex analyses of their impact. These risk factors include:

- Hip height of cattle. This effect is not simply a breed effect even though *Bos indicus* cattle are taller, as breed was not associated with foetal/calf loss
- Average body condition score prior to calving and after calving
- Dietary protein and digestibility levels
- Adequacy of phosphorous in the diet
- Season/period of calving

[91] Holmes *et al* (2011)
[92] Holmes (2010)

An example of the complexity of these analyses is demonstrated in the analysis conducted by Trish Cowley on the impact of season/period of calving as part of the CashCow project.

The analysis was conducted only for the Victoria River District region in the north-west of the Northern Territory, with the primary market being steers weighing <350 kg for live export[93]. The process to analyse period of calving effects on gross margins was:

- Split the year into four calving seasons (periods): early wet (November-January), late wet (February-April), early dry (May-July), and late dry (August-October).
- Produce four Breedcow models. In each model, two-thirds of calves were born in one period, and 11% in each of the other three periods. Weights of cattle for input into each model were derived from modelling data available from the region for animal growth in relation to time of birth, whether weaning was at the first or second annual muster, and when sales could be conducted. The overall weights for each class of animal were then adjusted for proportion born within each period. Net values of cattle were derived in a similar manner. Weaning rates and mortality rates for each class of female was then derived primarily from the CashCow project output plus other published information and local experience, and adjusted in each model for the proportion of females calving in each period. All of the above was then considered in calculations to derive variable costs for supplementation for every class of animal in each Breedcow model.
- Use the model outputs to derive simultaneous equations, that when solved, produced the relative values of calves at weaning per kg.
- Conduct a partial budget to derive the partial returns for cows calving in different seasons, based on weaner values, weaning rates, cow mortality rates, net cow values, and supplementation costs.

From the considerable input and output generated, the basic outcome was that in this region of northern Australia the most profitable calving time was the late dry to early wet seasons, and the least profitable calving time (at least $30/calf less) was the early dry season.

This process is for just one of the ABARES zones. There are 20 other zones for which Beef CRC templates have been prepared. All need to have similar analyses completed before an overall impact of time of calving can be derived. A post-project opportunity exists to improve the Beef CRC templates by “truthing” the accuracy of production variables, such as weaner production, within regions using the CashCow data.

7.2.3 Analyses of variance in operating margins

With operating margin available, the effect of risk factors on annual net beef production could be directly tested, thereby quantifying the financial impact of each risk factor. Similarly, the relationship between operating margin and annual net beef production within productivity zone could also be tested. This would test the hypothesis that the economically-achievable level of annual net beef production and

[93] Cowley (2012)

weaner production is at the 75th percentile level of observations made within the production zone.

One method to test this hypothesis is a possible follow-on project to apply the BRICK to the majority of project collaborators to determine operating margins in herds with known performance parameters (derived from this project).

7.3 Extension priorities for managing identified key risk factors

The CashCow project findings will be relevant to many stakeholders, and a planned extension program will be critical to clearly describe the outcomes and potential solutions for northern breeding herds. Key to the extension program is delivering the new messages, management tools and language in a form that is both interesting and applicable to northern breeder herds.

The extension message will revolve around the simple questions:

- ‘Do I have a problem in my herd?’
- ‘How much liveweight is my breeder herd producing?’
- ‘Do I have the data to work this out?’

From these simple questions, the majority of the CashCow project findings can be used. A major outcome from the extension plan will be increasing producer’s ability and desire to record the key data required to enable them to determine the health of their breeding business.

Standardised record keeping, calculation tools, and the business analysis tool (BRICK) developed in the project can be used to determine current production and status of businesses, enabling comparisons with the CashCow project’s calculated *achievable performance* for their land’s capability. If a herd is below the achievable level of performance, reproductive outcomes from the tools can be used to understand the current level of performance, and target areas to improve.

We recommended the extension plan focus on four tiers of target audience:

1. Cooperating CashCow project properties
2. Future beef extension/research staff
3. Northern Australia beef producers
4. Cattle veterinarians and private beef cattle consultants

7.3.1 Application of project outcomes in the northern beef industry

A strong paradigm in the beef industry is that the best measure of a breeding herd’s performance is its pregnancy or weaning rates. As for any class of beef cattle, the primary focus is efficient beef production. Therefore assessing breeding herd performance should focus on that, and use appropriate reproductive outcomes to understand why herd production is at the level it is.

For a business to improve, it must be able to describe its current situation, what are achievable targets for improvement, and changes needed to reach those targets

(**Figure 127**). This is only possible if business data are collected and analysed in a meaningful manner. Data that can be readily collected can describe current business performance, both biologically and financially. More detailed data may describe aspects of under-performance and potential reasons. Economic analyses may then be used to analyse the potential impact if various business practices are to be altered.

Standardised data collection can be used to derive, at both herd and mob levels:

- Annual liveweight production per cow
- Weaner production
- Cows pregnant within four months of calving
- Pregnancy to weaning losses
- Level of risk factors that may affect performance
- Business performance

Questions producers should ask and that CashCow can provide direction on are:

- How much beef is my breeding herd producing?
- What is an achievable level of performance in my environment?
- If performance is not at an achievable level, what is the likely problem?

Data used to derive answers to the above questions are derived from collating information from each sector of a herd. If collected in a simple, organised manner, the same data can be used to assess whole herd and individual mob or management group performance.

A recommended system is mob-based and in its basic form is a hard copy (book) entry system. This makes it available to almost all producers. The specific requirements need to be built and road tested with assistance from major stakeholders and especially beef producers.

The basic requirements to calculate all significant performance and production indicators are as follows:

- A herd description annually at a nominated time for closing numbers. This time must be the same each year. It is easiest and most useful if this date is after the final round of weaning each year, and before any branding of the subsequent year's calves commences.
- Entry of details at any branding, weaning, spaying, purchase, or sale as they occur.
- An annual summary of business income and costs by cattle, labour, depreciation, and variable costs.
- The above data could be stored in an office-based, hard-copy repository called the "**Pink book**". This information could readily be transferred to electronic formats. The above data can also be derived from many available herd performance recording systems
- To enable diagnostics of why performance and production are not reaching achievable levels, and to enhance the ability to produce basic herd performance

data, a supporting “paddock” record system is advisable. The following would be entered into a “paddock” **Blue book**:

- A diary entry for any events of significance that are not recorded elsewhere, e.g., water delivery, pasture management, cattle sickness and injury, cattle treatments.
- A structured record of cattle movements to enhance the ability to maintain a clear understanding of herd structure, numbers and whereabouts.
- Annual reproductive assessment.
- Regular (e.g., water run) pasture assessment.
- Supplementary feeding.
- Diagnostic tests from the environment or animals.
- Routine weather recording, which may be derived from interpolated internet data.

