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Review of Aspects of Breeding Herd Performance
from Beef Cattle Projects on the Arid Rangelands
of the Alice Springs District

by
Jocelyn Coventry BSc, BVMS, MACVSc

This thesis is presented for the degree of
Master of Philosophy,
of Murdoch University, WA
in the year of 2013
DECLARATION

I declare that this thesis is my own account of my research.

The main content is based on review of data from three primary beef cattle projects.
Published and unpublished reports from these primary beef cattle projects have been cited where used for summaries and analyses.

(Jocelyn Coventry date)
To effectively record the variability that is a feature of beef cattle herds on arid rangelands, sustained periods of objective data collection are required. This has been infrequently achieved on pastoral properties in the Alice Springs district of the Northern Territory. In this thesis, historical data are analysed from three primary beef cattle projects with breeding herds north of Alice Springs. Each of these projects involved data and sample collections during a 4- to 5-year period. Publications from each project were reviewed to identify summaries on breeding herd performance and gaps in data analyses. Where gaps were identified and data were available, new summaries and analyses were undertaken. The results of those analyses enabled comparison with existing knowledge about beef cattle production on arid rangelands, and provided new information on reproductive performance, mortality, nutritional deficiencies, infestations and infections in continuously-mated herds of the Alice Springs district.

Information on reproductive performance and mortality was provided for different age and gender groups respectively. The aged cow group had the highest percentage of conception losses before branding (10.3%). Heifers had the highest peri-/post-natal conception losses (4.5%), with suspected dystocia and mortality in up to 20% of some heifer groups. For lactating individuals in ‘forward store’ body condition at muster, the pregnancy percentage of heifers (45%) was similar to that of other cow age-groups (48–53%). Extrapolated (unconfirmed) annual mortality was 6.5% in herd bulls and up to 3.1% in cows.

Information on specific cattle health issues was provided about potential dietary deficiencies in phosphorus (P), vitamin A and nitrogen (N), as well as about intestinal parasite infestations and infection with bovine viral diarrhoea virus (BVDV).

Phosphorus deficiency, as defined by serum P (≤ 1.1 mmol/L) and faecal P (≤ 0.19%),
was associated with low rainfall, dry grass, absence of pasture germination, landsystems with low soil P, and lactating or aged cows. Sub-optimal levels of serum vitamin A (< 0.26 mg/L) were associated with dry seasonal conditions, low body condition and aged cows. A fall in cattle nutrition based on faecal N below 1.23% was related to the presence of lactation and pasture germination. Clinical intestinal nematodiasis (faecal egg counts over 700 eggs per gram) in weaned calves was correlated with a large rainfall event after a long dry period. In one herd endemically infected with BVDV, individual cows became seronegative during a 3-year period.

Results of the thesis study provided benchmarks to establish and validate measures of cattle health and reproductive performance in the Alice Springs district. Regional reference ranges were established for albumin (cows: 32–43 g/L) and haemoglobin (cows: 125–153 g/L). Averages over 3- to 5-year periods were provided for annual branding (range: 64–87%) and weaning (range: 79–84%) percentages. The highest mean annual number of branded calves per herd bull was calculated at the lowest examined bull percentage (24.6 calves at 4.1% bulls). The average weight of weaned calves per 100 kg of mated cows was established under varied herd and seasonal conditions (range of averages: 37–64 kg).

The challenges of collecting and analysing data from extensively-managed cattle herds can necessitate the use of default measures, extrapolations and estimations. In this thesis, the use of default measures helped to define conception losses, measures of body mass-at-conception, annual mortality, arid rangeland pasture conditions for ‘optimal’ cattle nutrition, variable seasonal conditions, and diseased sub-groups.

In summary, this study contributes to the knowledge about cattle grazing on arid rangelands. The key contributions are in the analyses that establish and validate benchmarks, as well as in the discussions on reproductive performance and ‘best practice’ management.
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### ABBREVIATIONS

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<td>Australian Bureau of Agricultural and Resource Economics and Sciences</td>
<td>ABARES</td>
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<tr>
<td>agar gel immunodiffusion</td>
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<td>aspartate-A-transferase</td>
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<td>Australian agricultural and grazing industries survey</td>
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CHAPTER 1. INTRODUCTION

SECTION 1.1. BACKGROUND TO THE PRESENT STUDY

Australian rangelands occupy arid or semi-arid regions with average annual rainfall below 350 mm. This supports native vegetation for the extensive grazing of livestock (Miegs 1958) and constitutes a key resource for beef cattle production. On arid rangelands, most activities for cattle production focus on the management of breeding herds. Factors affecting production include deaths, disease, reproductive failure and the regional aspects of climate, vegetation and water distribution. Profitable beef production and sustainable grazing of cattle on the arid rangelands of central Australia requires knowledge and research from the arid region rather than from other (temperate and tropical) regions of Australia. As an example, the effect of arid rangeland aspects on cattle metabolism and nutrition creates a need for local (regional) reference ranges to assist in the interpretation of laboratory investigations. The lack of objective information about beef cattle performance in the Alice Springs district of the Northern Territory has been noted during the past 40 years (Box & Perry 1971; Hasker 2001, p.31; Holroyd & O’Rourke 1988). Other than survey and ‘local consensus’ data on average breeding herd management and performance in the district (GRM International 1987; Leigo c. 2006; NT-DPI&F 1994a,b,c; 1995a,b,c; Oxley et al. c. 2006; Petty, Holt & Bertram 1979), original publications have generally been limited to reports on single issues such as liveweight gain (Low & Wood 1979), water medication (Hill 2003) and heifer conception (Schatz 2011).

Prospective herd studies over a minimum period for collection of basic biological data (3–5 years), as per Holroyd and O’Rourke (1988), have rarely been conducted on beef cattle properties in the Alice Springs district due to the physical and logistical challenges associated with remote locations and extreme environmental conditions. Consequently any studies that have been completed are both unique and valuable.
CHAPTER 1. INTRODUCTION

This thesis presents a study based on the review, summary and retrospective analysis of data or laboratory results from three primary beef cattle projects. These projects had been undertaken within a 32-year period (1970–2001) on properties north of Alice Springs. Analyses for the thesis have provided a point of reference for cattle research, plus benchmarks of breeding herd health and performance under the conditions of the primary beef cattle projects. The academic contribution of this thesis lies in these analyses, which have been undertaken exclusively for and reported in the present study’s results.

Discussion of the present study’s findings has been supported by reference to, and comparison with, findings from other studies on arid rangelands of Australia, Africa and the Americas. In the following chapter, core activities and known limitations for beef cattle production in the Alice Springs district are detailed and contrasted with aspects of beef cattle production on comparable arid rangelands. The limited refereed literature for this area is supported, where available, with data from publications (information sheets, newsletters or reports) and internal reports by relevant scientific research and extension organisations. Together with regional survey and ‘local consensus’ data, many of these sources have had limited critical review.
CHAPTER 2. REVIEW

SECTION 2.1. CATTLE PRODUCTION - ALICE SPRINGS DISTRICT AND COMPARABLE ARID AREAS

2.1.1. Natural Resources

2.1.1.1. Location and Climate

The Alice Springs district of the Northern Territory is situated in the centre of Australia and surrounds the township of Alice Springs (latitude: 23.7°S, longitude: 133.9°E, elevation: 548 m) (Figure 2-1). The pastoral area of approximately 300,000 km² (Bastin, Shaw & Dance 1998) is a component of Australia’s productive arid rangelands (Hacker, Beurle & Gardiner 1990; Low 1978a) and is used to extensively graze livestock. Beef cattle properties of the district extend 300 km to the north (21.5°S) and to the borders of Western Australia (129°E), Queensland (138°E) and South Australia (26°S).

The Alice Springs district, together with the Pilbara region of Western Australia (the Pilbara) and the south-west region of Queensland (south-west Queensland), satisfies the Koeppen climate classification of an arid area (Stern, de Hoedt & Ernst 2005) and is representative of the arid region of northern Australia (Clarke 1991, p.1; Perry 1962, p.11; Thomson 1999, p.4; Wilson 1977).
Comparable arid regions are also found in south-west Africa, in south-west United States of America (USA) and in northern Mexico (Peel, Finlayson & McMahon 2007). These latter regions include arid areas in the Northern Cape and North-West provinces of South Africa, in the Central and Southern regions of Namibia, in the USA states of Arizona, New Mexico and Texas, and in the Mexican state of Chihuahua.

The variation in seasonal and diurnal temperatures in the Alice Springs district is wide, as indicated by the range in long-term mean monthly minimums and maximums at the Alice Springs Airport for January (21.5–36.4°C) and July (4.1–19.7°C) (Bureau of Meteorology 2012a). Summer temperatures often exceed 38°C for long periods and frosts can occur for several consecutive days in winter (Bertram, Oliver & Dance 1996). The elevated daily temperatures effect a high rate of evaporation (Miegs 1958), which averages 3,000 mm for a 1-year period and is over ten times the long-term mean annual rainfall of 285 mm. Rainfall in the district is erratic and the annual average is low, varying between 100 mm in the south-east to 350 mm in the north (Bureau of Meteorology 2012b,c; Roeger & White 1996). Approximately 65% of annual rain falls between November and March (Roeger & White 1996) and a large proportion is often derived from one or two significant rainfall events (Roeger & White 1996; Whittem 1964). Historically there has been an average of one year in four of generalised, non-seasonal drought (dry year, poor year) in the Alice Springs district (Foran 1984; Roeger & White 1996). This has been associated with a persistent absence of effective rainfall for substantial pasture growth (NT-DPI&F 1999a). Effective rainfall is defined as 25 mm with 25 mm of ‘follow-up’ rainfall (Perry 1962, p.121). Where rainfall is especially low and irregular in the southern half of the district, both winter and summer rainfall is important for pasture growth. In the northern half of the district, rainfall is increasingly summer-dominant, so winter rainfall is relatively unimportant for pasture growth (Perry 1962, p.258). Non-seasonal drought has also been a feature of arid areas

2.1.1.2. Land, Soil and Water

The landform and soil features of the Alice Springs district range from deserts to lowly fertile soils (Perry 1962, p.13). Many landsystems have a substantial deficiency in soil nitrogen (N) and phosphorus (P) (Foran 1984; Williams 1979). Soils of other arid lands have specific regional deficiencies, for example, soils of Namibia are deficient in major nutrients and micronutrients such as manganese (Mn), iron (Fe) and zinc (Zn) (Sweet, Burke & Reynolds 2002), and some soils of Arizona are believed to be deficient in copper (Cu) and selenium (Se) (Sprinkle et al. 2006). Arid rangelands are located close to major recognised deserts in south-west Africa (Namib and Kalahari deserts), south-west USA and northern Mexico (Sonoran and Chihuahuan deserts), as well as in Australia (e.g. Tanami, Simpson, Sandy, Gibson and Strezlecki deserts).

In the Alice Springs district there is little permanent surface water and the sub-artesian groundwater is of varying quantity and quality (NT-NRETAS 2012a,b). Groundwater is also a key resource in Namibia (Sweet 1998), northern Mexico (Estrada et al. 2002) and south-west USA (Nabhan & Taylor 2004). Access to water with deep boring technology on the arid rangelands of South Africa has enabled establishment of commercial grazing (Palmer & Ainslie 2002). Where access to water has been limited during drought conditions in Arizona, this has necessitated importation of livestock water (Eakin & Conley 2002).

2.1.1.3. Vegetation

The relationship between arid rangeland vegetation and beef cattle production is determined by rainfall, temperature (Ross 1976), land condition (score) (Chilcott et al. 2005) and the type of landsystem (Bastin, Shaw & Dance 1998; Freidel & Squires 1983;
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Perry 1962, p.14). In the Alice Springs district, these influence the availability, digestibility and nutritional value (Siebert, Newman & Nelson 1968) of the native pasture (perennial and annual grasses, forbs, herbage) (Bastin, Shaw & Dance 1998; Perry 1962, p.209), introduced buffel grass (*Cenchrus ciliaris*) (Bohning 1997; Kok, Collopy & Stretch 1987) and topfeed (edible trees or shrubs) (Askew & Mitchell 1978; Bastin 1998; Squires 1981, p.46). The presence of topfeed is also an important part of the diet on the arid rangelands of south-west Queensland (Clarke 1991, p.18), south-west Africa (Palmer & Ainslie 2006; Sweet, Burke & Reynolds 2002) and south-west USA (LeViness 1993; Sprinkle, Grumbles & Meen 2002).

Erratic rainfall on arid rangelands characteristically produces rapid, but short, periods of localised plant growth (Bertram, Oliver & Dance 1996; Western & Finch 1986). Winter rain in the Alice Springs district can produce good quality growth of forbs that dry off quickly and leave little standing feed, while good summer rain can produce growth of grass with potential for a standing feed reserve of up to 800 kg per ha (Bastin, Hyde & Foran 1983; Roeger & White 1996). However, the high annual variability in production of pasture dry matter (DM) (< 250 vs. > 2000 kg DM per ha) on Australia’s rangelands is a major source of risk for herd and pasture resource management (Squires 2006). Variable forage production capacity has also been described for the cold and hot deserts of south-west USA and northern Mexico (100–1,300 kg per ha) (Huntsinger & Starrs 2006).

Grass-growing rain can also produce as much tree foliage as grass (Winkworth 1983). On the arid savannah of south-west Africa, a biomass of shrubs and trees that can exceed 16,000 kg per ha has been cited (Palmer & Ainslie 2006). In the absence of further rain, arid rangeland vegetation dries and decreases in palatability, DM digestibility (DMD) as well as nutritional value (Bertram, Oliver & Phillips 1996). Fall in pasture crude protein (CP) to less than 6 to 6.25%, where it is insufficient to maintain
liveweight, has been noted for arid rangelands in central Australia (Phillips 2000),
south-west Africa (Hudson 2002, p.47) and south-west USA (Sprinkle 2001b). Dietary
DMD relates to metabolisable energy (Wilson 1974) and decreases with increasing
levels of dietary fibre and tannins. When DMD is below 41%, it is difficult for cattle to
consume enough to maintain liveweight (Shrubb 2000).

Areas of northern Australia with acute deficiency in available soil P (< 4 ppm)
(McCosker & Winks 1994, pp.2-4) include lands with spinifex (*Triodia* spp.) and mulga
(*Acacia aneura*). Deficient soils (< 6 ppm available soil P) have been recognised over
65% of the Alice Springs district (NT-DBIRD 2004, p.99). In general, landsystems with
poor fertility (spinifex sand plains, dune fields and plains, mountains and hills, salt
lakes) are incapable of carrying livestock in most seasons (0–1.5 head per km$^2$). In the
case of mulga woodland, this rangeland pasture-type is suitable only as ‘drought
reserve’ or for grazing cattle at low stocking rates (1.2–2.3 head per km$^2$) (Bastin 1989;
Bastin, Hyde & Foran 1983). Landsystems with better fertility, such as those with
(Barley) Mitchell grass (*Astrebla pectinata*), may carry up to 8 head per km$^2$ (Bastin,
Shaw & Dance 1998). Arid rangelands have similar carrying capacity in South Africa
(equivalent: 2.5–3.3 large-stock units per km$^2$, where one large-stock unit equals 450 kg
liveweight) (Palmer & Ainslie 2002). Arid rangelands have more variable grazing
capacity in northern Mexico (equivalent: 4–16 animal units per km$^2$, where one animal
unit equals 454 kg liveweight) (Gonzalez Gonzalez 2006, pp.31,34) and in south-west
USA (equivalent: 1–16 animal units per km$^2$) (Huntsinger & Starks 2006). With
extensive grazing research in New Mexico, grazing capacity has been set at the
equivalent of 1.3 to 3.5 animal units per km$^2$ (Holechek 1992; Winder et al. 2000).
Liveweight gains of 0.5 to 1.2 kg per day (Bertram 1984; Foran 1984; Low & Wood
1979) have been reported for calves and steers in the Alice Springs district. In
comparison, extrapolation of the liveweight estimates made by property managers has
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suggested lower annual growth of young cattle or steers in the Pilbara and south-west Queensland (mulga country: 0.41–0.42 kg per head per day; Mitchell grass country: 0.45–0.53 kg per head per day) (Bortolussi et al. 1999a,b). However, reports from trials in south-west Queensland have also indicated potential for growth of steers at up to 0.81 kg per head per day on mulga country (Clarke 1991, p.30).

During good seasons in the Alice Springs district, beef cattle can be fattened at high stocking rates (Bastin 1989) on the more productive arid rangeland pasture-types (Siebert, Newman & Nelson 1968; Squires & Siebert 1983; White 1996). In other seasons, conservative stocking rates and selective grazing or browsing (Ward 1975) provide cattle with a diet containing the CP and DMD needed to maintain liveweight and body condition (Freidel & Squires 1983; Squires & Siebert 1983). Seasonal patterns of selective feeding reflect the diverse type (Bastin 1998) and variable palatability of pasture and topfeed (Bohning & Wilkie 1999; Chippendale & Murray 1963). Topfeed provides an important feed reserve for cattle (Bastin 1998; Whittem 1964), particularly during a ‘dry period’ (seasonal drought). Browsed topfeed can constitute 20% of the diet (Chippendale 1968; NT-DPI&F 1995b; Squires & Siebert 1983), and together with forbs, can provide a diet with higher CP (Freidel & Squires 1983; Siebert, Newman & Nelson 1968) and DMD (Newman 1969) than dry grass pasture. On the arid rangelands of South Africa, the CP content of grasses and shrubs may show little seasonal variation (Palmer & Ainslie 2006). However some browsed topfeed species on rangelands contain high levels of fibre or tannins (Hakkila et al. 1988; Jackson et al. 2009, p.134; Nunez-Hernandez et al. 1992), which contribute to the low DMD noted for topfeed (Bertram 1988; Holechek, Pieper & Herbel 2004, pp.335-38).
2.1.2. **Cattle Industry**

2.1.2.1. **Beef Cattle Properties**

The cattle industry of the Alice Springs district is based on the low quality forage and low average carrying capacity of arid rangelands. This is best suited to enterprises that graze large numbers of beef cattle on vast areas (Siebert, Newman & Nelson 1968). Beef cattle properties occupy 218,859 km$^2$ of the available pastoral area in the district. The average property area is 3,885 km$^2$ (range: 450–11,000 km$^2$), and the paddocks (3–90 per property) average 335 km$^2$ (range: 13–1,500 km$^2$) in area (Bertram, Oliver & Dance 1996; Leigo c. 2006). Not all property areas may be suitable for grazing. The ‘usable area’ averages 3,278 km$^2$ for a group of properties south of Alice Springs (McCosker, McLean & Holmes 2010, p.48). Beef cattle properties are slightly smaller in south-west Queensland (average: 2,225 km$^2$) and the Pilbara (average: 3,270 km$^2$) (Bortolussi et al. 1999a,b).