The most complex data systems require computer entry, and use individual animal and site identification. Summary information from data recorded is used to generate some of the tabulated data entry described here, and also produces direct analysis of performance indicators.

7.3.2 Using data to support decision making

In a beef business where there are multiple recorders and users of data, and where access to and use of electronic systems is often not practical, hard copy is a very valuable form for data and information storage. Computer entry of the hard copy achieves back-up for data security, and facilitates analysis. Initial entry of data into electronic formats requires hard copy print-outs.

Data are only useful to collect if it is used to support decision making. Further, if incomplete data are collected, then the effort that went into data collection may be wasted. Therefore, a business must decide which data entry is required to achieve the required data analyses, and then develop the discipline to enter the data as required.

Data analysis can be conducted by anyone with a clear understanding of beef production and business. The data collected may be analysed by simple methods. However, complex electronic systems are required for more advanced analyses that will elicit more valuable output. An example of an intermediate method is the BRICK, developed within this project.

The most basic data required for determining whether a beef business is performing at an achievable level are outlined in **Table 140**. In some instances, these data are already available and simply need to be organised into a suitable and secure format. If not available, then usually at least two years of data may be needed for an initial analysis. Systems to derive the denominator for annual net beef production from breeding herds rely primarily on records of numbers and average weight of each class of animal.

Once a business is described in terms of the environment, and animal and financial performance, the available input and output information can then be used in economic analyses to test “what if” scenarios, e.g., what could be the relative benefits or disadvantages of implementing a defined new management systems. The most common software used for this is BREEDCOW.

8 Discussion and conclusions

This project has investigated the productivity of commercial breeding female beef cows in north Australia and the reasons for its variation. An epidemiological approach was used with ~78,000 cows over three to four years in 72 beef businesses in which the relationships between a comprehensive range of animal and environmental measures with cow and herd performance and production were quantified. The study was limited to females beyond their first pregnancy. The major relationships can guide management that targets the animal and environmental factors with most influence.

A key feature of the project was its focus on both production and performance. The function of breeding beef cattle herds is net saleable liveweight production, the primary income source. Liveweight production in breeding herds is achieved through weaned calves and by cows surviving and gaining weight, which are performance traits and used to indicate where opportunities for improvement exist if production is inadequate. Further, although weaning rate is the most commonly used measure of performance of breeding herds in northern Australia and the most common proxy for herd productivity, it is very common for culling, re-mating, spaying and other decisions to be made during or after mating or at the time of pregnancy diagnosis and these seriously affect the ability to accurately calculate weaning rate. Recognising these issues, the CashCow project has developed a series of new measures of performance and related them to liveweight production.

A second feature of this project is that it has identified achievable levels of production and performance for north Australian environments within the current economic framework. This was taken as the 75th percentile in distributions within land type, thus reflecting underlying nutrition and other inherent environmental influences. The selected level takes account of higher levels of performance occurring randomly, due to uncontrollable events, because of very good management, or because of over-investment to achieve the outcome. Average performance and production of well-managed breeding cows in the recently completed Beef CRC study across the same four land types (unpublished data) was similar to the 75th percentile level in this research, thus providing further confidence that this level of performance is achievable.

Finally, the project has quantified the effects on cow and mob performance of a large range of nutritional, management, environmental, infectious disease, and phenotypic or genotypic factors.

The large variation in all performance and production parameters suggests large land-type and seasonal effects and opportunities to improve for many beef businesses. The project has provided a framework for producers, managers and their advisors to use to investigate the following two questions:

1. How much beef is my beef breeding herd producing
2. Is this at an achievable level given the environment, and if not why not?

8.1 Production

Median levels for liveweight production ratio varied from 0.14 kg liveweight per kg cattle in the Northern Forest to 0.30 in the Central Forest cow herds. Substantial variation occurred, with the achievable level 0.06-0.07 kg/kg of cattle/yr above the median within country type. Achievable liveweight production was 29-37% above the median within country type.

Within country type, weaner production for half the herds was generally within ~25 kg/cow of the median. Achievable weaner production in the Southern and Central Forest is double, and in the Northern Downs >60% higher, than in the Northern Forest. Achievable weaner production and liveweight production were both similar to expected annual steer growth in these country types. This highlights a major project outcome: both weaner and cow liveweight production may be comparable to steer growth in the same situations. This may apply on average, and would be a useful guide through seasonal differences; e.g., in years with poor feed available, achievable production will be lower. Using achievable steer growth may enable adjustment for specific situations within country types, where underlying nutrition is substantially different, i.e., much lower or higher.

Cow growth and survival, percent pregnant, foetal/calf loss, and average weaner weight each explained 20-50% of the variation in liveweight production ratio, thus emphasising the importance of their measurement for beef business evaluation. These figures also indicate that many of these variables are related, and change in one often is related to change in another.

Achievable weaner production may indicate appropriate weaning management. For example, if achievable weaner production is 150 kg/cow, then an enterprise weaning 90% calves (only pregnant cows retained less foetal/calf losses) should ideally aim for an average weaning weight of 167 kg (150 ÷ 0.9). In this situation, if, for example, a higher average weaner weight was required for market reasons, this would generally require extra inputs, such as supplements, and weaner production per cow would be increased. However, in the absence of increased inputs average weaner weight is most often increased by delaying time of weaning, which then increases the risk of a lower proportion of cows becoming pregnant within four months of calving and thus lower subsequent weaner production per cow. Another example is phosphorous supplementation in a deficient situation where 60 calves are weaned per 100 cows retained at an average weight of 160 kg. If the effect was to increase weaner production (parallel to steer growth) by 30 kg annually, then this supports 70 calves weaned per 100 cows retained with an average weaning weight of 180 kg, a 30% increase in liveweight production per cow.

Other than surveys, there are no data of either mortality or reproductive rates at a regional or national level in Australia. A herd modelling approach has suggested that approximately 1 million post-weaning age cattle die before slaughter in Australia annually; that three-quarters of this loss occurs in north Australia and that annual female mortality rates average over 7% in the nutritionally unendowed regions of northern Australia[94]. Several reports for specific situations in northern Australia's nutritionally unendowed regions, which regularly endure climatic extremes, indicate losses can exceed 10% at a herd or individual animal class level[95,96,97,98,99]. Recently, Henderson *et al*. [100] reported cow mortality rates within primarily Northern Forest regions ranging between 4% and 13% per year, and annual losses on individual property ranging from 1% to 28%. Other than region, significant herd-level causes of

[94] Fordyce G and Niethe G, unpublished data
[95] Fordyce *et al* (1990)
[96] Fordyce *et al* (2009)
[97] Jayawardhana *et al* (1992)
[98] Jubb *et al* (1996)
[99] Sullivan and O'Rourke (1997)
[100] Henderson *et al* (2013)

elevated mortality rates were lack of segregation for targeted dry season management, and phosphorous supplementation in cows >10 years of age. They also considered botulism to be a primary cause, but the available data were inappropriate for testing the association between loss and vaccination.

In two case studies investigated in this project (**Table 139**), 5-6% adult animal mortalities reduced the business's operating margin by approximately $0.20/kg of all liveweight produced. Therefore, cow mortalities are a significant issue affecting beef production within breeding production systems in north Australia.

8.2 Performance

Cow production is a function of reproductive performance, survival and growth. Therefore, the focus of this project has been pregnancy during the first four months of lactation (P4M), foetal/calf loss between pregnancy and weaning, cow survival, weaner weight and cow weight. Large variation in commercial herds for each of these has been demonstrated. There was 20-30% variation in reproductive rates and ~10% variation in foetal/calf loss for half the herds in all regions. The distribution in cow herd performance was reasonably consistent across all country types except in the Northern Forest where percent pregnant was considerably lower, and reproductive wastage and cow mortalities were considerably higher than in other regions.

Analysis of publications on the reproductive performance of beef cattle in northern Australia collated to 1989[101] demonstrated that the approximate percentage of breeding cattle data available from the Southern Forest, Central Forest, Northern Downs and Northern Forest was 2%, 27%, 6%, and 65% respectively, which probably represents the relative degree of production 'problems' within breeding herds in these country types. Excluding the Northern Forest annual pregnancy rates that were in the vicinity of 30% higher in previous publications, estimates for median and achievable levels for annual pregnancy rate, foetal/calf loss, and cow mortalities did not differ greatly between reports to that time and the CashCow project findings for the Northern Forest and Northern Downs country types. The differences in annual pregnancy rates between the Cash Cow project and previous publications is likely due to the fact that the latter were primarily derived from research herds, and highlights the value of the CashCow project in demonstrating what is achievable under commercial conditions. A good example of this is if we use the achievable annual pregnancy rate for all breeding females in the Northern Forest (73%; **Table 25**) and the achievable percentage foetal/calf loss for this country type (9.6%; **Table 30**) to derive the achievable weaning rate (63%) we find this is considerably less than many producers would consider is achievable.

8.2.1 Performance: Nutrition

The risk factors found related to all aspects of liveweight production of breeding herds can be classed as related to nutrition, management, environment, infectious disease or genotype/phenotype. The dominant effects are due to the large range of nutritional variables. In this study they included year, country type, body condition score and its change, pasture available, wet and dry season protein adequacy, risk of wet season phosphorous deficiency, delay in follow-up rainfall to a wet season break, age, and month of calving. Not all of these had significant impacts on all performance variables, and this may have been because their effects overlapped partially or

[101] Holroyd & O'Rourke (1989)

completely with other factors; for example, pasture quality will determine, in part, condition score. Therefore, non-significance does not preclude their consideration within a strategy to achieve changes in the parameters that do have significance.

The most limiting aspect of beef cattle reproduction in northern Australia is the ability to cycle in early lactation[102], a primary pre-cursor for conception. A vast amount of detailed research on folliculogenesis has shown that, to achieve early-lactation conception, this 5-month process must start well before calving, and at all stages are sensitive to nutrition[103]. Nutritional influences on cows are mostly expressed as body condition or changes in body condition, thus emphasising its importance as an assessment criterion in managing conception rate. However, some nutritional influences have direct metabolic effects without significant impact on body condition or weight; an example is short-term, pre-calving energy supplementation, commonly referred to as spike feeding that influences early folliculogenesis[104].

Each unit increase in body condition score measured around mid-pregnancy was associated with approximately 12% higher pregnancy rate within four months of subsequent calving, similar to many literature reports, except in the Northern Forest where the effect was 2% pregnant per condition score, but where cows were 36-59% less likely to conceive than cows of the same age and body condition from other regions. This occurred because Northern Forest cows lost more body condition in late pregnancy and lactation than in other regions. Rather than discounting the importance of body condition in the Northern Forest, this research emphasises that management to maintain condition is more important here than elsewhere, as excessive weight loss may lead to both cow and calf mortality. This is underscored by the average mortality in this country type being 6-9% higher than elsewhere.

Weaning and having adequate pasture available to readily satisfy voluntary feed intake are two of the most important strategies in managing body condition. Dry season suckling has been associated with 10-15 kg of liveweight loss per month[105]. Weaning at the end of the growing season is very effective in preserving body condition[106]. As availability of pasture and water is confounded with body condition, these factors did not have independent significant effects on cow pregnancies.

Age effects on percentage becoming pregnant within four months of calving were lowest in the Northern Forest with only 6% difference between first-lactation and mature cows compared to 10-20% difference in other regions. Cows mature skeletally at about 4.5 years of age[107], and continue to increase in weight (at a decreasing rate) at the same body condition score to at least eight years of age. Therefore, the effects of age appear due to more energy being partitioned to reproduction as cows age. This outcome indicates the benefits of segregating pregnant and lactating cows younger than five years for preferential nutritional management.

Although CashCow has been able to provide some potential explanations for the low performance in the Northern Forest e.g. the 7.5% lower percentage P4M when wet season protein levels are low, the fact that country type was a significant factor in all performance measure models indicates that there are factors associated with country type that were either not measured in CashCow or are unknown. There is very

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[102] Entwistle (1983)
[103] Scaramuzzi *et al* (2011)
[104] Fordyce *et al* (1997)
[105] Dixon *et al* (1998)
[106] Sullivan *et al* (1992)
[107] Fordyce *et al* (2013a)

limited research on effects of wet season nitrogen supplementation to breeding cows in northern Australia, but the limited data[108], [109] are consistent with our findings.