On arid rangelands of south-west Africa, south-west USA and northern Mexico, the privately-owned property of a beef cattle business is preferentially called a ‘ranch’ (Huntsinger, Forero & Sulak 2010; Ortega-Ochoa et al. 2008; Palmer & Ainslie 2002; Sweet, Burke & Reynolds 2002). Together with associated grazing leases, these properties in overseas countries are significantly smaller than beef cattle properties in the Alice Springs district, for example: in Namibia (average: 66 km$^2$) (Adams & Devitt 1992); in the North-West province of South Africa (average: 41 km$^2$) (Hudson 2002, p.67); and in New Mexico (average: 200 km$^2$ of private and leased rangeland) (Holechek 1992).

Notable development of the cattle industry in the Alice Springs district has occurred with the introduction of rail and road transport to replace cattle droving (Shaw, Bastin & White 1996; Whittem 1964), with installation of subdivisional fences (Chisholm 1983) and additional water-points (Freidel & Squires 1983), plus with reticulation of pumped
wet (NT-DPI&F 1994b,c; 1995b). According to 26% of surveyed cattle managers, a combination of subdivisional fences and additional water-points has enabled grazing over 100% of the property (Leigo c. 2006).

In average seasons, the district has carried 250,000 to 300,000 head of beef cattle (ABS 1998), and historically, the district’s population of beef cattle has peaked in years of good rangeland feed growth or low market prices. Drought and the Brucellosis and Tuberculosis Eradication Campaign (BTEC) of the 1980s (Henderson 1998) have triggered substantial destocking.

In general, at least 5,000 cattle are required for a beef cattle property in the district to be financially viable (NT-DPI&F 1995b). Most properties carry 2,000 to 8,000 mixed cattle (Bertram, Oliver & Dance 1996) and most managers have reported 1,000 to 5,000 head in the breeding herd (Leigo c. 2006). South of Alice Springs, the breeding herd has averaged 2,786 head for a benchmarking group (McCosker, McLean & Holmes 2010, p.48). In contrast, property managers have reported less cattle for breeding herds in south-west Queensland (average: 682 head) (Bortolussi et al. 1999b) and the Pilbara (range of averages: 2,185–3,723 head) (Bortolussi et al. 1999a; McCosker, McLean & Holmes 2010, p.50).

Beef cattle herds on arid rangelands of south-west Africa, south-west USA and northern Mexico are smaller than those in the Alice Springs district, for example: in Namibia (average: 450 large-stock units, where one large-stock unit equals 450 kg liveweight) (Adams & Devitt 1992); in the North-West province of South Africa (average property: 250 head of cows) (vTI & DLG 2011); in New Mexico (medium-sized cow-calf operation: 250 animal units, where one animal unit equals 454 kg liveweight) (Holechek 1992) and in Arizona (average commercial herd: 225–250 head) (Conley et al. 1999).

Beef cattle properties in the Alice Springs district were initially stocked with Bos taurus cattle (Shorthorn, Hereford, Aberdeen Angus, Murray Grey) (Locke 1985, p.43; Shaw,
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Bastin & White (1996) and their crosses (Petty, Holt & Bertram 1979). However in the past decade, managers have mainly reported Hereford and Santa Gertrudis breeds (Leigo c. 2006). Pure *Bos indicus* and *Bos indicus*-infused cows have provided increased marketing opportunities for live cattle export, but have decreased returns in southern store markets and produced early concerns about lower calf production (Petty, Holt & Bertram 1979). The property breeding objectives reported by managers for herd quality, survival, growth and market suitability (Leigo c. 2006; NT-DPI&F 1994a; 1995b,c) have been addressed through culling strategies and introduction of bulls with desirable phenotype, improved genetics or *Bos indicus* genotype.

Cattle managers in the district have, in general, reported mustering and yarding twice a year (Leigo c. 2006; NT-DPI&F 1994a,b) with methods that achieve a mustering efficiency of 50 to 95% (Chisholm 1983; Petty c. 1977; Petty, Holt & Bertram 1979). Labour-saving infrastructure (strategic fencing, bayonet traps, permanent stock yards with drafting gates, calf races, loading races and ramps) has enabled managers to minimise the labour requirements for cattle work (mustering, castrating, branding, ear-marking, tagging, dehorning, weaning and turning off).

### 2.1.2.2. Cattle Enterprise and Economics

Beef cattle enterprises in the Alice Springs district have high fixed and variable costs related to the remote location and long distances to markets (Henderson 1998). The need to shift cattle long distances is common to enterprises in other arid areas of Australia (Clarke 1991, p.15; McCosker, McLean & Holmes 2010, p.51). High costs can be off-set by economies of scale, downscaling of operations during drought and labour-saving infrastructure to minimise the staffing requirements. However, the cost of beef cattle production per head turned off for the Alice Springs district has increased from a range of $26 to $155 per head in 1979 (Petty, Holt & Bertram 1979), to an

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1 Selection for transport and sale to markets.

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average of $393 per head in 2000 (Hooper 2001). Regional cattle turnover from the
district has fluctuated with seasonal conditions and market prices (ABS 1998; Reeves &
Crellin 1972). An average of 27% turnover has been calculated for a 10-year period
Survey and ‘local consensus’ data indicate that cattle production in the district has
focused on breeding and trading of store cattle (Leigo c. 2006). The productivity per
cow is considered to be the key measure of performance for beef cattle enterprises in the
Alice Springs district and the Pilbara (McCosker, McLean & Holmes 2010, p.16). Cattle
managers in the Alice Springs district have reported that where and when the rangeland
pasture-type and good seasons permit (NT-DPI&F 1994a,b,c; 1995a,c), fat cattle (3- to
4-year-old steers, speyed cows) have been produced and turned off with the cull cattle
(bulls, cows) to abattoirs (Bertram, Oliver & Dance 1996; Leigo c. 2006; Oxley et al. c.
2006). Store cattle (15- to 24-month-old steers or heifers) have been sent to export and
domestic markets, as well as to interstate properties and feedlots (NT-DPI&F 1994a,b,c;
Oxley et al. c. 2006).
Similarly for beef cattle properties in hot arid regions of USA and Mexico (Arizona,
New Mexico and Chihuahua), Huntsinger and Starrs (2006) have noted that breeding
enterprises (cow-calf production) predominate and store cattle (calves) are exported to
local backgrounding properties or USA feedlots.

2.1.3. General Herd

2.1.3.1. Nutrition
Optimal nutrition for cattle on arid rangelands is limited by the erratic occurrence of
effective rainfall and risk conditions that cause deficiency in dietary energy, CP or P.
Management of these risks is based on grazing strategies and supplementation.

On beef cattle properties in the Alice Springs district, continuous grazing and rotational
grazing are common strategies. In south-west Africa, rotational grazing is a common
practice (Hudson 2002, p.50; Palmer & Ainslie 2006; Sweet, Burke & Reynolds 2002), however, there is indication that continuous grazing with a moderate stocking rate can favour better animal performance (Palmer & Ainslie 2006). In south-west USA and northern Mexico, continuous grazing has been common and rotational grazing has become popular (Gonzalez Gonzalez 2006, p.26), however the cost of fencing can be prohibitive (Eakin & Conley 2002).

The temporal pattern of grazing pressure in the Alice Springs district is influenced by the distribution of open livestock water-points, spelling of fenced areas (Leigo c. 2006; Shaw, Bastin & White 1996) and seasonally-adjusted stocking rates to suit the carrying capacity of rangeland pasture-types (Bastin 1998). The latter has also been demonstrated on arid rangelands of the USA (Holechek, Pieper & Herbel 2004, p.226).

During dry periods in the Alice Springs district, supplementation helps sustain efficient grazing and browsing. More than 50% of surveyed cattle managers have reported the provision of supplementation, either all year-round or regularly during dry periods (Schatz 2011, p.93). Escalating dietary energy deficiency that occurs during a dry year is addressed with additional drought management strategies (NT-DPI&F 1994a,b,c; 1995b,c) such as strategic culling (partial destocking) and opening of more water-points to reduce and redistribute the grazing pressure. The use of supplementation, new pasture areas and destocking has also been reported in response to drought conditions in south-west Queensland (Clarke 1991, p.49), Arizona (Eakin & Conley 2002), and Namibia (Lange, Barnes & Motinga 1998; Sweet 1998). Where delay has occurred in either the redistribution or reduction of grazing pressure during prolonged dry periods, there has been a noted increase in land degradation (Hudson 2002, p.28; Ortega-Ochoa et al. 2008), an increase in plant poisonings (Nabhan & Taylor 2004; Sweet 1998) or a decrease in cattle performance (Fynn & O'Connor 2000) on arid rangelands of south-west Africa, south-west USA and northern Mexico.
Cattle managers in the Alice Springs district have reported the use of non-protein N (urea) and P supplementation (Leigo c. 2006) to reduce the risk of deficiency in dietary CP and P, particularly when cattle start eating increasing amounts of topfeed (NT-DPI&F 1994b,c; 1995a,b,c) or faecal output suggests decreasing intake and decreasing flow of ruminal digesta. The cattle diet on spinifex or mulga lands may be low in CP, high in fibre or high in tannins that can exacerbate mineral deficiencies (Miller, Gutteridge & Shelton 1994). However, consumption and digestion can be improved by urea supplements (Squires 1981, pp.46,55), along with sulphur (S) to compensate for the tannins and non-protein N (Rayment, Walker & Keerati-Kasikorn 1983). Together with supplement additives (molasses, salt), the method of supplementation reported by managers (lick blocks, loose mix, water medication) (Leigo c. 2006) promotes acceptance (NT-DPI&F 1994b,c; 1995c) and regulates consumption (Bertram 1987). A variety of licks providing minerals, salt and N are also a part of normal cattle management in south-west Queensland (Clarke 1991, p.43), south-west Africa (Hudson 2002, p.81; Sweet, Burke & Reynolds 2002) and south-west USA (Holechek, Pieper & Herbel 2004, p.315; Sprinkle 2001b, 2001c). In contrast, use of supplementation has not been as widespread in the Pilbara (Smith et al. 2010a, pp.17-18).

In the Alice Springs district, the cost of freight has limited the use of energy and true protein supplements to short-term yard feeding, e.g. with drought rebates (NT-DPI&F 1994a, 1995b) or for supplementation at weaning (NT-DPI&F 1994b). In comparison, there has been concern that subsidised or supplementary feeding of fodder during drought may encourage poor management practices on arid rangelands of south-west Africa (Sweet 1998), south-west USA (Eakin & Conley 2002) and northern Mexico (Ortega-Ochoa et al. 2008).
2.1.3.2. Disease

The cattle diseases reported by managers in the Alice Springs district have included botulism and plant poisoning, lice, eye cancer, ‘pink eye’ (infectious kerato-conjunctivitis), ‘peg-leg’ (lameness associated with phosphorus deficiency), dystocia, unexplained deaths, scouring, ‘lack-of-rain’, ‘respiratory’ problems, nutritional deficiencies and ‘three-day sickness’ (bovine ephemeral fever) (Leigo c. 2006; NT-DPI&F 1994c; 1995a,b).

Diseases that have been either of lesser concern or not reported include vibriosis, trichomoniasis, helminthosis (including intestinal nematodiasis), coccidiosis and external parasites (flies, midges, ticks). There has been little awareness of some deficiencies (vitamins, trace minerals) and infections (with leptospires, bovine viral diarrhoea virus (BVDV) and bovine herpes virus type 1 (BHV1)).

Nutritional Deficiencies

Fluctuation in the quantity and quality of rangeland pasture accentuates or attenuates deficiencies in dietary energy, CP and other production-limiting nutrients (Ray et al. 1989). Dietary deficiencies in CP and P that have been identified in the Alice Springs district have been associated with depression in reproduction, growth or survival, as well as with the presence of ‘peg-leg’ (Hare 1985, p.79), botulism poisoning (NT-DPI&F 1991b) and low blood P in cows (Barnes & Jephcott 1959). Areas acutely deficient (spinifex and mulga lands) (McCosker & Winks 1994, pp.75-78) or seasonally deficient (Coventry 1992) in available soil P have been implicated in these deficiencies. Seasonal P-deficiency has also been reported on other arid rangelands of northern Australia (Bortolussi et al. 1999a,b; Clarke 1991, pp.33,60; O'Rourke, Winks & Kelly 1992), Namibia (Grant, Biggs & Meissner 1996) and USA (Holechek, Pieper & Herbel 2004, pp.359-61).
Concern about micronutrients in arid rangelands has been reported with respect to potential vitamin A deficiency in young cattle of south-west Queensland (Holroyd, Hill & Sullivan 2005) and New Mexico (Watkins & Knox 1950). Concern also has been reported with respect to available copper (Cu) in the Alice Springs district (McEllister c. 1991; NT-DPI&F c. 2000, p.61), Namibia (Grant, Biggs & Meissner 1996) and south west USA (Holechek, Pieper & Herbel 2004, p.360; Sprinkle, Grumbles & Meen 2002). Following reporting on deficiencies in Zn, Cu and Se for cattle on arid rangelands of Arizona, a treatment trial demonstrated benefit from supplementation with Cu and Se in ruminal boluses (Sprinkle et al. 2006).

Reports of deficiencies in sodium (Na), S and Cu, have been noted for northern Australia (Judson & McFarlane 1998), but consideration of these in the Alice Springs district has been over-shadowed by a need to address deficiencies in energy, CP and P. To date, definition of seasonal nutritional deficiencies in cattle of the district has been limited.

Poisonings
A report in the mid 1960s attributed loss of cattle to botulism poisoning on properties of the northern Alice Springs district (Hare 1985, p.80). A survey 30 years later (1990–1991) demonstrated the presence of *Clostridium botulinum* type C and D spores in cattle faeces from herds in the district (McEwan 1990; NT-DPI&F 1992a, p.6).

Toxins of native plants (nitrate, cyanide, oxalate, monofluoroacetate (1080)) have caused large livestock losses under risk conditions in the district (Chippendale & Murray 1963). Poisonous plants of concern have included *Acacia georginae, Indigofera linnaei, Sarcostemma australe, Gastrolobium grandiflorum and Duboisia hopwoodii* (Freidel & Squires 1983). Poisonings by similar native plant species and locally-specific insect intoxications have been reported in south-west Queensland (Clarke 1991, pp.58,66). Plant poisonings have also been reported for the arid rangelands of Mexico
(Buller, Hernandez & Gonzalez 1960), South Africa (Kellerman, Naude & Fourie 1996) and south-west USA (Allison 1994; James, Nielsen & Panter 1992; Ruyle 1993). The risk of poisoning in South Africa has been shown to increase under drought conditions when cattle eat poisonous plants that they would normally avoid (Hudson 2002, p.28). The risk of plant poisoning has also been associated with heavy grazing (Holechek 2002) or reduced availability of palatable, non-poisonous species in the USA (Holechek, Pieper & Herbel 2004).

Bacterial and Viral Infections

*Campylobacter fetus subsp. venerealis*

Infection of cattle by *Campylobacter fetus* subsp. *venerealis* (vibriosis) causes venereal disease with infertility and reproductive loss (OIE 2008b). Vibriosis has been previously documented in extensive cattle herds of northern Australia (Norman et al. 2002) and there is evidence of its presence in cattle on arid rangelands. Surveys have detected the bacteria in bulls of the Alice Springs district (NT-DPI&F 1991b); herd testing and disease investigations (Animal Health Australia 1999; Clarke 1991, p.62) have demonstrated vibriosis in cattle herds of south-west Queensland; and an increase in the pregnancy percentage with vaccination against vibriosis has indicated presence of the disease in cattle herds of the Pilbara (Nickels & Cruickshank 2002).

In south-west Africa, use of a polymerase chain reaction (amplification assay) (PCR) has promoted reporting of vibriosis. For example, 2.1% (25/1201) of bull samples from Namibia have been positive for *C. fetus* using PCR (Madoroba et al. 2011), and *C. fetus* has been isolated in samples from the North-West province of South Africa. However, differentiation between *C. fetus* subsp. *fetus* and *C. fetus* subsp. *venerealis* has proven difficult with only PCR and phenotypic tests (Schmidt, Venter & Picard 2010).
Neospora caninum
Infection by *Neospora caninum* (neosporosis) occurs world-wide, with primary intestinal infestation of canids (definitive hosts) and tissue infection of intermediate hosts such as cattle (Radostits et al. 2007, p.1509). Neosporosis of cattle is characterised by horizontal and vertical transmission, latent and congenital infection, abortions and neonatal calf loss (Dubey, Scharer & Ortega-Mora 2007; Radostits et al. 2007, p.1509). Bovine neosporosis has been reported in all states in Australia (Moloney & Kirkland 2006) and is considered an infrequent or low level cause of reproductive loss where beef herds are associated with wild canids (Kirkland et al. 2012, p.21). The economic impacts are estimated to be significant for some beef herds (Moloney & Kirkland 2006), but are generally unknown in northern Australia (Sackett et al. 2006, p.21).

In the Alice Springs district, serum antibodies to *N. caninum* have been reported on a beef cattle property, in association with mummified foetuses and a large local presence of wild dogs (P Saville (NT Department of Resources) 2011, pers. comm.). In the comparable area of south-west Queensland, low seroprevalence ($\leq 9\%$) of *N. caninum* has been reported (Landmann & Taylor 2003, p.12).

*Tritrichomonas foetus var.*
Infection of cattle by *Tritrichomonas foetus var.* (trichomoniasis) causes venereal disease with infertility and reproductive loss (OIE 2008d). In Australia, the *brisbane* strain (variety) predominates and trichomoniasis has been previously documented in extensive northern cattle herds (Norman et al. 2002). In the Alice Springs district, trichomoniasis has been detected in local and introduced bulls during surveys and disease investigations (NT-DPI&F 1991b). In contrast, limited testing of bulls has failed to detect trichomoniasis in south-west Queensland (Clarke 1991, p.62).

In beef cattle herds of western USA, the presence of trichomoniasis has been associated with natural (uncontrolled) mating (BonDurant 1997). A prevalence of up to 50% has
been estimated on arid rangelands of south-west USA (Kattnig 2003), and with PCR testing, infection by *T. foetus* has been demonstrated in New Mexico (6.4% of bulls) and Arizona (3.4% of bulls) (Wenzel 2007).

Similarly for arid rangelands of south-west Africa, 3.8% (45/1201) of bull samples in Namibia have been PCR positive for *T. foetus* (Madoroba et al. 2011).

*Leptospira spp.*

Infection of cattle by spirochaete bacteria of the genus *Leptospira* spp. can result in disease of zoonotic and economic concern (leptospirosis) that can include abortions, stillbirths and agalactia (Bolin & Alt 1999; Faine et al. 1999, p.193; OIE 2008a). Some incidental serovars of *Leptospira* spp. (*australis, zanoni, celledoni*) have occasionally been isolated from cattle in northern Australia (McGowan 2003; Perry 2000), however two leptospires are recognised as major cattle pathogens in Australia—*L. borgpetersenii* serovar *hardjo* genotype *hardjo-bovis* (*L. sv. hardjo*) and *L. interrogans* serovar *pomona* (*L. sv. pomona*) (Hungerford 1990, p.478). Transmission occurs efficiently between maintenance hosts via infected urine, milk or placental fluids. Infection of indirect hosts depends on environmental contamination by a direct host, with conducive conditions (moisture, neutral pH, warmth) to enable survival and transmission (Bolin & Alt 1999). In surveys of unvaccinated beef cattle herds of semi-arid Australia, antibody titres have been reported to *L. sv. hardjo* in western New South Wales (46% herd prevalence) (King 1991) and central Queensland (15.8% crude individual animal seroprevalence) (Black et al. 2001). Antibody titres have also been reported to *L. sv. pomona* in western New South Wales (59% herd prevalence) (King 1991) and central Queensland (4.0% crude seroprevalence) (Black et al. 2001). Higher reported antibody titres for *Leptospira borgpetersenii* serovar *tarassovi* (*L. sv. tarassovi*) in cattle of northern South Australia (Durham & Paine 1997), central Queensland (13.9% crude seroprevalence) (Black et al. 2001) and the upper half of the Northern Territory (37–55% seroprevalence) (Andrews
1976) suggest that there has been widespread exposure to this serovar in extensive beef herds. However, pathogenicity of this serovar has not been proven in cattle (Black et al. 2001; McGowan 2003).

In contrast to the prevalence in tropical (wetter) areas, leptospirosis has been assumed to be less prevalent in arid areas of Australia (Perry 2000). In the Alice Springs district, indication of bovine leptospiral infection has been limited to reports of antibody titres to *L. sv. hardjo* in cattle at abattoirs (NT-AI&AB c. 1973; NT-DPI&F 1989, p.38; 1991a, p.24) and on properties (NT-DPI&F 1992b; 1994d, p.93). There are no records of titres to *L. sv. pomona* in cattle and there are no bacterial cultures of *L. sv. tarassovi* to match serological evidence of bovine infection in the district (NT-AI&AB c. 1973).

Evidence of bovine leptospirosis in arid rangelands of the Americas has been supported by reports of antibody titres (MAT > 1:100) to *Leptospira* sp. serovars (*hardjo, canicola, grippotyphosa, icterohaemorrhagiae and pomona*) (up to 14.3% seroprevalence) in Arizona (Songer et al. 1983), and by isolation of *L. sv. hardjo* (genotype *hardjo-bovis*) from cattle in New Mexico (Miller, Wilson & Beran 1991). In arid and semi-arid areas of Mexico, titres (MAT > 1:100) to *Leptospira interrogans* (including serovars *hardjo* (genotype *hardjo-prajitno*), *wolffi* and *tarassovi*) have been reported in at least 31% of tested cattle (Alvarez et al. 2005).

**Bovine viral diarrhoea virus**

Bovine viral diarrhoea virus (BVDV, bovine pestivirus) is distributed world-wide (OIE 2008c). Infection by this virus results in a complex of bovine respiratory, gastrointestinal, thrombocytic, haemorrhagic, reproductive, congenital and immunosuppressive disease syndromes (Radostits et al. 2007, p.1248), including mucosal disease (BVD/MD). Vertical transmission, production of persistently viraemic calves and development of the fatal mucosal disease play important roles in the epidemiology and pathogenesis of BVDV (OIE 2008c). Infection by the BVDV genotype 1 in
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Australian cattle is sporadic and the resulting diseases (Hungerford 1990, pp.378-79) have variable morbidity and mortality.

The seroprevalence of BVDV has been variable for studies in northern Australia (40–92%) (Littlejohns & Horner 1990; St. George et al. 1967), the Northern Territory (0–100%) (Brown 2002; Schatz, Melville & Davis 2008), and the northern areas of South Australia (9–97%) (Durham & Paine 1997). Clinical disease resulting from BVDV infection in northern Australia has been reported in Queensland (Bock, Rodwell & McGowan 1997; Taylor & Rodwell 2001) and in the tropics of the Northern Territory (NT-DPI&F 1999b, p.125).

Historically, serum antibodies to BVDV have been found in all surveyed cattle herds in the Alice Springs district (St. George et al. 1967). More recently, ad hoc cattle disease investigations and a property survey have indicated that over 80% of cattle seroconvert to BVDV by the time they have reached maturity (NT-DBIRD 2003; Schatz, Melville & Davis 2008), however clinical BVDV-related disease has not been confirmed in the district (Coventry 2006).

For arid rangelands of South Africa, evidence of BVDV infection has been demonstrated with positive immunofluorescence and PCR testing in the North-West province (Kabongo 2005, p.134), and with isolation of BVDV (genotypes) 1 and 2 in cattle from the Northern Cape and North-West provinces (Ularamu 2010). In Namibia, the seroprevalence of BVDV (49%) in surveyed cattle has indicated widespread infection (Depner, Hübschle & Liess 1991).

For arid rangelands of the USA, over 70% seroprevalence of BVDV (three endemic geno-subtypes: 1a, 1b and 2) has been demonstrated in weaned, unvaccinated beef calves in New Mexico (Fulton et al. 2005). An earlier survey demonstrated that western cattle herds, including herds from Arizona and New Mexico, were more likely to have antibody titres to BVDV and to be vaccinated for BVDV (Paisley, Wells & Schmitt
In Chihuahua, 62% prevalence of antibodies to BVDV has been reported in beef cattle (Suzan et al. 1983).

**Bovine herpes virus type 1**

Bovine herpes virus type 1 (BHV1) is a worldwide pathogen of cattle and is responsible for disease complexes that mainly involve the respiratory and genital tracts, such as: infectious bovine rhinotracheitis (IBR); infectious pustular vulvovaginitis (IPV); and infectious balanoposthitis (IBP) (Vialard et al. 1998). In Australia, the BHV1.2b subtype is present (Office of the Gene Technology Regulator 2005) and IBR is a primary cause of bovine respiratory disease (BRD) in feedlots (Smith, Young & Reed 1995). In extensive cattle herds of Australia, seroprevalence is high (96% of bulls, 52% of cows) (Radostits et al. 2007, p.1349). Because of uncontrolled mating and venereal spread, the genital forms (IPV, IBP) are believed to be common (St. George et al. 1967). Historically, serum antibodies to BHV1 have been found in 71% (10/14) of the surveyed cattle herds in the Alice Springs district (St. George et al. 1967). More recently, serum antibodies to BHV1 have been found in young adult cattle during disease investigations (NT-DBIRD 2003) and clinical disease has been suspected to follow infection with BHV1 (NT-DPI&F 1991b, 1992b).

In comparison, serum antibodies to BHV1 have been reported in 78 to 90% of cattle in adjacent semi-arid areas of the Northern Territory and South Australia (Brown 2002; Durham & Paine 1997). In south-west Queensland, BHV1 is suspected to have caused sickness and mortality of weaners and young stud bulls (Clarke 1991, p.66).

High seroprevalence to BHV1 has also been reported for arid rangelands of south-west Africa and Mexico. In Namibia, up to 80% seroprevalence to BHV1 has been reported in cattle and higher prevalence in the more arid southern areas has been associated with ‘poor farming conditions’ (Geiger et al. 1990). In Chihuahua, 70% prevalence of antibodies to BHV1 has been reported in beef cattle (Suzan et al. 1983).
Despite evidence of bacteria, protozoa, leptospires and viruses that could cause venereal or reproductive disease in beef cattle herds of the Alice Springs district, there is no information on the regional epidemiology or production implications arising from infection by these pathogens.

Parasite Infestations

Internal parasites

Internal parasites, such as intestinal helminths and coccidia, have a medium economic impact on cattle in northern Australia (Sackett et al. 2006, p.21). When climatic conditions or environmental (paddock, yard) conditions are conducive to lifecycle requirements of these parasites, there is potential for infestations to be exacerbated by the stress of environmental extremes, management or poor nutrition (Radostits et al. 2007, pp.1502,1542).

Four species of intestinal nematodes (intestinal helminths) are reported in the Alice Springs district (Oesophagostomum radiatum, Haemonchus placei, Cooperia pectinata and C. punctata) (Coventry 1998; NT-DPI&F 1989, p.24); low levels of eggs from H. placei and Cooperia spp. have frequently been found in the faeces of young cattle (Smeal 1995, pp.51,83). On other arid rangelands in south-west Queensland, Haemonchus sp., Cooperia spp., Oesophagostomum sp. and Trichostrongylus sp. have been cultured from the faeces of young cattle (mean: 30 epg) suggested that the infestations had little effect on productivity (Clarke 1991, p.57). With the exception of weaner and yearling cattle in wet years (Nickels 2002), helminths have similarly not been considered a problem in pastoral areas of Western Australia (Mitchell 1987). In south-west USA, three genera of intestinal nematodes (Cooperia spp., Nematodirus sp., Oesophagostomum sp.) have been common to cattle from Arizona and New Mexico (Becklund & Allen 1958). Faecal egg counts have been low for cattle of undefined age on rangeland (average: 33 epg) and
low for cows (mean: 33 epg) (Miller 1993). Overall, the economic impact of infestations has not been considered important for cattle from Arizona and New Mexico (Becklund 1964). In the North-West province of South Africa, predominantly *H. placei* and *Cooperia* spp. have been identified on commercial beef cattle properties (Reineke 1960). With the exception of calves, intestinal helminths have not been a big problem for extensive cattle enterprises elsewhere in south-west Africa (Sekokotla 2005, p.37). Other internal parasites that can be of concern to cattle include cestodes, trematodes and various migrating larvae. There are no definitive reports of parasitic cestodes or trematodes in beef cattle of the Alice Springs district (Small & Pinch 2003). Similarly in Western Australia, abattoir submissions have failed to detect sterile or fertile hydatid cysts of *Echinococcus granulosus* in cattle from the Pilbara (Lymbery et al. 1995). Two parasitic nematodes of the subcutaneous tissue (*Onchocerca gibsoni, O. gutturosa*) (Hungerford 1990, p.1403) are not of serious production significance in the Alice Springs district. In comparison, cattle in arid regions of south-west USA and northern Mexico are frequently annoyed by the adult fly of *Hypoderma lineatum* (*L*) (Geden & Hogsette 2001; Radostits et al. 2007, p.1588; Smith 1990, p.1281) and migrating larvae can be found at various stages in untreated cattle at slaughter (Byford, Craig & Crosby 1992; Geden & Hogsette 2001; Quintero-Martínez et al. 2007).

Intestinal infestation with coccidia (coccidiosis) is a problem recognised in young cattle with yard feeding and overcrowded conditions (Radostits et al. 2007, p.1500). Coccidiosis reported in orphaned and early-weaned calves on properties in the Alice Springs district has involved two species (*Eimeria bovis, E. zuernii*) (NT-DPI&F 1992b).

Although internal parasites are a considered threat for extensively-grazed cattle in northern Australia and evidence exists for infestation with intestinal nematodes and
coccidia in cattle of the Alice Springs district, there is limited information to define the risk of intestinal parasitism.

*External parasites*
Adverse effects by flying insects (biting, irritation, infestation, and transmission of bacteria, viruses or nematode parasites) (Smeal 1995, pp.178,125) have been reported for cattle in the Alice Springs district: *Lucilla* sp. and *Chrysomya* sp. have caused ‘fly strike’ (facultative larval myiasis) (Animal Health Australia 2003b; NT-DPI&F 1992b); *Musca vetustissima* has produced ocular irritation and carried bacteria that cause infectious bovine kerato-conjunctivitis; and *Culicoides* spp. have probably been the intermediate hosts of *O. gibsoni* and *O. gutturosa* (Smeal 1995, p.178), as well as vectors of bovine ephemeral fever (BEF) virus (Animal Health Australia 1997; NT-DPI&F 1992b).

Incursions of *Haematobia irritans exigua* have been infrequent in the Alice Springs district (Coventry 2011), but this fly is endemic in the Pilbara (Nickels 2002) and south-west Queensland (Clarke 1991, p.54). A related species (*Haematobia irritans irritans*) parasitises cattle in south-west USA and is a significant cause of production loss (Geden & Hogsette 2001; Radostits et al. 2007, p.1603). Given favourable weather conditions, there is risk of incursion by screw-worm flies (*Cochliomya hominivorax*) into the south-west USA from nearby infested areas of northern Mexico (Graham & Hourrigan 1977). Infestations by endemic (*Damalinia bovis, Linognathus vituli*) and introduced (*Haematopinus sp.*) cattle lice have been recorded on cattle in the Alice Springs district (NT-DPI&F 1986). Similarly, lice commonly infest cattle on the arid rangelands of Western Australia (Nickels 2002), Queensland (Clarke 1991, p.53) and the USA (Geden & Hogsette 2001). Mites (*Psoroptes* spp.) have been less widespread in cattle of south-west USA (Geden & Hogsette 2001).
The free-living stages (eggs, larvae, nymphs) of parasitic cattle ticks (*Boophilus microplus*, renamed *Rhipicephalus microplus*) are not suited to the dry conditions of an arid region, however this tick has been a minor problem in south-west Queensland (Clarke 1991, p.56) and incursions have been reported in the Pilbara (Animal Health Australia 2002). In seasons of above-average rainfall, the Alice Springs district may also sustain incursions. In Chihuahua, quarantine has been used in past years to maintain freedom from *Boophilus* sp. after an eradication campaign (Graham & Hourrigan 1977). In central Namibia a low level of endemic tick infestation and associated tick fever has been reported by a cattle manager (Latimer 2002). In the Northern Cape province of South Africa, a tick-borne protozoal parasite that causes ‘tick fever’ (*Babesia bigemina*) has been recorded (du Plessis, de Waal & Stoltsz 1994) and two ticks (*Hyalomma truncatum*, *Rhipicephalus evertsi evertsi*) that are capable of carrying the agent of ‘heartwater’ (*Cowdria ruminatum*), have been found on cattle (du Plessis, Boersema & van Strijp 1994). In the north of Arizona and New Mexico, there have been recordings of *Dermacentor andersoni*, which is a vector for anaplasmosis in cattle (Geden & Hogsette 2001; James et al. 2006).

There is commonality for beef cattle herds of arid rangelands in having endemic infestations, as well as infrequent incursions of external parasites that threaten introduction of novel viral or microbial disease.

**2.1.3.3. Deaths**

Management to limit cattle mortality in extensively-grazed herds of the Alice Springs district is challenging, given the many potential causes of mortality and the difficulties for confirming and recording death of individual cattle. Detection of cattle carcases is difficult if visibility and accessibility are poor in vast paddock areas (Leigo c. 2006; Niethe 1996), or there is rapid decomposition and removal by scavengers (de Witte, Jubb & Hedlefs 1998). Difficulty in confirming cattle deaths is compounded by either a
lack of individual cattle identification and recording (Bortolussi et al. 1999a), poor paddock security or poor mustering percentages (Holroyd & O'Rourke 1988). In general, annual cattle losses are best defined by the combined number of recorded cattle deaths (based on cattle confirmed dead or euthanased) and unconfirmed cattle deaths (based on extrapolation of recorded absence from consecutive musters). An example of this sort of combined loss has been reported for cattle on mixed arid rangelands of Western Australia (Thomson 1999, p.12).

Overall there has been a lack of information about cow deaths in the mulga land of northern Australia’s arid region (Holroyd & O'Rourke 1988). In the Alice Springs district, data on annual mortality percentages and reasons for cattle deaths have been based on surveys, ‘local consensus’ data, modelling and *ad hoc* disease investigations. The annual mortality of cattle herds in the district that has been reported in ‘local consensus’ data (range: 1–6%) (NT-DPI&F 1994b, 1995b) varies more than in a Northern Territory Government (NTG) summary and a survey of cattle managers by the Australian Bureau of Agricultural and Resource Economics and Sciences (ABARES) (range: 3–5%) (Bertram, Oliver & Phillips 1996; Hooper 2001). Documented cattle mortality on other arid rangelands has been similar in south-west USA (range: 2–7%) (Herbel et al. 1984; Holechek 2002; Holechek, Pieper & Herbel 2004, p.424), and higher in Western Australia (range: 4–20%) (Kok, Collopy & Stretch 1987; Thomson 1999, pp.19,39). The latter may have reflected ‘poor seasons’.