The faecal P to dietary ME ratio used in this project as a risk measure of phosphorous deficiency followed the same seasonal pattern as pasture dry mater digestibility. Perusal of average values for each land type suggested the threshold value of 420 mg P/kg ME recommended by Jackson *et al*[110] for lactating cows maintaining weight would be appropriate. However, the method used in analyses was to vary the threshold to find the most discriminatory point; i.e., the data informed the analyses. The result was a threshold of value of 500 mg P/kg ME. Many of the project cows within recognised phosphorous-deficient areas were supplemented with phosphorous, thus complicating the interpretation. Even though the analyses could not indicate a response to supplementation in such areas, P:ME ratio appears to enable a relative risk of phosphorous deficiency to be discerned. In this way, the 25% difference in first-lactation cows pregnant within four months of calving when above or below the wet season P:ME ratio threshold was reduced to 5-10% in older cows. As well, there was a 13% difference in annual pregnancy rates in Northern Forest cows compared to cows in other country types. These findings indicate that strategies to ensure phosphorous adequacy should first target young breeding females (weaning to re-conception after first calving), but wherever possible should also include all lactating cows as these are the animals most at risk of the adverse effects of phosphorous deficiency.

Cows in above-moderate body condition had 3% and 9% lower confirmed pregnancy to weaning foetal/calf loss, when the FP:ME ratio was above and below 500 mg P/kg ME, respectively, than cows in poorer condition when diagnosed pregnant. Northern Forest cows experienced 3-7% higher loss than elsewhere. In the Northern and Central Forest, but not Northern Downs and Southern Forest, foetal/calf loss was 10% higher when P:ME ratio was below 500 mg P/kg ME. The reasons for these effects are unclear, though it may be that milk delivery of calves is limited when diet and body reserves cannot supply adequate energy and fluids; a 35 kg calf needs 3-5 L of milk daily from the day of birth, depending on how hot it is, and a non-suckling calf can lose enough fluids in <2 days under hot conditions to perish.

What is clear is that phosphorous adequacy is a major determinant of cow and herd performance. What is less clear is how to most cost-effectively ensure phosphorous adequacy in specific situations. This is highlighted by the fact that there were some paddocks in the Northern Forest and Northern Downs on properties that did not provide phosphorous supplements where the mob FP:ME ratio was >500 mg P/kg ME. Further, investigation into what contributed to cattle in these paddocks being considered at low risk of the adverse effects of phosphorous deficiency is strongly recommended.

The energy drain of out-of-season calving (July-September) substantially extends post-partum anoestrus, reducing pregnancy rates within four months of calving by 30-60%, except in the Northern Forest where the overall low rates limit the effect to a 10-20% depression in early-lactation pregnancies (to virtually no pregnancies). Cows calving in April-June are also out-of-season and experience intermediate levels of post-partum anoestrus. Out-of-season calving did not elevate foetal/calf loss, probably because the cows calve in reasonable condition at this time of the year; however, lactation causes substantial weight loss and delayed return to oestrus.

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[108] McCosker *et al* (1991)
[109] Fordyce *et al* (1994)
[110] Jackson *et al* (2012)

These effects were also apparent in the Southern Forest where calving is deliberately programmed for July-September, primarily for marketing reasons.

Mortality rates were 2-9% higher if mid-pregnancy body condition score was less than moderate, depending on amount of available pasture. If available pasture was <2000 kg/ha, losses were 5-7% higher. Delayed follow-up rainfall to a break in the season increased cow mortalities by an average of 4%. Mortalities were 6-9% higher in the Northern Forest than in other regions. There was a trend for 1-2% higher cow mortalities if they calved in the April-September period. The magnitude of these effects were not as great as reported by Fordyce *et al*.[111], but the latter occurred under seasonal extremes when overall loss exceeded 20%.

Cow performance in the Northern Forest was substantially poorer than in other country types: 35-60% fewer cows pregnant within 4 months of calving; 6-10% higher foetal and calf loss when the THI was not >79 for at least 2 weeks in the month of calving; 6-9% higher cow mortality rate. The poor performance of Northern Forest cows resulted in much lower impacts of other major risk factors here than in other country types, e.g., the effect of body condition score. The country type effect in the analyses does not inform potential managerial remedial action. However, the primary deficiencies of protein and phosphorous throughout the year are well established. These effects were seen in analyses, but may not have been accurately expressed if some of the effects were shifted to country type. The lack of effect due to supplementation may be partly due to the confounding effect of deficiency and supplementation, and this may have further diluted the real quantum of effect of existing deficiencies. The contribution of higher environmental temperatures was only evident in reproductive wastage, where the levels were usually elevated in all regions to the normal Northern Forest level when there was sustained high THI.

The contribution of low pasture biomass to mortality reflects lower quality feed in many situations as cows will have already grazed off the most nutritious pasture components. However, most importantly, it underscores that production cannot be achieved from nothing. On two properties in this project, a cow mortality rate of approximately 5% with similar loss in steers was associated with a $0.20/kg reduction in business operating margin; therefore, under the very marginal prevailing business conditions in northern Australia, an average of 6% higher mortality due to insufficient biomass will almost certainly cause business loss. The only solution is to manage herd size through pasture monitoring and budgeting to avoid the possibility of inadequate available pasture.

Strategies to achieve a body condition score of 3 or better at the PD muster will improve cow survival, and at the same time, reduce the costs associated with crisis strategies to minimise cow mortalities. These include:

- Weaning management, which heads preventative strategies. Good weaning management targets cow condition conservation as much as calf weaning weight.
- Water quality and distribution to readily satisfy animal requirements and minimise energy expenditure for access.
- Pasture management to achieve adequate nutritional value and access (quantity and distribution) of feed.

[111] Fordyce *et al* (1990)

- Timing mating, if it is not continuous, to avoid dry season lactations, which is a major cause of condition loss.

The combined outcome of improving nutrition on breeding herd productivity can be substantial. An example is that by improving general management (e.g., waters, pasture utilisation, weaning) and achieving phosphorous adequacy could increase pregnancy rates in a hypothetical herd from 75% to 85%, reduce foetal/calf loss from 8% to 6% and reduce mortalities of 500 kg cows from 2.5% to 2%. With only small increases in average weaner liveweight achieved by more conceptions at an optimum time, liveweight production per cow for this herd would increase by 30%. This is the level of difference between the median and achievable levels of liveweight production found.

8.2.2 Performance: Management

Neither manager experience, bull mating percentage, mob size, nor mustering time, method or efficiency had significant effects on the percent of cows pregnant within four months of calving, nor any significant effect independent of nutrition on cow mortality rates. However, mustering within a month of calving and low mustering efficiency were both associated with elevated foetal/calf loss: +2.5% and +9%, respectively. It is likely that both of these associations were due to calf separation from their dams, causing calves to perish. There are clearly obvious benefits in implementing management that avoids mustering breeding cattle around calving.

8.2.3 Performance: Environment

Elevated temperature-humidity index (THI) around calving was associated with 4-7% higher losses, except in the Northern Forest. As for nutrition effects, in some situations, this could be mediated by insufficient delivery of milk to the neonatal calf, and mostly because of increased requirements of calves under hot conditions that may more than double the rate of fluid loss from the typical daily average of 7%. This is the more likely situation in the Northern Forest where high loss always occurs. Higher THI is also associated with higher rainfall, and calving into wet and boggy conditions may cause calves to become hypothermic and or struggle physically to survive. Shelter belts and draining topography may increase survival of neonatal calves when THI is high.

This research found that where wild dogs were considered to be adversely impacting on herd productivity losses were significantly higher, and losses were similar whether baiting or other methods of control were used. This finding is consistent with other independent research[112], and indicates that management of wild dogs be conducted under guidance from experienced ecologists to ensure expected benefits of inputs are received.

8.2.4 Performance: Infectious diseases

This project has confirmed that BVDV (pestivirus) has major impact on cow reproductive performance if exposed at critical times. Infection was widespread with only about 20% of mobs having a seroprevalence <20%, i.e., most cows were naïve in these herds. Evidence of a high prevalence (>30%) of recent infection varied

[112] Allen (2013)

between years, but typically was about 10-20% of mobs. In these mobs foetal/calf loss was 10% higher (P<0.001) than in mobs with a low prevalence of recent infection, consistent with the international and national literature. Also in mobs with a high seroprevalence of BVDV (>80%sero-positive), 23% fewer cows were pregnant within four months of calving than in mobs with a low seroprevalence (P=0.03). Further investigation may determine whether the former mobs were also mobs with a high prevalence of recent infection.

Though BVDV and botulism are considered by animal health professionals to be diseases of major impact in northern Australia, neither was ranked as such in a recent analysis, primarily because of the lack of published evidence[113]. The outcomes from this project, in association with other recent findings may now allow objective assessment of at least BVDV's impact across the region, thereby attracting proportionate RD&E attention.

Although previous BEF virus infection (3-day sickness) was widespread in mobs tested in 2011, there was no association with probability of cows becoming pregnant. Unfortunately, as herd monitoring finished in 2011, the impact of BEF virus infection on foetal/calf loss was not able to be determined.

N.caninum infection was widespread with only about 20% of mobs tested showing no evidence of infection. Similar to the findings from the MLA-funded project B.AHW.0042[114], *N.caninum* infection was not associated with any significant impact on reproductive performance in northern Australian beef herds. It is unclear why Neospora-induced abortions have a high incidence in intensive production systems such as dairy, and not under the extensive grazing systems of northern Australia. Though the previous research showed low horizontal transmission rates, it appeared a majority of infections were either vertical (cow to calf during pregnancy) or occurred prior to first mating; both of these infection sources are related to low abortion rates. The strain of *N.caninum* infecting these cattle could also be of low virulence for the conceptus, though this is not the case within north Queensland dairy cattle populations[115].

The prevalence of Leptospiral infection in unvaccinated herds was surprisingly very low given that in many cases the co-operating properties experienced higher than average rainfall during some stages of the project. Median mob seroprevalence for both *L.hardjo and L.pomona* was typically <20%, with fewer than 10% of mobs showing evidence of recent infection. There was a trend for higher foetal/calf loss in mobs that had evidence of widespread recent infection with the pig-adapted serovar, *L.pomona,* consistent with the findings of previous studies[116].

About 1 in 10 mobs showed evidence of widespread infection with *Campylobacter fetus venerealis* (the cause of vibriosis, also called campylobacteriosis), and in these mobs, infection was associated with a 7% higher incidence of foetal/calf loss compared to mobs with low-moderate prevalence. This was a somewhat surprising finding as this disease is usually associated with early gestation loss usually before pregnancy is confirmed. However, it is not uncommon for herds to be infected with both *Campylobacter fetus venerealis* and *Trichomonas fetus*. In a study conducted in the Victoria River District, 56% of herds surveyed contained bulls infected with one or the other, and occasionally both organisms. Therefore, it is possible that in some CashCow mobs with widespread evidence of *Campylobacter* infection that

[113] Sackett *et al* (2006)
[114] Fordyce *et al* (2013b)
[115] Landmann *et al* (2011)
[116] McGowan (2003); McCool *et al* (1988)

Trichomonas infection was also present and was responsible for some of the observed losses.

Botulism is known to be a major cause of cow mortality across northern Australia. However, 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.

8.2.5 Performance: Genotype/Phenotype

Breed (percent *Bos indicus*) was not a significant influence on any performance parameter studied. This may have been because what is perceived as a breed effect is usually associated with a trait that is prevalent at different levels across breed, e.g., hip height. There was a trend for females with <50% *B.indicus* content to have a higher percent pregnant within four months of calving than females with >75% *B.indicus* content, consistent with the findings from Beef CRC III.

Tall cows were found to have 5% lower pregnancy rates during lactation and 4% higher foetal/calf loss than short cows, respectively. The reasons for this are unclear, but may relate to partitioning of energy by larger cows that are the result of heavy bias towards selection for growth, and little selection applied for reproductive success. Beef CRC research has previously shown that early-life growth is unrelated to reproductive traits[117]. Mature size is not the same as early-life growth even though they may be correlated. If selection practices continue to increase mature size as they have, this effect may increase. Alternatively, active selection for reproductive success may counter the correlated negative effects caused by selection for large mature size.

Re-mated cows that did not lactate in one year experienced 4% higher foetal/calf loss in the subsequent year; the effect was double this in second-lactation and aged cows. This indicates some repeatability of this trait. If pregnant cows fail to wean a calf, they should be culled if there is evidence for the reason causing loss, e.g., poor udder or teat conformation, or it is clear that any re-conception will not result in a profitable outcome for that cow.