In the Alice Springs district, managers have reported higher cattle mortality during drought (range: 3.5–10%) (NT-DPI&F 1995a,c). In comparison in Namibia, low cattle loss (2%) has been reported by commercial cattle managers during drought (Sweet 1998), but higher, more variable cow mortality has been reported for indigenous and introduced cattle breeds under research conditions (average: 5–15%) (Schoeman 1989).
Estimates of cow mortality percentage (Bolam, Jubb & Kerr 1998; Jubb, Vassallo & Annand 1996; Niethe 1996) can be undertaken with a male-to-female turnoff ratio and branding percentage. If used for a reasonable period of time with a regional cattle population, this off-sets a concern about the use of this ratio for arid rangelands (McCosker, McLean & Holmes 2010, p.16), upon which breeding herd numbers have cycles of build-up after the destocking that is needed during prolonged dry periods. For example, based on a branding percentage reported by cattle managers for good seasons in the Alice Springs district (75%) and a male-to-female turnoff ratio of 3:2 calculated from five years of district data (1991–1995) on the NT Waybill database (pers. obs.), a 12.5% mortality percentage has been estimated for female cattle. This is higher than other estimates of the annual female mortality (range: 7–10%) (Cann 1993; Henderson 1996; Petty c. 1977), higher than averaged reports by managers in the district (range: 3–4.9%) (Dixon 1995, p.2; Hooper 2001; Leigo c. 2006; Niethe 1996), and higher than reports for aged cows (≥ 8 years old: 7%) (Leigo c. 2006; NT-DPI&F 1994b). However, this estimate is consistent with a more recently modelled (12.8%) mortality percentage for female cattle (Perkins, Henderson & Banney 2012).

Mortality percentage of unweaned and weaned calves can also be as high. A calf mortality percentage of 20 to 25% is believed to have occurred in the district during a prolonged drought in the 1960s (Petty c. 1977), when reported cattle mortality was up to 25% (Reeves & Crellin 1972). Under average seasonal and management conditions in the district, it is suggested by Petty (c. 1977) that mortality from branding to 12 months of age averages 2% for female calves and 6% for male calves. This is consistent with the range of mortality percentages more recently reported by managers in the district for branded and weaned calves (< 12 months old: 1.8–6.2%) (Hooper 2001; Oxley et al. c. 2006).
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As well as the noted association with drought, potential causes of cattle mortality in the district have been associated with misadventure, mismanagement (NT-DPI&F 1992b, 1994c), predation (Eldridge, Shakeshaft & Nano 2002; Petty, Holt & Bertram 1979), plant poisoning (Chippendale & Murray 1963; McKenzie, de Witte & Williams 1994; NT-DPI&F 1994c; 1995a,b,c) and botulism poisoning (Bertram, Oliver & Phillips 1996). Most of these causes of cattle mortality have been recognised on arid rangelands of Western Australia (Smith et al. 2010a, pp.20,28; Thomson 1999, pp.13,30) and south-west Queensland (Clarke 1991, pp.58-67). Plant poisoning is a problem that has also been reported for arid rangelands of northern Mexico (Buller, Hernandez & Gonzalez 1960), south-west USA (Holechek 2002; James, Nielsen & Panter 1992) and South Africa (Kellerman, Naude & Fourie 1996). Other reported causes of mortality have been dystocia and ‘unknown’ causes on arid rangelands of Western Australia (Thomson 1999, pp.11,15) and south-west USA (National Agricultural Statistics Service 2011).

Management strategies to limit cattle mortality in the Alice Springs district have included: weaning; supplementation; culling for excessive age (cull-for-age) at 8 to 10 years of age (NT-DPI&F 1994b); strategic destocking to improve nutrition or to decrease consumption of poisonous plants (NT-DPI&F 1994a,b; 1995a,b,c); agistment; vaccination against botulism (Cann 1991; NT-DPI&F 1994a,c); and control of predators (NT-DPI&F 1994a). Similarly for the arid rangelands of Western Australia, weaning, culling for excessive age and vaccination against botulism have been promoted in order to reduce cow mortality (Agriculture Western Australia 1999; Kok, Collopy & Stretch 1987). Modelling for breeding herds in the Alice Springs district and the Pilbara has shown that reduction in cow mortality has the most positive influence on profitability (McCosker, McLean & Holmes 2010, pp.50,52).
2.1.4. Herd Bulls

2.1.4.1. Bull Health and Breeding Soundness

Herd health and procedures
Under the extensive management conditions of the Alice Springs district, herd health procedures for bulls have generally been limited to vaccination against vibriosis and botulism (B Broome (Elders Pastoral) 2011, pers. comm.), external parasite treatment (for lice) (Leigo c. 2006), and nutritional (urea and P) supplementation.

Recruitment
Selection of bulls for recruitment into breeding herds of the Alice Springs district has been based on testing of undefined aspects of reproductive tract soundness (‘fertility testing’) (NT-DPI&F 1994a, 1995b), structural soundness (NT-DPI&F 1994a,b; 1995a,b,c) and a background indicating potential to acclimatise quickly to arid rangeland conditions (paddock-grazed, locally-bred) (NT-DPI&F 1994b,c; 1995a,b,c).

Bull purchases for south-west Queensland have been made from local and more coastal studs (Clarke 1991, p.24). Structural soundness, temperament and conformation have been important selection criteria for cattle managers in the Pilbara and south-west Queensland (Bortolussi et al. 1999a,b; Clarke 1991, p.32).

Cattle managers in the Alice Springs district have observed that it may take up to 12 months for recruited bulls to acclimatise, if those bulls either originated from ‘soft’ country (NT-DPI&F 1994c), or had excessive body condition prior to translocation (NT-DPI&F 1995c), or were introduced when fresh green pasture was limited (Petty, Holt & Bertram 1979). The growth of young bulls (< 15 months old) in the district has been delayed when introduced onto seasonal feed of low quality and quantity (NT-DPI&F 1995b), but 15- to 18-month-old bulls have appeared to acclimatise more quickly than 2- to 3-year-old bulls (NT-DPI&F 1994b, 1995b). These issues have been
compounded by foot and leg injuries during transportation and after introduction of bulls (NT-DPI&F 1990).

**Culling**
Over a quarter of surveyed cattle managers (28%) in the Alice Springs district have reported that their herd bulls are ‘fertility tested’ every two to ten years (Leigo c. 2006). Assessment of reproductive soundness using serving capacity testing is not easy to undertake or interpret, and this may contribute to a noted reluctance for use in northern Australia (Bertram 2003, p.27). Review of bulls has more frequently been based on ongoing physical and structural soundness, with initial observation of faults during a muster or a bore-run (NT-DPI&F 1995a,c), and then culling of bulls during routine yarding of the breeding herd (NT-DPI&F 1994b). Other than culling herd bulls for excessive age (cull-for-age) at 6 to 8 years of age (NT-DPI&F 1994a,b,c; 1995a,b,c), managers have reported culling for faults such as undesirable temperament, structural unsoundness, lameness, eye problems, or damaged sheath and penis (NT-DPI&F 1994a, 1995b). Similarly in the Pilbara and south-west Queensland, cattle managers have reported selective culling of herd bulls for age, temperament and soundness, as well as for disease, problems of the reproductive tract, and ‘poorly-performing’ calves (Bortolussi et al. 1999a,b; Clarke 1991, p.25).

In general, death and selective culling are the main reasons for removal of herd bulls from a breeding herd. However there has been limited information available for the Alice Springs district, regarding the dynamics of herd bull removal and the effectiveness of selective culling for removal of unsound bulls.

### 2.1.4.2. Mating and Progeny Potential

**Management of mating**
A continuous (uncontrolled, year-round) mating system has been used by nearly all beef cattle properties in the Alice Springs district (Shaw, Bastin & White 1996). Cattle
managers in the district have considered that continuous-mating is best and seasonal
(controlled) mating is potentially disastrous (NT-DPI&F 1994b, 1995c) or impractical
(NT-DPI&F 1994a, 1995b), particularly in terms of paddock and labour requirements
(Schatz 2011, p.91). This is consistent with reasons that have been previously given by
Holroyd (1977, p.23) for northern Australia. However, managers in the district have
also reported some seasonal mating and artificial insemination (AI) (Leigo c. 2006).
Maiden heifers have been the management group most likely to be seasonally-mated in
the district (Schatz 2011, pp.91,98).
Continuous-mating is a feature of the Pilbara and south-west Queensland (Bortolussi et
al. 1999a,b), with some seasonal mating in south-west Queensland from January to May
(Clarke 1991, p.25). In the Pilbara, bull control is a problem, even for seasonal mating
of heifer groups (Smith et al. 2010a, p.33). In contrast, seasonal mating is generally
favoured on arid rangelands of south-west Africa (Hudson 2002, p.33; Latimer 2002)
and south-west USA (LeViness 1993; Sprinkle 2000).
The bull percentages used by cattle managers in the Alice Springs district have been
determined by cattle and paddock factors, such as: breed requirements for Bos indicus
(range: 7–8% bulls) compared to Bos taurus (3% bulls) (NT-DPI&F 1994a); risk that
herd bulls may lose breeding soundness during the season (NT-DPI&F 1994c); and
paddocks with hilly terrain (NT-DPI&F 1995c) or uncontrolled (natural surface) waters
(Petty, Holt & Bertram 1979). In the 1970s, managers reported an average of 3.5% bulls
(range: 0–16%) (Petty, Holt & Bertram 1979) when cattle herds still had a high average
percentage of unselected, unimproved yearling and mature bulls (mickey bulls, scrub
bulls). In the Pilbara, the excessive presence of unselected, unimproved bulls in
association with uncontrolled waters and inefficient (80%) musters has been noted with
respect to the unpredictable effect of these bulls on calf production (McCosker, McLean
& Holmes 2010, p.51). Average bull percentages that have been quoted for the Alice
Springs district by Leigo (c. 2006) (5.6%) and ABARES (2010) (4.6%) are higher, and the quoted range (2–10%) (Leigo c. 2006) has been narrower than the previous report from the 1970s. Similarly, a moderate range of bull percentages has also been noted for other arid rangeland breeding herds in New Mexico (6.5% bulls) (Holechek 1992) and in the North-West province of South Africa (2–4% bulls) (Hudson 2002, p.33).

For properties in the Alice Springs district, there has been limited evaluation of bull percentages and the age structure of herd bull groups.

Suitability for enterprise
Promotion of herd improvement over time in the Alice Springs district has included: the annual bull sales initiated in the 1950s (Hare 1985, p.108); a NT Government bull purchase incentive scheme in the 1980s; and field day events in the 1990s to promote improved bull selection and recruitment (NT-DPI&F 1997, p.183). During the beef-slump of the mid-1970s, the percentage of unimproved bulls increased in cattle herds (average: 6.5% mickey and scrub bulls). The use of station-bred (‘home-grown’) herd bulls has involved retention of uncastrated male calves at branding in hard country or in dry times (NT-DPI&F 1994c). This has been reported by surveyed cattle managers for 14 to 20% of properties (Leigo c. 2006; Petty, Holt & Bertram 1979). Managers in the district have also reported purchase of herd bulls from sales and studs, both in the Northern Territory and interstate (Queensland, South Australia, New South Wales) (Leigo c. 2006; NT-DPI&F 1995c). Managers have reported bull selection criteria (including suitability for the enterprise) with attention to muscling, maturity, polledness, breed and estimated breeding values (EBVs) for carcase traits and fertility (Leigo c. 2006; NT-DPI&F 1994a; 1995b,c). In comparison, cattle managers in the Pilbara and south-west Queensland have reported selection of herd bulls based on temperament, structural soundness and conformation, with differences in the regional emphasis on
coat colour (for the Pilbara) and EBVs (for south-west Queensland) (Bortolussi et al. 1999a,b).

2.1.5. Cows

2.1.5.1. Breeding Herd Management

Herd health and interventions
Cows generally receive minimal individual assistance for problems of health or dystocia under extensive management in an arid region (Thomas, Bailey & Holechek 2000). In the Alice Springs district, herd management activities for cows include dehorning, speying, nutritional supplementation, external and internal parasite control and vaccinations. Vaccines for prophylaxis against botulism, vibriosis (B Broome (Elders Pastoral) 2011, pers. comm.), tick fever and clostridial disease (5-in-1 vaccine, 7-in-1 vaccine) have been purchased by cattle managers in the district (Leigo c. 2006).

Nutrition
Inadequate nutrition on rangelands will result in loss of liveweight, decreased conception rates and (with prolonged low levels of nutrition) increased mortality rates (Entwistle 1984). Research to identify cost-effective strategies for cow nutrition has focused on supplementation trials with P, S, true protein, non-protein N and water medication on arid rangelands of Australia (Clarke 1991, pp.28,33,34; Dixon 1995; Hill 2003) and south-west USA (Judkins et al. 1985; Ray et al. 1993). Research on the arid rangelands of south-west USA has also extended to stocking strategies (Winder et al. 2000) and drylot feeding (Herbel et al. 1984). In the Alice Springs district, cost-effective management of cow nutrition has been restricted to weaning, grazing and supplementation strategies, as noted above.
Recruited heifers

In the Alice Springs district, cattle managers have reported selection of heifers for recruitment into the breeding herd at an average of 18 months old (range: weaner-age to 24 months old) (Leigo c. 2006). Conformation, type and temperament have been reported as the most important selection criteria (Schatz 2011, p.94). Comparison between heifers based on measures of post-weaning growth and fertility is difficult in multiple-sire, continuously-mated herds (Fahey et al. 2000, p.38) on account of the range of heifer ages that confounds assessment of the objective criteria. Managers in the district have reported heifer retention rates as high as 100% and averaging 62% (Leigo c. 2006). Over half of surveyed managers (58%) in the district have reported segregation of heifers as a group, either until the first mating (maiden heifers), second mating (first-calf heifers) or during their lifetime (Leigo c. 2006). Other managers have reported weaning and segregation of maiden heifers only during poor seasons (NT-DPI&F 1995c). Joining of maiden heifers has been reported at 8 to 18 months old (NT-DPI&F 1995a,b) and at an average of 265 kg liveweight (Oxley et al. c. 2006). Mixed-age maiden heifers south of Alice Springs have conceived at an average of 284 kg liveweight (Schatz 2011, pp.38,41).

In the district, 85% of surveyed cattle managers have reported the use of young bulls (< 2.5 years old) for mating maiden heifers (Schatz 2011, p.91), and 16% have reported seasonal (controlled) mating of maiden heifers (Leigo c. 2006), commencing mostly from November to January (Schatz 2011, p.91). The period from the end of December is potentially the best time to control-mate maiden heifers (Petty 1993; Schatz 2011, p.58). This would align subsequent calving and lactation with a grass-growth period associated with summer rainfall for northern Australia (Jephcott, O’Kane & Braithwaite 2001). However, the probability of effective summer rainfall in the Alice Springs
district (> 50mm over a 2-month period) only rises to 70% at Barrow Creek, 300 km north of Alice Springs (Clewett et al. 2003).

Heifer management has been inadequately addressed in areas of the district where handling of cattle herds is minimal and subdivisional fencing is absent or inadequate (Petty 1993). Although some limited reports in the Pilbara (Smith et al. 2010a) and the Alice Springs district (Schatz 2011) have highlighted issues of heifer nutrition, growth and puberty, production problems associated with inadequate heifer management (heifer stunting, dystocia and death) (Entwistle 1984) remain poorly defined in the arid region of northern Australia (Niethe, Bertram & Carpenter 1988; Petty 1993). On other arid rangelands, variation in the reproductive efficiency of maiden heifers that results from differences in age, mature weight, adaptation, breed or supplementation, has been reported from trials in Namibia (calving percentage: 77–91%) (Schoeman 1989), North-West province of South Africa (pregnancy percentage: 8–62%) (du Plessis 2004, p.53) and Arizona (‘calf crop’ percentage: up to 92%) (Ray et al. 1993).

For beef cattle properties in the Alice Springs district, there has been limited information about the performance and fate of recruited heifers.

**Culling**

Criteria reported by cattle managers for culling of cows from breeding herds in the Alice Springs district (Leigo c. 2006; NT-DPI&F 1994a,b,c; 1995a,b,c; Petty, Holt & Bertram 1979) have included aspects of fertility, mothering ability and structural soundness. Managers in the district have reported culling for excessive age from 10 years old (NT-DPI&F 1994a,c; 1995a), but the average reported age of all cull cows has been 8.5 years old (range: 7–12 years of age) (Leigo c. 2006). Similar culling criteria have also been reported for cows on arid rangelands of Arizona (failure to conceive or produce a calf for two consecutive years; physical unsoundness of feet, legs, udder or eyes; > 10 years old) (DeNise & Torabi 1989; Kattnig & DeNise 1992; Tanida,
CHAPTER 2. REVIEW

Hohenboken & DeNise 1988; Tronstad & Gum 1994). In the Pilbara and south-west Queensland, cattle managers have reported that, in addition to being culled for reproductive failure, physical unsoundness, and excessive age, cows have been culled for undesirable temperament, excessive body condition, disease and ‘poor quality calf’ (Bortolussi et al. 1999a,b).

Opportunities to increase culling pressure, especially for an increase in heifer selection pressure, are irregular for a beef cattle enterprise on arid rangelands. In the Alice Springs district, high culling occurs after the sporadic seasons with good nutrition that initiate high cow fertility and increasing cattle numbers. Cattle managers in the district have estimated that on average, 18% of cows are culled each year (Schatz 2011, p.89). In contrast, up to 60% of cows (75% of properties) and up to 99% of heifers (49% of properties) were culled in the district during the 1970s following extremely good rainfall, but poor market prices (Petty, Holt & Bertram 1979). On arid rangelands of Arizona, culling from the breeding herd has been reported for up to 29% of a cow age-group (Kattnig & DeNise 1992), and the average annual culling rate of herds (10–15%) may increase to 50% during drought conditions (Eakin & Conley 2002).

Speying has been undertaken for surplus or cull cows on beef cattle properties in the Alice Springs district (NT-DPI&F 1994b, 1995a). However, these cows may have greater value if they are not speyed, but are instead sold either to breeder markets or to abattoirs (Niethe & Holmes 2008; NT-DPI&F 1994c).

Use of pregnancy testing has been reported by 21% of surveyed cattle managers in the district (Leigo c. 2006). Targeted pregnancy testing in extensive herds is acknowledged as a tool to identify pregnant cows suitable for sale (NT-DPI&F 1994b,c), and non-pregnant cows for export, feedlots or abattoirs (Niethe 1986, p.28; NT-DPI&F 1994a).

For continuously-mated herds on arid rangelands, pregnancy status is not a definitive indicator of breeding potential, so managers in the Alice Springs district have used
lactation status and body condition (NT-DPI&F 1994c) to assess recent reproductive
performance and to identify cows for culling.

In general, records on the dynamics of cow removal by selective culling have been
limited in the district.

2.1.6. Calf Production

2.1.6.1. Conception, Pregnancy and Calving

The time of calving in the Alice Springs district has been linked to improved cow
nutrition and initiation of oestrus following weaning or effective rainfall. Cattle
managers have noted that bulls commence mating activity five to six weeks after
effective rainfall (NT-DPI&F 1994c; Petty c. 1977). Pending summer rainfall in the
district, the majority of calving has tended to be concentrated in the subsequent spring
months (September–December) (Shaw, Bastin & White 1996). Similarly for
continuously-mated herds in the Pilbara and south-west Queensland, cattle managers
have reported a peak in calving from September to January (Bortolussi et al. 1999a,b) as
long as there is no failure of summer rains (Clarke 1991, p.25). A minor calving peak in
February and March for the Alice Springs district (Petty, Holt & Bertram 1979) has
been associated with either early winter weaning, or winter rainfall with growth of
rangeland feed in the southern district (NT-DPI&F 1994c). Anoestrus arising from sub-
optimal nutrition during lactation or drought (NT-DPI&F 1995b) prolongs the inter-
calving interval and, in general, is associated with calving in alternate years (Entwistle
1978).

Pregnancy percentage has an provided an indication of the conception percentage in
seasonally-mated herds: in south-west Queensland for cows and heifers in different
years (range: 40–93%) (Clarke 1991, p.27); and in the North-West province of South
Africa for indigenous and crossbred cows (range: 77–94%) and heifers (13 to 15 months
old) (range: 8–62%) (du Plessis 2004, p.53). In comparison, there has been some
reporting on the pregnancy percentage of continuously-mated cows in the Alice Springs district, on multiple properties (NT-DPI&F 2001b, p.65) and on individual properties (Coventry, Leigo & Saville 2007, p.10; Hill 2003, pp.9,13; Schatz 2011, pp.38,61), but this has provided limited objective information about conception percentage for beef cattle herds of the district.

2.1.6.2. Branding

Branding percentage
The annual branding percentage is the primary reproductive parameter quoted by cattle managers for breeding herd performance efficiency in the Alice Springs district (Henderson 1996), but the accuracy of this parameter is debatable. The apparent number of cows mated in the previous year may be reduced by cow deaths or by inefficient musters (Bolam, Jubb & Kerr 1998; Entwistle 1984; McGowan & Holroyd 2008). The number of branded calves may also be reduced by inefficient musters, with some calves not being branded until the following year when over 12 months of age. In a continuously-mated breeding herd, the number of branded calves is further confounded by the undefined calving period and the multiple musters needed to brand all calves born in one year.

In the district, branding percentages have varied from 25% to more than 75%, according to ‘local consensus’ data for poor to good seasons (NT-DPI&F 1994a,b,c; 1995a,b,c). Similarly for Arizona, reduction in ‘calf crop’ (calving percentage) by 10 to 40% has been associated with a poor season (Eakin & Conley 2002). In the Alice Springs district, different rangeland pasture-types are also associated with a wide range in branding percentage (45–90%) (Bertram, Oliver & Phillips 1996; NT-DPI&F 1994a). In contrast, more conservative ranges of branding percentage have been reported from surveys in the district, over a 10-year period (1991–2000) (52–79%) (ABARES 2010) and for different cow age-groups (53–78%) (Schatz 2011, p.97).
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Based on a branding percentage reported by managers for good seasons in the Alice Springs district (75%), the average inter-calving interval is 16 months. This is consistent with a previous district estimate of more than 15 months (Petty c. 1977), and is also similar to an average interval for beef herds elsewhere in northern Australia (Braithwaite & de Witte 1999).

Branding percentages have averaged over 70% on other arid rangelands in Western Australia (75%, 78%) (Kok, Collopy & Stretch 1987; Stone & Burnside 1987), in the mulga lands of south-west Queensland (72%) (O'Rourke, Winks & Kelly 1992) and in New Mexico ('calf crop' (calving) percentage: 75%) (Holechek, Pieper & Herbel 2004, p.432). In south-west Queensland, locality and seasonal conditions are associated with a wide range in the reproductive performance (Clarke 1991, p.26). In south-west USA, 'calf crop' (calving) percentage has been demonstrated to vary with drought compared to normal years (70% vs. 93%) (Judkins et al. 1985) and with moderate compared to conservative stocking rates (62–78% vs. 82–85%) (Holechek, Pieper & Herbel 2004, p.226; Winder et al. 2000). These ranges are similar to those of ‘calving percentages’ that have been averaged, either for indigenous and introduced cattle breeds in Namibia (75–90%) (Schoeman 1989), or for different indigenous cattle breeds during drought years in the North-West province of South Africa (69–87%) (Collins-Lusweti 2000).

2.1.6.3. Weaning

Managed weaning
Historically, calves in the Alice Springs district have been weaned either naturally by 15 months of age (Petty c. 1977), or with management intervention between 5 to 10 months of age (Leigo c. 2006; NT-DPI&F 1994a, 1995c). Managed weaning has been recognised as a strategy for young cattle education and maiden heifer management, as well as a strategy to promote cow nutrition, reduce post-partum anoestrus, increase first-calf heifer conception (Schatz 2011, p.49), and increase cow survival during dry years.
(NT-DPI&F 1994a,b; 1995a,b,c). Although staggered calving under a continuous-mating system will reduce the positive impact of weaning across a breeding herd (Entwistle 1978), the positive effect has been enough to reveal by default, lower weaning percentages in the district when (managed) weaning is delayed until calves are 8 months old (Petty, Holt & Bertram 1979). In 25 years, the use of managed weaning by surveyed cattle managers in the district has increased from approximately 35% of beef cattle properties (Petty, Holt & Bertram 1979) to 95% of properties (Leigo c. 2006). This has been promoted by installation of internal fencing for effective segregation of weaned cattle. The two reported periods of weaning activity in the Alice Springs district (April–May, August–October) (NT-DPI&F 1995a,c) correspond to the biannual musters needed for continuously-mated breeding herds.

In comparison, weaning has been reported by all surveyed cattle managers in the Pilbara and south-west Queensland (Bortolussi et al. 1999a,b). Managers have reported minimum weaning weights of 50 kg in the Pilbara and 145 kg in south-west Queensland, and also minimum weaning ages of 3 to 6 months old (Bortolussi et al. 1999a,b). Seasonal-mating of herds in south-west Queensland, in particular, has been associated with strategic weaning (Clarke 1991, p.25).

In the Alice Springs district, cattle managers have also reported a range of minimum weaning weights (range: 80–280 kg) (Oxley et al. c. 2006). Almost one-quarter of surveyed managers (23%) have weaned at different weights in accord with seasonal conditions (Leigo c. 2006). The lower estimated weaning weights have reflected weaning of calves from first-calf heifers (Schatz 2011, p.92), strategic early weaning (at 6–20 weeks old) and weaning of steers during drought (NT-DPI&F 1994a,c; 1995b). Similarly during a period of drought in Chihuahua (Ortega-Ochoa et al. 2008), calves have been early-weaned at less than 147 kg liveweight.
CHAPTER 2. REVIEW

Research with seasonally-mated breeding herds on arid rangelands of south-west Africa has demonstrated that variation in weaning weight can be attributed to aspects of the dam’s breed and frame size in that environment (du Plessis 2004, p.55; Schoeman 1989). Similarly in south-west USA, research has demonstrated effects on weaning weight from dam factors (Bellido et al. 1981; Sprinkle et al. 2006; Winder, Rankin & Bailey 1992), as well as from the breed of sire (Holloway et al. 2002), rangeland grazing pressure (Thomas et al. 2007; Thomas, Bailey & Holechek 2000), and pasture growth after seasonal rainfall (Holloway et al. 2002).

In comparison for beef cattle breeding herds in the Alice Springs district, analysis of weaning weight records has been limited to issues such as the seasonal growth rate of calves (Low & Wood 1979).

Weaning percentage
Similar to the annual branding percentage, the annual weaning percentage is calculated with cattle figures that are subject to inaccuracies from cow deaths and estimations of cow or weaned-calf numbers (Entwistle 1984). In the Alice Springs district, cattle managers have reported an average weaning percentage of 76% (range: 35–90%) (Leigo c. 2006). In comparison, managers in benchmarking groups have reported an average weaning percentage of 52% south of Alice Springs and 53% in the Pilbara (McCosker, McLean & Holmes 2010, pp.48,50). On other arid rangelands in south-west Africa, a range in average weaning percentage (63–84%) has been associated with dam adaptation to the environment (Schoeman 1989).

Measures of reproductive efficiency
For the Alice Springs district, the most commonly used parameters for describing reproductive efficiency of beef cattle herds have been annual branding and weaning percentages. Compound measures such as the weight of weaned calves per 100 kg of mated cows have not been used.
CHAPTER 2. REVIEW

2.1.6.4. Reproductive Failure

The extent and cause of reproductive failure (failure to conceive; pre-, peri- or post-natal reproductive losses) is poorly defined for beef cattle breeding herds in the Alice Springs district. A lack of information about ‘failure to conceive’ for extensively-grazed cattle has resulted from: a lack of reports on repeat pregnancy testing of cows (Entwistle 1984; Holroyd 1978); inability of rectal palpation to detect very early embryonic death (Holroyd 1977, p.3); and confounding by a continuous-mating system.

Calculation of reproductive losses between conception and weaning has been limited in the district. Foetal and calf mortality (including abortions) of 5 to 10% has been considered normal in central Australia (Foran 1984).

Causes of pre-natal losses in central Australia may include factors previously recognised in northern Australia, including heat stress, venereal disease (Entwistle 1974) and nutritional factors associated with drought. On arid rangelands of Texas, pre-natal loss has been associated with years of low rainfall together with increased consumption of dietary tannins (Holloway et al. 2002).

Reports about calf death following dystocia and hyperthermia have been noted for the semi-arid region of Australia (Entwistle 1974). For the arid rangelands of the Alice Springs district, calf death has been reported following mismothering, predation (Foran 1984) or death of the lactating cow during poor seasonal conditions (Perry 1962, p.267).

Dystocia has been rarely reported (Oxley et al. c. 2006) because cattle managers generally lack the opportunity to observe calving cows. In contrast, dystocia has been reported in Namibia (average: 0–5%) for herds with indigenous and introduced cattle breeds (Schoeman 1989).

For the Alice Springs district, the focus of surveys and anecdotal reports has been calf death between birth and weaning (combined peri- and post-natal losses) rather than pre-natal losses. These formal and informal reports have indicated 4 to 10% calf mortality.
CHAPTER 2. REVIEW

(Petty c. 1977; Petty, Holt & Bertram 1979; Schatz 2011, p.97). This is similar to that reported for calves from Namibia (average for different cattle breeds: 3.6–9.4%) (Schoeman 1989) and Arizona (average by year 0.4–9.3%) (Ray et al. 1989).

In comparison, some higher post-natal calf loss has been indicated in the North-West province of South Africa (average for different cattle breeds: 9.7–19.6% of calves) (du Plessis 2004, p.54). Some lower post-natal calf loss has also been indicated for breeding herds of New Mexico (4% calf loss), especially with (lower) stocking rates that reduce grazing pressure (0.5% calf loss) (Holechek 1992).

Overall, first-calving heifers, and sometimes second-calving cows, on arid rangelands have tended to have: higher foetal losses (Holloway et al. 2002); some peri-natal loss as a result of dystocia (Clarke 1991, p.63; Sprinkle 2001a); and higher post-natal calf loss (Ray et al. 1989). In the Pilbara and southern Alice Springs district, reproductive loss involving possible pre- and post-natal components has been reported in 8 to 12% of first-calving cows (Schatz 2011, pp.38,44; Smith et al. 2010a, pp.27,29).

For the Alice Springs district, predation by dingoes (3–18% of calves) (Eldridge, Shakeshaft & Nano 2002; Petty, Holt & Bertram 1979) has been a major causal factor in reports about peri- and post-natal calf deaths. The predation of calves reported in New Mexico (up to 5% of calves) has mostly been perpetrated by coyotes, black bears, mountain lions, feral dogs, bald eagles, golden eagles or ravens (USDA, APHIS & ADC c. 1999). In Namibia, leopards or cheetahs have been implicated in predation (10–20% of calves) (Latimer 2002).

In general, information about calf losses in the Alice Springs district has been limited.

SECTION 2.2. LABORATORY TESTING

2.2.1.1. Reasons for Laboratory Testing

Examples of the laboratory testing that is required for disease investigations (NT-DPI&F 2001a) or for health surveys (Thrusfield 1995, pp.266-84) have been given in
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Section 2.1.3.2 above. Biochemical values for beef cattle in the Alice Springs district have been previously reported for investigation of nutritional deficiency (Barnes & Jephcott 1959) and for limited reference ranges (White 1984). Faecal chemistry has been promoted as a means of assessing the nutrition of beef cattle herds, either directly through analysis of faecal percentages of P and N (Faecal %P, Faecal %N) (McCosker & Winks 1994, p.xv), or indirectly through analysis of faecal percentage of dry matter (Faecal %DM) (Lyons, Machen & Stuth 2000). Interpretation of biochemistry and faecal chemistry for cattle in the district has been limited by the lack of regional reference ranges, cut-off values or guidelines for use.

2.2.1.2. Regional Use and Interpretation of Test Results

Regional reference ranges for biochemistry
There are various sources of reference ranges for normal laboratory test values and reference cut-off points for abnormal values, including those from individual laboratories or standard texts such as Latimer, Mahaffey and Prasse (2003), Radostits et al. (2007) and Smith (1990). Specialised reference ranges, like those provided by Deane et al. (1997) or Monke et al. (1998), may be required to account for biological variation in unique populations or analytical variation in laboratory tests (enzymes, urea, glucose, cholesterol, creatinine, globulin, albumin, total protein) (Boyd 1984). Regional reference ranges for extensively-managed cattle herds may be justified where sample collection, storage or transport consistently cause analytical variation, or where biological variation results from physiological adaptations to an extreme environment.

Regional guidelines for faecal chemistry
There are standard reference ranges for faecal chemistry values, but guidelines are needed for interpretation of faecal test results on arid rangelands (Hakkila et al. 1988; Jackson et al. 2009, p.4; Nunez-Hernandez et al. 1992). This requirement has persisted, even with the introduction of Faecal Near Infra-red Spectroscopy (F-NIRS) (Coates
CHAPTER 2. REVIEW

2004) to supersede the use of faecal chemistry on rangelands of north Australia. F-NIRS has been used with confidence to predict dietary digestibility and dietary ‘non-grass’ (carbon 3 (C3) plant content for rangelands of north Australia), however on spinifex and mulga lands, there have been regionally-specific and non-regionally-specific problems. Firstly, F-NIRS has not provided reliable predictions of dietary P (Coates 2004, p.31), so analysis of Faecal %P (faecal chemistry) is still necessary. Secondly, F-NIRS has not been calibrated for arid rangelands (Coates & Dixon 2007) and has not provided reliable predictions of dietary N as a measure of available dietary CP in this region. A high dietary percentage of some C3 plants (e.g. forbs) has been related to an under-prediction of diet quality by F-NIRS. A high dietary percentage of other C3 plants, such as topfeed species with an evident tannin content, has been related to over-prediction of available dietary N and unpredictability of average daily gain (Jackson et al. 2009, p.5). Less digestible topfeed species may also be over represented in faecal samples (Squires & Low 1987).

SECTION 2.3. SUMMARY

In this chapter, aspects of the natural environment and the cattle industry that limit or support beef cattle production in the Alice Springs district have been reviewed. Limited measures of performance or production for breeding herds in the district have been contrasted with aspects of beef cattle performance on comparable arid rangelands of Australia, south-west Africa, south-west USA and northern Mexico. With reference to cattle nutrition on arid rangelands, the review has also addressed limitations to the use and interpretation of laboratory testing. In the following chapter, the materials and methods are described for a study based on three primary beef cattle projects in the northern Alice Springs district.
CHAPTER 3. MATERIALS AND METHODS

SECTION 3.1. INTRODUCTION
In this chapter, the materials and methods of the study described in this thesis (present study) are detailed, along with relevant background information from the primary beef cattle projects. These details address the minimal conditions for collection of basic biological data, as per Holroyd and O’Rourke (1988), as well as the challenges for long-term collection of cattle data and samples under extensive-grazing conditions.

SECTION 3.2. SITES

3.2.1. Location
The present study involved retrospective analysis of data and laboratory results from three primary beef cattle projects on arid rangelands of the northern Alice Springs district (sites A, B and C). All sites were located within the arid area of the Northern Territory (Figure 3-1). The primary project at each site involved collection of data and samples for four or more years (Table 3-1).

3.2.1.1. Paddocks
The paddock features, infrastructure for cattle management and relative areas of rangeland pasture-types are detailed in Appendix 1, along with photographic examples of the major landsystems in the paddocks. Mulga shrubland, spinifex sand plains, and alluvial plains with associated range areas were features of the three sites.

3.2.1.2. Climate
The primary beef cattle project at each site was undertaken under a range of poor to excellent seasonal conditions. Annual rainfall totals and the range of temperatures (average monthly maximum and minimum) are summarised for the study in Table 3-2, along with description of seasonal conditions, based on two periods of 6-months cumulative rainfall per year. The temperatures were based on daily temperatures.
CHAPTER 3. MATERIALS AND METHODS

recorded at the nearest weather station (Bureau of Meteorology 1991-2001; Low et al. 1979). The monthly rainfall totals recorded at the nearest permanent recording station are graphed for each site in Appendix 2.

Figure 3-1. Location of sites with respect to climatic classifications for the Northern Territory.
## Table 3-1. Location and primary beef cattle projects for sites.