8.2.6 Variance explained by multivariable models

Multivariable models all followed a similar general pattern with a single outcome variable (such as whether or not a cow became pregnant in a particular breeding period), and multiple explanatory variables (such as body condition score of cows, nutritional measures of pasture quality, cow age class). The general analytical aim was to produce a parsimonious, explanatory model that could be used to identify major drivers influencing the outcome of interest and in turn inform extension messages to producers to improve key performance indicators on their properties.

One way of assessing the explanatory power of a statistical model is by estimating the amount of variance in the outcome that is explained by the model. These measures are generally expressed as the proportion of total variance in the outcome that may be explained by the model.

While it may seem logical that a model that explains a higher proportion of the total variance may be considered in some sense to be better than a model that explains a

[117] Johnston *et al* (2009)

lower proportion of variance, there are some problems in this approach. Such comparisons can really only be made with confidence when the models being compared have identical outcome variables and differ only in the explanatory variables. In situations where different models have differing variability in the outcome variables, estimates of the proportion of variance explained will differ even if the relationships between the explanatory variables and the outcome remain the same in the different models.

A study that is conducted under controlled conditions (selection of animals based on similarity in origin, breed, age, sex, management practices etc.) has the capacity to reduce variability in measurements of both outcomes and explanatory variables, and explanatory variables under more controlled conditions may explain relatively more of the variation in an outcome. In contrast, an observational study where animals may be sourced from a wide variety of properties, and of any breed, age and sex, is likely to have more variability in any measurements. Even if the same measurements were then made on animals from these two different study types, it is likely that the resulting statistical models would produce different estimates of proportions of variance explained.

It is important to note that it is not necessarily a requirement that a multivariable model explain a high proportion of variance in the outcome in order to identify interventions that may have important practical impacts in the real world. A statistical model may account for relatively little of the total variance in a particular outcome and yet still identify important drivers of the outcome and inform practical recommendations that producers can apply to improve productivity and profitability.

The statistical models developed in this study may be described as explanatory models and not as predictive models. The distinction is important. Explanatory models are used to test or develop theories about causal associations between potential explanatory variables and a specific outcome. Statistical associations in explanatory models are then used to develop causal hypotheses (this factor is likely to influence the outcome) which in turn can be used to produce practical recommendations (producers should apply these management changes to influence the outcome on their properties). The associations in explanatory models have to be able to be understood in a causal sense so they can be used to inform future interventions. The practical impact of these characteristics is that explanatory models are often simpler and do not include complex interactions or large numbers of variables because such things make the models so complex they cannot easily be interpreted. The general aim is to produce a final model that only includes the major explanatory factors and interaction terms are often limited to two way interactions (interactions involving only two variables).

Explanatory models are generally used to improve our understanding of the factors that can influence an outcome (such as pregnancy rate in beef cows). This then leads to recommendations, such as optimal times to mate, when to wean, how to manage nutrition to ensure optimal condition. Part of this process often includes predicted means for different groups or explanatory variables to help users understand the interpretation of the findings of the model.

In contrast, predictive models do not have to be understood, and may in fact be so complex that they are often referred to as black-box models. The usefulness of predictive models is in predicting the outcome given a specific set of future measurements. As an example, imagine a situation where a producer might sit at a computer and enter a number of specific pieces of data about one cow and a range of other factors (breed, age, sire measures, dam measures, past fertility and calf production, time of year, days since calving, lactation status, weight, body condition score, dentition, faecal analyses, pasture quality, rainfall, temperature, latitude and longitude, date and a range of other factors). The producer has no need to understand the mathematical associations in the model or how it works. The model takes the input data and applies some mathematical algorithms that may include components of random variability and produces an estimate of probability of that individual cow producing a calf from that mating.

In summary, our approach has been to develop parsimonious explanatory models to help identify and understand the major drivers for selected outcomes and to inform the development of management strategies to improve performance. We have measured the proportion of variance explained for each model and the results of these measures, while relatively low, are consistent with findings from other observational studies.

8.3 RFID technology in data collection

This project relied on ear tag RFID technology for data collection. However, despite its huge advantages, it was limited by the level of tag loss. Annual loss averaged approximately 2%, 3% and 4%, after the first, second and third years of tagging, respectively.

Rectifying this problem is an urgent research challenge if the use of this technology beyond the requirements of health regulations is to continue and be supported by beef producers and scientists.

8.4 Standardised herd performance recording

To take advantage of the findings of this project and other research outcomes relevant to breeding cow herds in northern Australia, a beef business must have an understanding of current production and performance of herd sectors, so that the cost-benefit of applying changes can be accurately gauged and efficiently implemented. This relies on herd performance recording. Currently, only a small minority of business have adequate performance recording to derive production and performance parameters.

As part of the project we have devised a herd performance recording system that involves annual collation of data from each sector of a herd in a simple, organised manner to assess whole herd and individual mob or management group performance and production. To calculate all significant performance and production indicators requires office records:

- Annual herd description at the end of the cattle year. Data required are numbers and average weight (even if this is estimated) for each gender x age group.
- Gender, weights and values at any branding, weaning, spaying, purchase, or sale as they occur.
- An annual summary of business income and costs by cattle, labour depreciation and variable costs.

The above data, especially over several years, enables calculation of KPIs using various software, most of which has been developed by beef business advisers. Operating margin—a key index that explains a very high percentage (82%, Phil Holmes, pers comm) of the variation in beef breeding business profitability—was able to be readily calculated using the herd. Outputs of analyses show the complexity in conducting and understanding beef business. If an accurate understanding of current production and performance is not available, then management decision errors can be made.