<table>
<thead>
<tr>
<th></th>
<th>site A</th>
<th>site B</th>
<th>site C</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Distance from Alice Springs</strong></td>
<td>45 km north-west of Alice Springs via Tanami highway</td>
<td>180 km north-east of Alice Springs via Plenty highway</td>
<td>160 km north-west of Alice Springs via Tanami highway</td>
</tr>
<tr>
<td><strong>Co-ordinates (approx. centre)</strong></td>
<td>-23° 30’ S, 133° 30’ E</td>
<td>-23°S, 134° 45’ E</td>
<td>-23°S, 132° 15’ E</td>
</tr>
<tr>
<td><strong>Total paddock area</strong></td>
<td>180 km²</td>
<td>540 km²</td>
<td>116 km²</td>
</tr>
<tr>
<td><strong>Primary beef cattle project</strong></td>
<td>CSIRO Rangeland Ecosystem Dynamics Study (Low 1978a)</td>
<td>NTG Pilot Cattle Herd Health and Performance Study (Coventry, Leigo &amp; Saville 2007)</td>
<td>NTG/MLA Producer Demonstration Site (Hill 2003)</td>
</tr>
</tbody>
</table>
### Table 3-2. Summary of rainfall and temperatures at sites.

<table>
<thead>
<tr>
<th></th>
<th>site A</th>
<th>site B</th>
<th>site C</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Rainfall totals</strong> and seasonal conditions, by financial year</td>
<td><strong>YEAR [RAIN (mm)] CONDITIONS</strong></td>
<td><strong>YEAR [RAIN (mm)] CONDITIONS</strong></td>
<td><strong>YEAR [RAIN (mm)] CONDITIONS</strong></td>
</tr>
<tr>
<td>end 1975</td>
<td>[ 439] excellent</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Temperature range</strong>, by financial year</td>
<td><strong>YEAR</strong></td>
<td><strong>RANGE (°C)</strong></td>
<td><strong>YEAR</strong></td>
</tr>
<tr>
<td>1975/76</td>
<td><strong>insufficient data</strong></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

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1 Based on records at nearest contemporary recording site.
2 Descriptions for seasonal conditions that are used in the present study.
3 Financial year (July to June); calendar year (January to December).
4 Based on seasonal descriptions for calendar years (Low & Wood c. 1980) and financial years (Low 1978b), plus rainfall and described forage conditions (Low & Wood 1979).
5 Based on rounded, average monthly minimum and maximum temperatures, as per records of nearest weather station.
CHAPTER 3. MATERIALS AND METHODS

3.2.2. Cattle
The present study was based on three continuously-mated beef cattle breeding herds and the extensive management used at the time of each primary beef cattle project (Appendix 3). The annual numbers of cattle at each site were based on muster records or reports, plus the site-specific criteria given in Sections 3.3.3.2 and 3.3.3.3 below. The numbers of mated cows, herd bulls, and branded or weaned calves are tabled in Appendix 4. The numbers of cows at muster varied at each site: up to 331 mixed-age Shorthorn cows at site A (Appendix 4); up to 1,231 mixed-age Poll Hereford cows at site B (Appendix 5); and up to 159 mixed-age Shorthorn x Santa Gertrudis cows at site C (Appendix 4). The numbers of cows mustered by year at each site are displayed with Gantt Charts in Appendix 6 and the numbers of cows removed or recruited each year are tabled in Appendix 7. Adjustment of cattle numbers, in order to better suit seasonal feed conditions, contributed to a substantial range in animal (cattle) equivalents (AE) and annual stocking densities at each site (Appendix 5).

SECTION 3.3. SAMPLES AND DATA FOR STUDY

3.3.1. Collection at Sites
Collection of data and samples from the rangeland pasture or cattle at the sites was undertaken by project and beef cattle property personnel during musters and surveys for the primary beef cattle projects (Appendix 8). Musters were undertaken at variable times, at least twice a year (Appendix 9). Surveys between musters enabled collection of additional data and samples. Collections were based on basic biological measures and standard sampling for cattle investigations, with some adaptation of collection techniques to minimise time and stress on livestock. In the absence of specific data or samples from any one of the primary beef cattle projects, analyses and discussions were focused on collections from the other two sites.
CHAPTER 3. MATERIALS AND METHODS

Cattle at site A were also involved in a BTEC property program (NT-DPP 1980) that included collection of blood for brucellosis testing (Low & Wood c. 1980). The primary beef cattle projects at sites B and C were completed after the declarations of ‘Freedom from Brucellosis’ (May 1989) (NT-DPI&F 1991a, p.10) and ‘Impending Freedom from Bovine Tuberculosis in the Northern Territory’ (end of 1992) (NT-DPI&F 1993, p.2).

Rangeland Data
Direct and indirect indicators of pasture growth were recorded. For site A, records were based on aerial surveillance and herbaceous vegetation scores (greenness, abundance) (Low, Müller & Dudzínski 1980). These vegetation scores helped to confirm categorisation of seasonal conditions for the study, as per Appendix 10. For site B, creek windmill grass (*Enteropogon ramosus*) was assessed on five Rangeland Condition Assessment (RCA) locations, by stage of greenness, level of recruitment (Appendix 10), percentage utilisation (grazed-class method), and set point photography (Schmutz 1971). Creek windmill grass was used as the pasture indicator because it has low to moderate palatability (Bowman & King 1998) and is variably grazed by cattle according to seasonal feed conditions (Squires & Siebert 1983). In the absence of a uniform measure of rangeland diet quality across all sites, cumulative rainfall was collated for 1-month, 2-month or 6-month periods (sites A, B and C) as an indirect indicator or predictor of pasture growth. On arid rangelands, increasing periods of cumulative rainfall equate to longer periods for pasture germination and growth (Bertram, Oliver & Dance 1996; Jurado & Westoby 1992), which in turn can be related to beef cattle production.

Cattle Data and Samples
At each site, data and samples were collected from individual cattle and groups of cattle from different classes, as detailed in Appendix 10. If required, stratified sampling was used to select representative groups (Appendix 11). Collected data included details of
CHAPTER 3. MATERIALS AND METHODS

age, liveweight\(^1\), frame size, body condition, pregnancy, lactation, and some aspects of bull breeding soundness (Appendix 12, parts a. and b.). As an example of differences in methodology between the primary beef cattle projects, cattle body condition was scored by a different operator (Appendix 8) and a different scale (Appendix 12 a. and Appendix 10) at site B (scale: 1–5) and site C (scale: 1–6). Appendix 10 also shows the relationship between body condition scores (BCS) and descriptive (categorical) terms for body condition. Collection of blood, faecal and oesophageal extrusa samples at site A was undertaken according to the design of the primary beef cattle project or the concurrent BTEC property program (Low et al. 1973; Low 1978b; Low & Wood c. 1980). Collection of blood and faecal samples at sites B and C was undertaken according to standardised collection techniques (NT-DPI&F 2001a).

3.3.2. Management of Samples and Data

Sample Testing

Although no results of laboratory testing on samples from site A could be used for the present study, results of laboratory testing on blood and faecal samples from sites B and C were suitable for use. Processed samples were tested at one or more laboratories (Appendix 12 b.). Interpretations of test results were based on reference ranges of the testing laboratory (NT-DPI&F 2001a) or the normal ranges used at the time of testing (J Allen 2006, pers. comm.)\(^2\). Reference to additional literature was made for the tests of blood glutathione peroxidise (GSH-Px)\(^3\), leptospiral serology (Chappel 1993; Faine et al. 1999, p.114), BHV1 serology (Young 1993), BVDV serology (Kirkland & MacKintosh 1993; McGowan et al. 2008), other reproductive pathogens (Hum & McInnes 1993; Vaughan 1993), faecal parasitology (Hungerford 1990; Radostits et al.

\(^1\) Liveweight was recorded with no standard curfew period at sites B and C, and with overnight food and water curfew at site A (Appendix 12 a.).

\(^2\) After 2006, the normal range for plasma vitamin A was refined to 0.26-0.60 mg/L and the organisation was renamed ‘Department of Agriculture and Food Western Australia’ (J Allen 2011, pers. comm.).

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Data Processing
Data were edited and graphed in Microsoft Office Excel 2003 and collated in Microsoft Office Access 2003. A survey to detect 5% errors with 2% precision (p = 0.05) indicated less than 0.22% errors in the processed laboratory data.

3.3.3. Interpretation and Analysis of Data

3.3.3.1. General

Data for present study
Data for the present study were sourced from the three primary beef cattle projects and included: records of field observations and measures (sites B and C); results of laboratory measures (sites B and C); project descriptions in published reports (sites A and C); and data in an unpublished report (site A). These data were augmented by records of interviews with the cattle managers or research officers who were involved in the primary beef cattle projects. All data analysed for the present study have been cited if sourced from unpublished and published reports on the primary projects. The summaries and analyses (descriptive, statistical) undertaken exclusively for the study have been reported in the study results. Where relevant, original descriptions and results from the primary beef cattle projects have been cited for the study’s materials and methods, or for the study’s discussion (Sections 7.2.1.1 to 7.3.5.3).

Descriptive analyses
Cattle data and sample test results were summarised in tables, based on ranges and averages for three or more years. This recognises recommendations for collection and averaging of such data, either for a minimum of three years (Bolam, Jubb & Kerr 1998), for three reproductive cycles within a 5-year period (O'Rourke & Howitt 1986), or for
five years of record-keeping (McCosker, McLean & Holmes 2010, p.16). The summary tables provided descriptive analyses, managed herd data where there was high between-year variability, and managed data in categories for statistical analyses.

Categorisation of data assisted identification of risk factors associated with lower measures of herd health and performance in the study. As detailed in Appendix 10, categories were based on individual animal variables, representative cattle groups, year-periods, opening seasonal conditions and levels of other explanatory factors (variables) that are described in Section 3.3.3.4 below. Cattle age-data were categorised by gender and class. Year-periods were categorised by either calendar year (January–December) or financial year (July–June).

Statistical analyses
Statistical analyses of data were undertaken in Microsoft Office Excel 2003 and StatSoft Statistica data analysis software.

In general, continuous variables were analysed using linear regression and a Pearson’s (product moment) correlation co-efficient (StatSoft 1984-2004), a Student’s t-test (Microsoft 1985-2003), or Kruskal-Wallis tests of difference between ranked categories (StatSoft 1984-2004). Where there were multiple test results relating to one individual in a category, only the earliest test result was retained for analyses. Key data distribution values (percentiles) (StatSoft 1984-2004) in test datasets were used as cut-off points in order to examine levels of normality, potential deficiency or potential disease. The use of this principle is detailed as a screening strategy for analysis of the variation in the laboratory test results.

In general, dichotomous and ordinal variables were reported as proportions and percentages of categories with a 95% confidence interval (95% CI), particularly when there was sub-sampling or extrapolation of herd data. A significant difference (p < 0.05) between categories was indicated when no overlap was found in the 95% CIs. If a low
proportion or percentage in a category did not meet the requirements for normal approximation of a binomial distribution (np ≤ 5 or n(1-p) ≤ 5) (Dawson-Saunders & Trapp 1994, p.144), then categories of a similar nature were combined before calculation of the 95% CI, or the exact binomial method was used as per Clopper-Pearson (AusVet Animal Health Services 2004) to calculate the 95% CI, or categories of variables were removed from the analyses.

Some categorical data were examined with an odds ratio and 95% CI, as per Woolf’s method (Kahn & Sempos 1989, p.58), with a chi-square test for independence (Microsoft 1985-2003), or with the Mann-Whitney U-test (for rank-sum) and the Kolmogorov-Smirnov test (for normality) (StatSoft 1984-2004). In general, statistical differences were reported either as highly significant (p < 0.01), as significant (p < 0.05) or as a tendency (p < 0.1).

### 3.3.3.2. Herd Bulls

The data on herd bulls were limited by factors at each of the three sites (Table 3-3).

Techniques to manage the data limitations were implemented for each site (Table 3-4).

<table>
<thead>
<tr>
<th>Factors</th>
<th>site A</th>
<th>site B</th>
<th>site C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Objectives of primary beef cattle project*</td>
<td>1\textsuperscript{b, c}</td>
<td>1\textsuperscript{o}</td>
<td>1\textsuperscript{o}</td>
</tr>
<tr>
<td>Absence of individual cattle identification</td>
<td>1\textsuperscript{o}</td>
<td>1\textsuperscript{o}</td>
<td>1\textsuperscript{o}</td>
</tr>
<tr>
<td>Loss of individual cattle identification</td>
<td>nu</td>
<td>1\textsuperscript{o}</td>
<td>1\textsuperscript{o}</td>
</tr>
<tr>
<td>Absence of muster records/reports†</td>
<td>2\textsuperscript{o}</td>
<td>2\textsuperscript{o}</td>
<td>1\textsuperscript{o}</td>
</tr>
<tr>
<td>Limited muster records/reports</td>
<td>1\textsuperscript{o}</td>
<td>1\textsuperscript{o}</td>
<td>1\textsuperscript{o}</td>
</tr>
<tr>
<td>Low mustering percentage</td>
<td>1\textsuperscript{o}</td>
<td>1\textsuperscript{o}</td>
<td>1\textsuperscript{o}</td>
</tr>
<tr>
<td>Limited age data</td>
<td>1\textsuperscript{o}</td>
<td>nl</td>
<td>1\textsuperscript{o}</td>
</tr>
</tbody>
</table>

* Objectives of the primary beef cattle projects at sites A and C did not include recording of herd bull dynamics or measures of the herd bull influence on calf production.
† ‘Records’ refer to raw data from field observations; ‘reports’ refer to draft (unpublished) or final (published) narrative summaries and descriptive analyses based on raw data from field observations.
1\textsuperscript{o} = primary limiting factor; 2\textsuperscript{o} = secondary limiting factor.
nl = not limiting; nu = not used; \textsuperscript{b} = limiting for bulls; \textsuperscript{c} = limiting for cows.
Table 3-4. Management techniques for data on herd bulls at sites A, B and C.

<table>
<thead>
<tr>
<th>Techniques</th>
<th>site A</th>
<th>site B</th>
<th>site C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Editing of bull records*</td>
<td>nu</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>Extrapolation of bull records/reports</td>
<td>+</td>
<td>+</td>
<td>nu</td>
</tr>
<tr>
<td>Records of bulls mustered</td>
<td>nu</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>Reports of bulls weighed</td>
<td>+ †</td>
<td>nu</td>
<td>nu</td>
</tr>
<tr>
<td>Records/reports of bulls released from yard</td>
<td>+ ‡</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>Repeat-records of individual bulls</td>
<td>nu</td>
<td>+ §</td>
<td>nu</td>
</tr>
<tr>
<td>Multiple types of individual bull identification</td>
<td>nu</td>
<td>+</td>
<td>nu</td>
</tr>
<tr>
<td>Records/reports on manager observations</td>
<td>+</td>
<td>+</td>
<td>nu</td>
</tr>
</tbody>
</table>

* Where duplication, biologically inconsistency or collection error were detected, the affected data were edited and noted as such in the study results.
† as per Low & Wood (c. 1980).
‡ released into paddock (Low 1978b).
§ records for three to five musters.
nu = not used.

Indicators of herd bull dynamics (bull percentage, percentages of bulls that were either recruited or removed, plus mortality percentage) were examined in financial year categories. This enabled appraisal of some of the activities that maintain an adequate number of functional bulls in a breeding herd. As indicated in Appendix 10, financial year categories were combined on the basis of the opening seasonal conditions.

Herd Bulls in the Paddock

Number and age

The annual bull percentage was calculated according to the following equation:

\[
\text{Bull percentage} = \left( \frac{\text{Number of herd bulls}}{\text{Number of cows, mated with the bulls}} \right) \times 100 \% 
\]

The 95% CI was also calculated for each bull percentage. The annual calculation for each site used the number of herd bulls in the paddock and the number of cows mated to produce calves in that year (Appendix 4) (sites A, B and C).
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The mean annual number of branded calves per herd bull with 95% CI was calculated using the cattle numbers in Appendix 4, and then was examined with respect to the seasonal conditions (Table 3-2) associated with the year of branding (sites A and B). The edited and extrapolated number of herd bulls took into account: low mustering efficiency as a result of obstinate bull behaviour and seasonal surface waters (WA Low 2006, pers. comm.) (site A); limited recording during dry seasonal conditions (site B); and an estimated (5%) annual loss of identification ear-tags from individual bulls (site B).

Recruitment of Herd Bulls

Number
The annual recruited percentage with 95% CI of herd bulls was calculated from extrapolated (nett annual), extra numbers of reported bulls (site A), and from the numbers of newly-tagged herd bulls that had no previously recorded individual identification ear-tag (sites B and C).

Removal of Herd Bulls
Records were closed for individually-identified herd bulls that were removed from the herd records, either dead (euthanased or found dead) or alive (culled, agisted or destocked). This included sale to various markets (turned off), agistment for drought management, and segregation for other breeding purposes. Records were retained on the database for other identified bulls that were absent from muster (missing).

Reasons and numbers
The reasons for removal were based on previous reports and interviews (site A), or were recorded as per comment from cattle managers (sites B and C). The annual removed percentage with 95% CI of herd bulls was extrapolated from the (nett annual) reduced numbers of reported bulls (site A), or calculated from the recorded annual numbers of bulls that were removed (dead or alive) (sites B and C).
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Deaths
The annual recorded mortality percentage with 95% CI of herd bulls was calculated from the number of individually-identified bulls that were confirmed dead or euthanased (site B). If death of an individually-identified bull was assumed by extrapolation and no carcase was recorded, death was then considered to be ‘unconfirmed’. The annual unconfirmed mortality percentage of herd bulls was extrapolated, as per O’Rourke et al. (1995), from the percentage of bulls that was recorded persistently absent from five consecutive musters. This percentage was then adjusted for the estimated (5%) annual loss of individual identification ear-tags (site B).

3.3.3.3. Cows
Some factors were limiting for data on cows (Table 3-3). Techniques to manage these data limitations were implemented for each site (Table 3-5).

Table 3-5. Management techniques for data on cows at sites A, B and C.