8.5 Recommendations for future RD&E

RD&E recommended	***Because***	***Potential impact***
Secure RFID attachment to cattle	2%, 3% and 4% loss in the 1st, 2nd and 3rd years after tagging	More devices placed at branding. More reliance for automated performance recording
Standardised herd performance recording at a mob level	No current relatively-simple way to assess breeder herd performance	Through simple systems, business owners can analyse their performance and identify problems
Risk factor (e.g., supplements / nutrient deficiency) impacts on herd performance parameters such as liveweight production ratio	No direct understanding on overall productivity is known other than through modelling	The economics of remedial action in specific situations could readily be tested
Achievable KPIs within country type	Without financial information, current levels have been simply nominated as the 75 percentile level	A clear understanding of achievable performance could be developed, built on widespread standardised herd and business performance recording
Testing the use of annual steer growth as a guide to achievable cow herd liveweight production	Preliminary results suggest this is a suitable guide, but further controlled testing and demonstration is required to have confidence in recommending this.	A simple guide will be available for commercial producers to set achievable production within specific situations.
Elucidating the specific problems causing diminished cow performance in the Northern Forest, and developing remedial management	There are clearly huge cow performance problems in the Northern Forest that need more specific elucidation to deal with	May provide much clearer direction for how liveweight production can be more profitable in this region
Application of genetic improvement to improve cow herd performance, including managing the tall cow problem	Part of the large variation in performance is clearly related to genetics, and practical systems to apply genotype changes are needed	Accelerated change may enhance the opportunity for beef businesses to remain profitable
Wet season protein effects on wet cow	Despite the clear effect seen in this research, there has	The use of wet season supplements may be

RD&E recommended	Because	Potential impact
pregnancies	been very little previous research on this in cows, and a need to assess efficacy of remedial action	better targeted
Understanding the high calf wastage in the Northern Forest, and developing remedial management	Foetal/calf loss is very high. The process by which extra calves perish is not understood, and must be if remedial management is to be developed	It may be quite possible to reduce loss in the Northern Forest by an average of 5% by using targeted management
Developing mechanisms to quantify the economic impact of risk factors on herd performance in specific environments	This process is quite complex and time consuming and needs professional input to best quantify impacts based on outcome produced by the project	Robust guidelines for beef business to assess the impact of adopting different management practices
Robust indicators of protein and phosphorous deficiency	These deficiencies are clearly widespread, but not so readily diagnosed, thus managed	Reliable diagnoses of primary deficiencies
Understanding pathogenesis and management of vibriosis	The high loss associated with vibriosis was not in line with the standard understanding of this disease	A clear understanding of best practice control methods for vibriosis and the likely cost-benefit
Cost effective strategies to manage delayed follow-up rainfall to a seasonal break	This was associated with 4 percentage points increase in mortality, with no obvious solution other than expensive energy supplementation	Costed options would be available for producers to consider in managing delayed follow-up rainfall
Demonstrating management systems that reduce cow mortality rates	Cow mortality rate was clearly very high in the Northern Forest, and risk factors indicated how it may be managed	Higher returns to beef producers with fewer cows dying

8.5.1 Research priorities for ancillary factors

Although the project team attempted to establish a collaborative project to evaluate the impact of wild dogs on breeder herd performance funding was not granted. However, a crude estimate of the impact of wild dogs was able to be derived from the foetal/calf loss model indicating that where dogs were considered to be adversely affecting production, foetal/calf losses were 5 to 7 percentage points higher than when they were not present. The critical issue was that use of recommended methods of controlling wild dogs did not appear to reduce the incidence of losses (as has been previously reported). This is a very complex issue and much further work needs to be done to determine how this impact can more effectively be controlled.

The CashCow project has clearly demonstrated the impact of wet and dry season nutritional status on reproductive performance, but the impact on performance of use of various supplements, although investigated, was inconclusive. Further research is required to determine how to achieve an adequate energy, protein and phosphorous status. Comparisons between management and resource of properties with an adequate versus inadequate status would be invaluable as the impacts of these nutritional factors on herd performance were generally large. CashCow has demonstrated that the females at greatest risk of the adverse effects of inadequate phosphorous status are first-lactation cows. Similar to the situation in people, research needs to focus on how to develop 'healthy bones' in young replacement heifers to enable them to later be able to maintain phosphorous homeostasis by mobilising bone reserves of phosphorous. Further, the observed interactions with body condition score suggest that muscle reserves of phosphorous may play a greater role in maintaining phosphorous homeostasis than previously recognised.

8.5.2 Further research to define impact

Change in liveweight of cows over a one year period spanning a cattle year still requires analysis. This outcome is a component of liveweight production.

The models for percentage pregnant within four months and percentage foetal/calf loss both found that tall cows had poorer performance than short cows. Whether this difference is primarily due to the frequency of the physiological impacts of gestation and lactation or is due to inherent difference in fertility needs to be further investigated.

Although performance of mobs in the Northern Forest was generally much lower than that achieved in the other three country types, there was considerable variation. While CashCow has identified the major factors affecting performance across the population of properties studied, we have not specifically examined the differences in these factors between herds in the upper and lower 25% for the key measures of reproductive performance and beef output. Further, we have not described the differences in resource and property management between these two categories of properties. A combination of further analysis of the CashCow database and face to face interviews with co-operating producers at the time of meeting to discuss individual property performance could readily provide the data required to evaluate these differences.

Period of calving significantly affected likelihood of cows becoming pregnant and risk of missingness, and in the VRD case study, profitability. There appears to be potentially significant benefits in managing heifers and cows such that the majority calve during an 'optimum' period. However, further work needs to be done to assess the economics of altering the calving pattern of a herd and to compare the strengths and weaknesses of different management strategies which could be employed to achieve this.

8.5.3 Ongoing reproductive performance monitoring

Although it is now over two years since the last crush-side data were collected and some impetus to continue this work has been lost, the feedback that the project team has received is that many CashCow producers would be prepared to continue to monitor the performance of selected mobs as it provided them with accurate data on how their cattle were performing. Further, during the course of the project several pastoral companies implemented their own systems for crush-side data collection of breeder performance.

The establishment of ongoing monitoring of performance of commercial breeder herds is critical to enable evaluation of the response to implementation of various management strategies designed to address the major factors affecting performance identified in the CashCow project. An example of performance monitoring against the CashCow estimates of achievable performance by country type is presented in **Appendix XVII**. This highlights the critical importance of monitoring cattle over consecutive years (minimum three, preferably six consecutive years) to obtain a true estimate of performance. Performance monitoring could be done at several levels. As is outlined in Section **4.5.4** weaner production—which simply requires recording numbers of calves weaned and weighing of a cross sectional sample of calves at each weaning round—provides a very good estimate of annual net beef production; this could be the base level of herd monitoring. The next level of monitoring would be those herds able to collect the data to input into the BRICK. Finally there is likely to be a group of producers who would be prepared to collect both the data required for the BRICK and the crush-side data required for detailed analysis of reproductive performance. However, the northern beef industry will need to identify the means by which those producers willing to participate in this monitoring program receive some compensation for the time and resources they invest in this initiative.

Further work needs to be done to incorporate the analytical tools developed to conduct the CashCow analyses into existing and future software programs for herd monitoring. In addition, further work needs to be done to improve the ease and accuracy of crush-side data collection to facilitate greater adoption by producers.

8.6 Operational outcomes from the project

The commercial data collection and summary service used (Outcross Pty Ltd) was successful within the extensive northern beef industry. The company implemented electronic data collection at the crush side, archiving of data across musters for individual animals and summary reporting of aggregated data. They developed a network of operators and liaised with veterinarians and producers to cooperate in data acquisition and management.

This was a large multi-site research project using an epidemiological method that involved the industry in its development, conduct and interpretation. Explanation of research processes, development of data collection tools and feedback on progress, results, and implementation were incorporated into the project through a series of producer meetings and individual discussions. Ownership of the project and its findings has been enhanced among producers by these processes.

Producers’ perspectives on research were included in the design of CashCow. The research has been carried out in a way that is feasible for producers but has retained scientific rigour in its design and analysis. Findings are directly relevant to the producers who participated and can be extrapolated more widely to the northern industry.

The research team has developed skills in multi-site epidemiological research on commercial properties where the emphasis has been on observing and measuring the real situation rather than attempting to change the reality. This has enabled the findings to quantify performance and set achievable targets for the industry. The acquired skills will be invaluable in future research and training.

Terminology for many measurements and outputs in the industry are confusing and contradictory. The research team has produced definitions and descriptions for a common language to enhance future communication.

8.7 Success in meeting objectives

All of the project objectives were successfully met, which is a testament to the combined commitments of the co-operating producers/mangers and their staff, the Outcross data collection team, the supporting diagnostic laboratories, and the CashCow project team.

8.8 Conclusions

The main conclusions from this very large project include:

- Achievable production and performance for the main country types used for beef cattle breeding in northern Australia have been defined, and it may be that annual steer growth in specific environments is a key indicator of achievable liveweight production per hectare from breeding herds.
- The large variation in production and performance suggests there is potential for many businesses to improve. Further, an understanding of prevailing and achievable performance in a specific environment and season enables a business to tailor management.
- A simple mob-based herd performance recording system was devised that produces the primary data needed to derive herd productivity and performance parameters, necessary in management decision making.
- The dominant effect of nutrition on cow performance indicates that targeted rangeland and animal management augmented with strategic supplementation are key elements of efficient cow herd management. Major nutritional impacts, some of which is mediated by body condition, were caused by phosphorous adequacy, available pasture, and seasonal conditions.
- Foetal and calf loss is high for many businesses across northern Australia, and is consistently high in the Northern Forest. The risk factors associated with increased percentage loss suggest that calf viability and suboptimal or complete failure of suckling as a result of cow, nutritional, and environmental factors are likely to be major causes of calf loss.
- All elements contributing to reproductive potential are severely compromised in the Northern Forest. This indicates that breeding cow performance RD&E in this region should maintain a high focus on non-genetic effects such as weaning, waters, supplements, disease management, and enhancing the calving environment.
- BVDV (pestivirus) has significant impacts on performance of cows exposed at critical times. Likewise with vibriosis, though the specific reason for the observed impact needs further investigation. The impact of botulism could not be assessed. In light of the projects' findings and professional opinion, best-practice control measures should be maintained or implemented across the region for all three diseases.

- Large mature size was associated with diminished reproductive performance. Attention to both reproductive traits and to mature size in selection of replacement breeding animals is required to overcome this.
- Suggestions for extension and research based on the outcomes from this project have been provided.

9 Extension

9.1 CashCow publications

Cooper A, Hedlefs R, McGowan M, Ketheesan N, Govan B (2011). Serological evidence of *Coxiella burnetti* infection in beef cattle in Queensland. *Australian Veterinary Journal* **89:** 260-264.

Cowley T (2012). Modelling the profitability of different calving periods in northern Australian breeding operations targeting the 350kg live export market. Master of Rangeland Management Thesis, *The University of Queensland, Gatton, Australia*.

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McCosker KD, McGowan MR, O'Rourke PK, Smith DR, Fordyce G, Burns BM, Joyner D, Phillips N, Menzies D, Newsome T, Perkins N, Morton J, and Jephcott S (2011). CashCow – exposing northern breeder herd productivity. *Proceedings of the Northern Australian Beef Research Update Conference,* p19-23.

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CashCow newsletters (**Appendix IV**).

9.2 Presentations and media releases

- Kidman managers conference November 2012 (Alice Springs)
- ILC managers conference February 2013 (Adelaide)
- Australian Agricultural Co Leaders forum (February, 2013)
- Consolidated Past Co managers conference (January 2013)
- Australian Cattle Veterinarians Annual conference (June 2013)
- Queensland Country Life (2009, 2012)
- Beef Central (2012)
- Beef 2012
- NBRUC 2011
- Frontier

9.3 Capacity building

Postgraduate training – Kieren Mccosker (PhD), Trisha Cowley (MSc), Ricardo Soares (European College of Veterinary Public Health and Epidemiology residency project), Megan Schibrowski (PhD), Alana Cooper (PhD), Whitney Dollemore (MSc).

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Appendices (supplied on request)

Appendix I. Evaluation of the accuracy of foetal ageing by co-operating cattle veterinarians

Appendix II. Roles of each member of the Cash Cow project team

Appendix III. Evaluation of the accuracy of assessment of body condition score by the Outcross data collectors

Appendix IV. Example of CashCow newsletter

Appendix V. Analysis of selected Beef CRC III and commercial property data used to inform design of CashCow analyses and measures of reproductive performance

Appendix VI. Nutrition report provided to CashCow producers

Appendix VII. Example of NIRS data collection sheet accompanying NIRs samples

Appendix VIII. Examples of Pregnancy Test Report, Wet & Dry Report and Weaning Report sent to cooperating producers

Appendix IX. Details of animal-, analysis mob- and property-level risk factors used in statistical analyses

Appendix X. Summary of observed intercalving intervals

Appendix XI. Example Management Survey

Appendix XII. Factors affecting P4M – final model

Appendix XIII. Estimated weight gain required for a female to gain 0.5 BCS

Appendix XIV. Factors affecting annual pregnancy rate – final model

Appendix XV. Factors affecting the percentage foetal/calf loss – final model

Appendix XVI. Factors affecting the prevalence of missingness (mortality) in breeding beef cattle in northern Australia

Appendix XVII. Excerpt from CashCow report to co-operating producers benchmarking performance of their enrolled mobs