<table>
<thead>
<tr>
<th>Techniques</th>
<th>site A</th>
<th>site B</th>
<th>site C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Editing of cow records*</td>
<td>nu</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>Extrapolation of cow records/reports</td>
<td>+</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>Records of cows mustered</td>
<td>nu</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>Records of cows surveyed</td>
<td>+ †</td>
<td>+</td>
<td>nu</td>
</tr>
<tr>
<td>Reports of cows weighed/pregnancy tested</td>
<td>+ ‡</td>
<td>nu</td>
<td>nu</td>
</tr>
<tr>
<td>Records/reports of cows released from yard</td>
<td>+ §</td>
<td>nu</td>
<td>+</td>
</tr>
<tr>
<td>Repeat-records of individual cows</td>
<td>nu</td>
<td>+ **</td>
<td>+ **</td>
</tr>
</tbody>
</table>

* Where duplication, biologically inconsistency or collection error were detected, the affected data were edited and noted as such in the study results.
† as per Low & Hodder (1976).
‡ as per Low & Wood (c. 1980).
§ released into paddock (Low 1978b).
** records for three to five musters.
nu = not used.

Indicators of cow reproductive performance and herd dynamics were based on edited or extrapolated numbers of cows in the paddock for each site (Appendix 7).
Cows in the Paddock

The edited and extrapolated number of cows was based on multiple data sources (Table 3-5) and took into account: the limited numbers recorded at a survey during drought (site B); annual mustering inefficiency (site B: estimated 2% in 1991/92\(^{1}\)); annual loss of individual identification (numbered) ear-tags (site B: estimated 1–2%); and loss of cows with individual identification ear-tags (site B: 3.5% in 1995; site C: 14% in 2000).

The performance of the breeding herd was assessed by indicators of reproductive performance potential (conception, lactation and branding percentages), reproductive performance efficiency (weaning percentage and weight of weaner-age calves), and breeding herd dynamics (percentages of cows that were either recruited or removed, plus mortality percentage). These indicators were analysed with respect to variables of time (month, year or time of muster), climate (temperature or rainfall) or biology (age, lactation, liveweight or body condition). As detailed in Appendix 10, variables were grouped in standardised categories: financial year categories were combined on the basis of the opening seasonal conditions; 6-months cumulative rainfall categories were defined according to the monthly rainfall records (Appendix 2) and the potential effectiveness of rainfall (Perry 1962, p.121); body condition scores (BCS) were combined in equivalent descriptive categories\(^{2}\); and age cohorts were combined in two age-categories.

\(^{1}\) The annual level of mustering inefficiency at site B (financial-year range: 0.2–3.8%) was calculated using records at muster for individually-identified cattle over three consecutive musters. However, the annual level could not be calculated for two financial year periods, due to a lack of muster records before the primary beef cattle project commenced (beginning of 1991) and during drought (end of 1994). In the absence of a calculated level, the annual mustering inefficiency at site B in 1991/92 was estimated, based on the average of the range for other financial years.

\(^{2}\) The two different scales for BCS were divergent for cows in ‘fat’ condition (Appendix 10).
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Conception

Numbers
Cows were pregnancy-tested by rectal palpation at the muster. The month of conception was estimated by the date of pregnancy testing and the stage of pregnancy (foetal aging).

The monthly conception percentage was calculated from the number of conceptions per month, as a percentage of the number of cows pregnancy-tested at the muster immediately following conception (sites A and B).

The annual conception percentage with 95% CI was calculated from the number of cows with at least one conception per financial year, as a percentage of the cows pregnancy-tested at three consecutive musters (4 to 8 months apart) (site B). Results of three consecutive pregnancy tests, during or after a defined financial year, enabled detection of conceptions for twelve months in a continuously-mated herd. Two pregnancy tests by rectal palpation have been considered satisfactory for estimation of conception percentage in an extensively-mated herd (Holroyd, Arthur & Mayer 1979), however additional muster data will help detect conceptions that are either missed if musters are more than 7 months apart, or are not covered by the normal timing of management musters. Detection of conceptions in individual cows using multiple rectal palpations after a mating period has been previously described by Holroyd (1987). Because the three primary beef cattle projects were independent of each other, field standardisation of the pregnancy testing technique to assist with interpretation by different operators at the different sites could not be undertaken. The representative nature of the pregnancy testing data was limited by the number of cows that remained in the paddock after muster (inefficient musters), the number of mustered cows not pregnancy-tested (cull cows), and long inter-muster periods that precluded detection of some conceptions by rectal palpation (site A: August–September 1972; site B: March–July 1994, March–June 1996). The pregnancy testing data were edited, where required
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to remove both repeat recordings of individual conceptions at consecutive musters (sites A and B) (WA Low 2006, pers. comm.) and biologically inconsistent data (site B).

Rainfall and muster effects
Pearson’s correlation co-efficients were calculated between the monthly conception percentage and monthly rainfall totals (Appendix 2), and between the monthly conception percentage and average monthly minimum temperatures, as per Table 3-2. Data pairs were not included in the correlation where there was suspected to be insufficient data to indicate all conceptions for specific months at site A (August–September 1972) and site B (March–August 1994).

The mean monthly conception percentage with 95% CI was examined in relation to the temporal distribution of musters and effective rainfall. The period of influence on potential conceptions was assumed to be two months during or immediately after a muster event when calves may have been weaned (sites A and B), one month after a significant rainfall event (> 25 mm) (Perry 1962, p.127), and two months after a significant rainfall event with ‘follow-up’ rainfall (> 50 mm).

Body mass effects
The reported mean weight-at-conception per calendar year for cows at site A (Low & Wood c. 1980) was averaged for consecutive years to provide default financial year values.

The weight and BCS of heifers and young-to-aged cows at conception (measures-at-conception) (sites B and C) were extrapolated from the liveweight and BCS of the individuals confirmed ‘non-pregnant’ by rectal palpation at one muster and ‘pregnant’ at the subsequent muster. If pregnancy was confirmed in the first trimester, measures-at-conception were based on the mean liveweight and median BCS for both musters. If pregnancy was confirmed in the second or third trimester, measures-at-conception were based on the liveweight and BCS for the muster prior to confirmation of pregnancy.
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This extrapolation provided measures-at-conception for site C in the absence of foetal-aging data and was repeated for site B to provide a comparative dataset.

The imprecision of individual extrapolated measures-at-conception was addressed by calculating mean weight-at-conception with 95% CI per financial year, plus median and range of BCS-at-conception.

Lactation

Temporal and rainfall effects

The lactation percentage with 95% CI was examined: per 6-months cumulative rainfall using lactation records at muster† compiled in five categories of potential rainfall effectiveness (Appendix 10); and per financial year using lactation records of the cows present at each biannual muster (double-mustered)‡ (sites B and C). Double-mustered cows excluded those culled at the initial muster, those introduced during the year and those that missed recording at one or both musters (sites B and C). Mustering efficiency was reduced for recently-calved cows, as well as after rain at site B (early 1992) and site C (early 2000 and 2001). Lactation records were collected for limited groups of cows at site B in 1992 and 1993 (no ‘heavy-pregnant’ or ‘cull’ cows), and in late 1994 (only survey groups during drought).

† Lactation percentage at muster
\[ \text{\%} = \left( \frac{\text{Number of cows recorded `lactating` at muster} \times 100}{\text{Number of cows recorded§ at muster}} \right) \%
\]

‡ Lactation percentage per financial year
\[ \text{\%} = \left( \frac{\text{Number of cows recorded `lactating` at one or both biannual musters} \times 100}{\text{Number of cows recorded§ at two biannual musters}} \right) \%
\]

§ recorded either ‘lactating’ or ‘non-lactating’
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Body condition and age effects
The lactation percentage with 95% CI was examined: per cow body condition using lactation records at muster compiled by BCS; and per cow age-group using lactation records compiled in four cow age-groups (Appendix 10) (sites B and C). The same database was used to examine pregnancy percentage with 95% CI per cow variables (lactation status, body condition and age-group) (site B).

Lactation failure
Recorded absence of lactation (lactation failure) after a confirmed (first-trimester) pregnancy, in conjunction with assessment of relative BCS and pregnancy status, was used to determine reproductive loss per cow age-group (sites B and C). The total loss, as a percentage of the number of pregnancies, was calculated with 95% CI. No lactation records were available for site A. Post-natal calf losses\(^1\) with 95% CI (reported: site A; recorded: site B) were also calculated as a percentage of the number of branded calves.

Calf Production

Numbers
The annual branding percentage was calculated according to the following equation.

This is in line with previous discussion by Entwistle (1984) about the use of branding figures:

\[
\text{Branding percentage} = \left( \frac{\text{Number of branded calves}}{\text{Number of cows, mated with bulls to produce the calves}} \right) \times 100\% \]

Branding percentage was reported as a whole number and the 95% CI was calculated.

Annual numbers of mated cows and branded calves are given in Appendix 4 (sites A and B). Calculations were based on the edited number of cows in the paddock (site B).

The number of yearling heifers was not reported in the total number of cows in the

---

\(^1\) Post-natal calf loss before branding (between calving and branding) was based on an original report for site A (Low & Wood c. 1980) and recorded paddock or yard observations by property staff (as per Appendix 8) during musters at site B.
paddock at site A (Low 1978b), so branding percentages were calculated after subtraction of the calves produced by the yearling heifers. Average annual branding percentages were calculated for at least four years (sites A and B).

The annual weaning percentage was calculated according to the following equation:

\[
\text{Weaning percentage} = \left( \frac{\text{Number of weaned calves \times 100}}{\text{Number of cows, mated with bulls to produce the calves}} \right) \% 
\]

Weaning percentage was reported as a whole number and the 95% CI was calculated. Annual numbers of mated cows and weaner-age calves\(^1\) are given in Appendix 4 (sites B and C).

Average annual weaning percentages were calculated for at least three years (sites B and C). Calculations were based on the edited number of cows in the paddock (sites B and C) and retrospectively edited numbers of weaned calves (site B). At site B, there were some musters with less than 100% efficiency, where (assumed equal) numbers of male and female weaner-aged calves were missed in the paddock. These weaner-aged calves missed being counted and removed with their age cohorts during the managed weaning. Eventually the missed female calves were identified, tagged and counted when mustered as 12- to 18-month-old heifers. The total number of male and female calves that missed the managed weaning was estimated as twice the number of new-tagged 12- to 18-month-old heifers. This number was added to the annual number of weaned calves for the relevant calendar year.

**Weight**

The mean weight with 95% CI of weaner-age calves was compared with the seasonal conditions prior to muster (Table 3-2). Calculations were based on site-dependent

---

\(^1\) Managed weaning of all calves was not undertaken at all sites, so ‘weaner-age calves’ refers to calves that were either permanently removed from their mothers (sites B and C: ‘weaned calves’), or calves that may have remained in the paddock with their mothers (site A: ‘unweaned calves’, site B: ‘missed managed-weaning muster’). Only weaner-age steers, not weaner-age heifers, were regularly removed from site A.
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criteria: the mean liveweight reported for mixed, unweaned calves (6–12 months old) at muster (Low & Wood 1979) (site A); the male-to-female ratio of weaned calves and the mean liveweight with 95% CI for weaned calves surveyed at muster (site B); or the mean liveweight with 95% CI for all weaned calves at muster (site C). Although the mean weight of unweaned calves at site A did not reflect managed weaning, it was comparable on the basis of seasonal conditions that influence the liveweight at which cattle managers in the Alice Springs district have weaned calves (Leigo c. 2006).

The weights of weaned calves, together with the number and weight of cows mated, were also used to calculate compound measures of reproductive efficiency.

The annual average weight of weaned calves per mated cow was calculated using the annual number of mated cows and the corresponding total weight of weaned calves (sites B and C). The total weight of calves produced was modelled on the mean liveweight and annual numbers of weaned calves.1

The annual average weight of weaned calves per 100 kg of mated cows was calculated using the annual average weight of weaned calves per mated cow and the mean liveweight of heifers and young-to-aged cows at the first muster of the calendar year (sites B and C).

Removal of Cows

Records were closed for individually-identified cows that were removed from the herd records, either dead (euthanased or found dead) or alive (culled, agisted or destocked). This included sale to various markets (turned off), agistment for drought management, and segregation for other breeding purposes. Records were retained on the database for other identified cows that were absent from muster (missing).

---

1 The total weight of calves produced was not modelled for site A because there was insufficient detail reported in the primary beef cattle project to confirm the total annual number of weaner-age calves.
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Reasons and numbers
The reasons for removal were based on previous reports (site A), or were recorded as per comment from cattle managers (sites B and C). The total number of removed cows at site A was not reported, but the nett annual numbers of cows removed (as displayed in Appendix 7) were extrapolated from the reduced numbers released into the paddock (Low 1978b; Low, Müller & Dudzínski 1980) after pregnancy testing at muster (Low & Wood c. 1980). The annual removed percentage with 95% CI of cows was calculated from recorded and reported annual numbers of cows removed (dead or alive) (sites B and C).

Deaths
The annual recorded mortality percentage with 95% CI of cows was calculated from the number of individually-identified cows that were confirmed dead or euthanased (sites B and C).

If death of an individually-identified cow was assumed by extrapolation and no carcase was recorded, death was then considered to be ‘unconfirmed’. The annual unconfirmed mortality percentage of cows was extrapolated, as per O'Rourke, Sullivan and Neale (1995), from the percentage of cows that was recorded persistently absent from five consecutive musters. This percentage was then adjusted for both the estimated (0.5–2%) annual loss of individual identification (numbered) ear-tags, and the propagated indeterminate error (Simanek 1996) (site B: 1991/92, 1992/93; site C: 1998/99). This extrapolation assumed that fencing and natural boundaries effectively retained cows within the paddock, and a high mustering percentage (> 90%) effectively reduced the chance of a cow being missed in the paddock.
CHAPTER 3. MATERIALS AND METHODS

Recruitment of Cows

Number

The annual recruited percentage with 95% CI of cows was calculated with some extrapolation and assumption of numbers.

With the exception of a consignment in late 1974, the number of recruited cows at site A (Low 1978b; Low, Müller & Dudzínski 1980; Low & Wood c. 1980) was extrapolated, either from the extra number reported as pregnancy tested (cows: ≥ 1.5 years old) after weighing at muster (cows: > 2 years old) (Low & Wood c. 1980), or from the nett number of other new cows released into the paddock (Low 1978b) after pregnancy testing (Low & Wood c. 1980).

Recruited cows at sites B and C were identified as new-tagged heifers (≤ 2.5 years old) (first year only) or new-tagged cows (≥ 1.5 years old, i.e. cows from both the heifer and young-to-aged groups). The total number of recruited cows was extrapolated from the recorded number of new-tagged cows, minus the estimated, accumulated number of lost individual identification ear-tags (site B). Unless culled, heifers were assumed to remain in the paddock for the year in which recorded (sites B and C).

Performance of recruited heifers

The performance of recruited heifers at site B was examined using a representative group of heifers with muster records for the first three years of their reproductive life (1.5 to 4.5 years old). These records were compared between the heifer and young cow age-groups (reasons for removal, retained percentage and lactation percentage with 95% CI). Heifer age cohorts were also examined with 95% CI, for presence at muster, number of lactation periods in 12 months, and conception percentages (non-lactating 1.5-year-old heifers and lactating 2-year-old heifers).
CHAPTER 3. MATERIALS AND METHODS

3.3.3.4. Laboratory Test Results

Bacteriology
Cultures for *Campylobacter fetus* subsp. *venerealis* and *Trichomonas foetus* var. in preputial scrapings of herd bulls (Appendix 12 b.) were used to determine the presence of herd infection at site B. The results of cultures for individual bulls were examined in categories of variables, i.e. age and financial year. Statistical analysis was undertaken, based on percentages with 95% CI.

Serology
Serological tests (Appendix 12 b.) were used: to determine levels (or titres) of serum antibodies to three high-priority pathogens (leptospires, BVDV, BHV1); and to establish serological evidence of their presence at site B. Interpretation of antibody levels for each serological test was based on advice from the testing laboratory, plus information from key texts regarding the expected level of antibody induced by each pathogen. Two types of statistical analyses were undertaken to examine serum antibody levels: (i) in order to detect differences in rankings of serum antibody levels and to comment on the association of risk factors with seroprevalence, percentages with 95% CI were examined in categories of gender, age and 2-months cumulative rainfall (prior to collection of blood samples); and (ii) in order to detect differences in the reproductive outcomes (lactation and pregnancy) associated with positive titres in cows, odds ratios with 95% CI and chi-square tests for independence were used.

*Leptospires*
Descriptive analysis of micro-agglutination test (MAT) results was undertaken, based on three titre-rankings of serum antibodies to three leptospiral serovars: seronegative (MAT \(\leq 1:50\)); lower positive (MAT = 1:100 or 1:200); and higher positive (MAT \(\geq 1:400\)). Interpretation of these rankings took into consideration, issues that vary the specificity and sensitivity of the MAT test, e.g. post-vaccination titres that are
indistinguishable from titres of natural infection (Bolin & Alt 1999; Smith et al. 1994), or the different levels of antibody induced by a host-adapted serovar compared to that induced by an incidental serovar. Given a host-adapted serovar, a MAT titre of 1:100 may be considered either ‘suspect’ (Smith et al. 1994) or the ‘positive’ cut-off point for recent infection (Bolin & Alt 1999; Radostits et al. 2007, p.1104). Given an incidental serovar, higher positive MAT titres are expected in association with disease (Radostits et al. 2007, p.1103).

No cattle were vaccinated against leptospirosis at site B, so it was assumed that with the exception of recently imported young bulls, positive MAT titres to the three specific leptospiral serovars would reflect natural exposure to one of the serovars. In imported bulls, low vaccination titres to *L. sv. hardjo* and *L. sv. pomona* (MAT 1:100–1:400) were expected to persist for three to six months (Bolin & Alt 1999; Hodges & Day 1987; Smith et al. 1994).

**Bovine viral diarrhoea virus**
Descriptive analysis of agar gel immunodiffusion (AGID) test results was undertaken, based on four rankings of serum antibody to BVDV: negative (AGID = 0 or 0.5); low positive (AGID = 1); medium positive (AGID = 2); and high positive (AGID = 3 or 4). No cattle were vaccinated against BVDV at site B, so development of vaccination antibodies was not a consideration for interpretation of these rankings.

**Bovine herpes virus type 1**
Descriptive analysis of serum neutralisation (SN) test results was undertaken, based on three titre-rankings of serum antibody to BHV1: seronegative (SN = 0 or 1:1.5); lower positive (SN = 1:3–1:48); and higher positive (SN = 1:64–1:2048). Development of vaccination antibodies was not a consideration for interpretation of these rankings.
CHAPTER 3. MATERIALS AND METHODS

Optimal Biochemical and Haematological Values

‘Optimal values’ of biochemical and haematological tests were defined and analysed, based on samples from three representative age-groups of breeding cattle (heifer, mature cow and mature bull groups) following ‘optimal’ seasonal conditions at site B. Seasonal conditions were defined as ‘optimal’ where the stage of greenness of the indicator grass (creek windmill grass) at the time of blood sampling was ‘drying up’ at one to five RCA locations on site B.

The 16 biochemical tests and five haematological tests selected for reporting of ‘optimal values’ are inclusive of the production animal profiles that have been recommended by the testing laboratory and standard texts such as Smith (1990, pp.386-88). No haematological tests were reported for bulls in the study.

Results for serum potassium (K) were not reported on account of poor handling that can cause false (high) levels (Dimeski, Clague & Hickman 2005; Smith 1990, p.392).

Two analyses were used to examine and compare ‘optimal values’. One-way analysis of variance (ANOVA) was used to compare the means of ‘optimal values’ for age-groups, but for data from four sets of biochemical values that violated Levene’s test for homogeneity of variance (p < 0.001), a non-parametric test (Kruskal-Wallis ANOVA by Ranks) was used to compare the age-groups. The 10–90th percentile range of ‘optimal values’ was compared with the reference range of the testing laboratory and the comparative range of two selected key publications (Boyd 1984; Radostits et al. 2007).

Variation in Biochemical Values

Six tests on serum and blood samples were examined as indicators of nutrition, i.e. serum urea, calcium (Ca), P, vitamin A, vitamin E and GSH-Px. The majority of these tests have been recognised as guides to a cow’s nutritional status (Radostits 2001, p.273; Whitaker 1997), and three tests were on the standard panel provided by the testing laboratory. Results for serum magnesium (Mg) and iron (Fe) were not examined.
CHAPTER 3. MATERIALS AND METHODS

because more than 95% of test results were within or above the laboratory reference ranges. Results for serum Cu and Zn were not analysed on account of an unsuitable type of collection tube or sample.

The biochemical tests were examined in relation to categories of variables that are either risk factors or indicators of cattle herd performance, i.e. age-group, financial year, lactation, pregnancy, BCS and liveweight. The young cow group at site B was used as the representative cow age-group for analysis of biochemical values. Where possible, biochemical values from this cow group were compared with values from the mature bull group at site B and the young cow group at site C. The latter comparative set of biochemical values was limited in number and type on account of the logistics for sampling and laboratory testing.

Four analyses were used to examine and screen the biochemical values: (i) Pearson’s correlation co-efficients were used to assess the relationship between liveweight and biochemical values; (ii) odds ratios with 95% CI or chi-square tests for independence were used to examine relationships; (iii) Kruskal-Wallis ANOVA by Ranks and Kruskal-Wallis Median Test (2-tailed multiple comparisons) were used to determine the difference between biochemical values in categories of variables, based on ranking of the values and the categories; and (iv) the 25th percentile biochemical value in the lowest ranked category was compared with the reference range of the testing laboratory for indication of nutritional deficiency. The screening strategy for these last two analyses is explained in more detail below.

Screening strategy

The screening strategy commenced with collation of biochemical values in categories of an explanatory factor (variable). Following this were two stages of assessment. The first stage was statistical analysis of ranking between the categories, in order to identify the lowest ranked category (based on the mean rank of each category). The lowest ranked
category was identified if the overall ranking between categories had at least a tendency to be different (p < 0.1). If a category with biochemical values was not consistent with these two criteria, then the values were not analysed further. The second stage of the strategy was examination of the 25th percentile biochemical value in the lowest ranked category. This focused on the lower quartile of values, in order to screen for a ‘tail’ where problems first occur in a production animal herd. The 25th percentile was used because it is a standard measure of descriptive statistics.

Although screening with this strategy may have had some issues with sample size and confounding by incidental variables (e.g. age and gender of cattle in some analyses), the impact was considered minor for the differences in the ranking of categories and the nature of the lower quartile of biochemical values. This strategy was adapted and also applied to analysis of faecal chemistry values and faecal parasitology counts.

**Variation in Faecal Chemistry Values**

Reference faecal chemistry values were used, both to indicate the threshold levels for maintenance (Faecal %P: > 0.2%, given Faecal %N: ≥ 1.3%) (McCosker & Winks 1994, p.56) and to define the physiologically-normal range (Faecal %DM: 12–24%) (Harper et al. 1997; Weiss & St-Pierre 2006) for analyses.

Faecal chemistry values were examined in relation to variables that may influence grazing behaviour or dietary quality and quantity, i.e. cattle risk factors such as age-group, gender, and ‘wet/ dry’ status\(^1\), or predictors of seasonal feed such as indicator grass greenness and recruitment, or 2-months cumulative rainfall prior to collection of faecal samples. The young cow and mature cow groups at site B were used as representative cow groups for analyses. Where possible, the faecal chemistry values from these cow groups were compared with faecal chemistry values from other groups at site B (store steer group) and site C (young cow and store steer groups). Comparative

\(^1\) ‘wet’ cattle (lactating (female) cattle); ‘dry’ cattle (non-lactating (e.g. male) cattle).
values were limited in number and type on account of differences in sample frequency and planned data collection. Where there was sampling bias, interpretation of analyses was restricted.

Four analyses were used to examine the faecal chemistry values: (i) Pearson’s correlation co-efficients were used to assess the relationship between faecal chemistry and biochemical indicators of body nutritional status (serum P, serum urea); (ii) Kruskal-Wallis ANOVA by Ranks and Kruskal-Wallis Median Test (2-tailed multiple comparisons) were used to determine the difference between faecal chemistry values in categories of variables, based on ranking of the values and the categories; (iii) the 25th percentile Faecal %P and Faecal %N values in the lowest ranked category were compared with the reference threshold values; and (iv) the 25–75th percentile (quartile range) Faecal %DM value in the highest ranked category was compared with the reference range.

Variation in Faecal Egg Counts and Oocyst Counts
The McMaster flotation technique for faecal counts of nematode eggs per gram of faeces (epg) and coccidial oocysts per gram of faeces (opg) was used to detect patent intestinal infestations (Smith 1990, p.185). Preliminary identification of the intestinal parasites was based on the morphology of nematode eggs, coccidial oocysts and cultured nematode larvae in a non-random (convenience) sub-group of faecal samples. Faecal egg counts were compared with a reference threshold of 500 epg, as reviewed by Radunz (1992), to determine clinical intestinal nematodiasis. This threshold is consistent with interpretations of moderate faecal (nematode) egg counts for *Haemonchus* sp., *Cooperia* spp. (Hansen & Perry 1994) and *Oesphagostomum* sp. (Cole 1986, pp.240-42). Faecal oocyst counts were compared with a reference threshold of 5,000 opg (Radostits et al. 2007, p.1503) to determine clinical coccidiosis.
Faecal counts were examined in relation to categories of variables that escalate or suppress intestinal parasite infestation, either via influences on the immune status (e.g. cattle risk factors such as age-group, gender, BCS, liveweight, lactation and pregnancy) or via influences on the free-living stage of parasites (e.g. indicators of environmental conditions such as seasonal conditions and indicator grass greenness). Three groupings of cattle age and gender at site B were used to represent and compare cattle classes in the analyses: (i) the mixed, weaned-calf group was used to represent the young cattle; (ii) the mature cow group was used to represent the cows; and (iii) the mature-to-older bull group was used to represent the herd bulls. The need for stratification of samples for the mixed, weaned-calf group and the mature-to-older bull group was determined by examination of means (two-sample t-test, assuming unequal variance) for $\log_{10}(\text{faecal egg count})$ and $\log_{10}(\text{faecal oocyst count})$ (Appendix 11). On account of a significant difference ($p < 0.05$) between means of $\log_{10}(\text{faecal egg count})$ for female and male weaned calves, bias in the analyses for the mixed, weaned-calf group was managed by sampling similar numbers of male and female calves (stratification). Some weaned calves were scouring and low in body condition but, as for all cattle faecally sampled at site B (Appendix 12 b.), they were targeted for sampling on the basis of opportunity rather than suspected intestinal parasitic disease. On account of no significant difference ($p > 0.1$) between the mean $\log_{10}(\text{faecal egg count})$ or mean $\log_{10}(\text{faecal oocyst count})$ of the mature bull and older bull groups, no stratification was used in sampling for the representative bull group.

Three analyses were used to examine faecal egg and oocyst counts: (i) Kruskal-Wallis ANOVA by Ranks and Kruskal-Wallis Median Test (2-tailed multiple comparisons) were used to determine the differences between transformed faecal counts ($\log_{10}(\text{faecal egg count})$, $\log_{10}(\text{faecal oocyst count})$) in categories of variables, based on ranking of the counts and the categories; (ii) the 90th or 100th percentile faecal egg and oocyst
counts in the highest ranked category of transformed counts were compared with the reference threshold counts for clinical intestinal nematodiasis or coccidiosis; and (iii) odds ratios with 95% CI were used to examine the relationship between a positive faecal egg count or a positive faecal oocyst count, and a nominal cut-off point between (low and high) liveweight categories of weaned calves (250 kg) and herd bulls (750 kg). If the 90th percentile faecal egg and oocyst counts exceeded the threshold, this represented a credible herd disease risk (at least 10% of sampled cattle at risk). If the maximum range was close to the reference threshold for intestinal parasitic disease, the prevalence of intestinal parasitic disease was examined in the sampled cattle population, based on the numbers sampled (Appendix 12 b.) and the 95% confidence level to predict the true prevalence of disease (Cameron 1999).

SECTION 3.4. SUMMARY

In this chapter, the materials and methods of a cattle study for three sites have been described. In the following chapter, the herd bull group dynamics at these three sites are reported for the present study.
CHAPTER 4. HERD BULL RESULTS

SECTION 4.1. INTRODUCTION

In this chapter, some dynamic features of the herd bull groups at sites A, B and C (relative number, age and breeding soundness) are described to indicate the number of functional bulls. Other dynamic features (recruitment, culling and death) are described to compare management of bull groups for breeding herds on arid rangelands. Considerations for description of herd bull dynamics at the three sites are detailed in Section 3.3.3.2 for the present study.

SECTION 4.2. HERD BULL DYNAMICS

4.2.1. Herd Bulls in Paddock

Number of herd bulls per financial year

For all three sites, the difference between the lowest and highest bull percentage was not significant for the analysed years (Table 4-1). The bull percentage calculation for site A in 1974/75 (3.6%) was not included in the analysis on account of the reported low mustering efficiency (WA Low 2006, pers. comm.).

Table 4-1. Bull percentage: financial year range for sites A, B and C.

<table>
<thead>
<tr>
<th>Site</th>
<th>Bull % (95% CI)</th>
</tr>
</thead>
<tbody>
<tr>
<td>site A</td>
<td>range [financial year] 5.7 (3.9, 7.6) to 8.1 (5.8, 10.3) [1973/74, 1970/71]</td>
</tr>
<tr>
<td>site B</td>
<td>range [financial year] 4.1 (2.9, 5.2) to 5.8 (4.4, 7.2) [1995/96, 1992/93, 1993/94]</td>
</tr>
<tr>
<td>site C</td>
<td>range [financial year] 7.0 (2.8, 11.3) to 8.2 (3.9, 12.4) [1999/2000, 1998/99]</td>
</tr>
</tbody>
</table>

Number of calves per herd bull

For both sites A and B, there was a significant difference (p < 0.05) in the lowest and highest values of the mean annual number of branded calves per herd bull (Table 4-2).
CHAPTER 4. HERD BULL RESULTS

Based on details of the season and the cattle numbers at sites A and B, the highest mean number of calves per bull for each site (11.9 calves and 24.6 calves respectively) was associated with a lower bull percentage at mating, and branding in a subsequent financial year that had improved (good and average respectively) opening seasonal conditions (Table 3-2).

Table 4-2. Mean number of branded calves per herd bull: financial year range for sites A and B.

<table>
<thead>
<tr>
<th>site</th>
<th>Mean annual number of branded calves per herd bull (95% CI)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>site A range - number of calves per bull [financial year] of branding</td>
</tr>
<tr>
<td></td>
<td>related bull % [financial year] of mating</td>
</tr>
<tr>
<td></td>
<td>site B range - number of calves per bull [financial year] of branding</td>
</tr>
<tr>
<td></td>
<td>related bull % [financial year] of mating</td>
</tr>
</tbody>
</table>

Age of herd bulls

At site A, the age of individual herd bulls was not reported for the beginning of the study, however some decisions about bull culling were based on the property manager’s knowledge of bull ages (WA Low 2013, pers. comm.). Recruitment of young bulls for the breeding herd was reported during good seasonal conditions. In 1974, ten young bulls (WA Low 2006, pers. comm.) were introduced from interstate studs (Low 1978b), and four ‘exceptional’ station-bred bull calves were retained in the breeding herd in 1973/74 (Low 1978b; Low & Wood c. 1980).

At site B, the recorded age of herd bulls ranged from 2.5 to over 9 years old.

Introduction of young bulls (2–3.5 years old) from interstate studs was recorded each year (Coventry, Taylor & Pinch 2002a).

At site C, the age of individual herd bulls at the beginning of the study was not reported, however standard herd management included use of 3- to 8-year-old bulls (Appendix 3).
CHAPTER 4. HERD BULL RESULTS

Young bulls were introduced into the paddock in 1999/2000, at the same time as a ‘first-calving’ heifer group.

4.2.2. Recruitment of Herd Bulls

Number of recruited bulls per financial year

The recruited percentage of herd bulls was significantly higher (p < 0.05) in financial years that opened with the better of two seasonal conditions recorded at a site, i.e. 55.6% with good conditions at site A; and 23.7% with average conditions at site B (Table 4-3). Confidence in the percentages at site A was reduced by the reported low mustering efficiency (WA Low 2006, pers. comm.) and the extrapolated (nett annual) extra numbers of reported bulls.

Table 4-3. Recruited percentage of herd bulls, averaged per opening conditions of financial years at sites A and B.

<table>
<thead>
<tr>
<th>Herd bulls - Recruited % (95% CI)</th>
<th>Opening seasonal conditions</th>
</tr>
</thead>
<tbody>
<tr>
<td>15.2 (6.5, 23.8)^b</td>
<td>—</td>
</tr>
</tbody>
</table>

Percentages with different superscripts within rows are significantly different (p < 0.05).

At site C, the highest percentage of herd bulls was recruited in 1999/2000 (43.5%). This reflected the introduction of young bulls at the same time as a ‘first-calving’ heifer group, as required by the design of the primary beef cattle project. Analysis by opening seasonal conditions was thus not warranted.
CHAPTER 4. HERD BULL RESULTS

4.2.3. Removal of Herd Bulls

Reasons for removal
In general, numbers of herd bulls were removed (dead or alive) from all three sites. Individual bulls were often removed for multiple reasons.

At site A, recorded reasons for the removal of herd bulls were limited. These reasons included agistment for drought management (1971/72) (Low 1978b), selective culling for excessive age (1970–1975) and behavioural problems (1973) (WA Low 2006, pers. comm.). Some culled bulls were noted to be in poorer condition than the remaining herd bulls (WA Low 2006, pers. comm.) and may have been culled for excessive age. No herd bulls were reported dead or euthanased, and there were insufficient data to extrapolate unconfirmed deaths.

At site B, removal of 37 herd bulls was recorded during a 5-year period. This included up to 3 head per year that were euthanased or found dead, and up to 14 head per year that were selectively culled. As a percentage of the removed herd bulls, the major (sole and composite) recorded reasons for removal were: disease or injury (38%); found dead or euthanased (24%); excessive age (24%); and arthritis (19%). The selectively-culled bulls had a mode and median body condition (BCS 2, on scale: 1–5) that was the same as that of the retained herd bulls.

At site C, mustered bulls were non-selectively removed (destocked) in 1999/2000 with the mixed-age group of cows, as required by the design of the primary beef cattle project. No herd bulls were recorded as dead or euthanased, and there were insufficient data to extrapolate unconfirmed deaths.

Number of removed herd bulls per financial year (culling plus confirmed deaths)
At site A, the percentage of herd bulls removed in financial years that opened with good seasonal conditions (25.0%) was not significantly different from the percentage in years opening with poor/dry conditions (24.2%) (Table 4-4). Confidence in these percentages
was reduced by the reported low mustering efficiency (WA Low 2006, pers. comm.) and the extrapolated (nett annual), reduced numbers of reported bulls.

At site B, the percentage of herd bulls removed in financial years that opened with average seasonal conditions (17.5%) was significantly higher (p < 0.05) than the percentage in years opening with poor/dry conditions (5.5%) (Table 4-4). Additional details regarding recorded and unconfirmed herd bull deaths are given below.

Table 4-4. Removed percentage of herd bulls, averaged per opening conditions of financial years at sites A and B.

<table>
<thead>
<tr>
<th>Opening seasonal conditions</th>
<th>Herd bulls - Removed % (95% CI)</th>
</tr>
</thead>
<tbody>
<tr>
<td>poor/dry</td>
<td>[financial years]</td>
</tr>
<tr>
<td>site A</td>
<td>24.2 (13.9, 34.6)</td>
</tr>
<tr>
<td>[1970/71, 1971/72,</td>
<td></td>
</tr>
<tr>
<td>1972/73]</td>
<td></td>
</tr>
<tr>
<td>site B</td>
<td>5.5 (1.2, 9.8)</td>
</tr>
<tr>
<td>[financial years]</td>
<td></td>
</tr>
<tr>
<td>[1991/92, 1994/95]</td>
<td></td>
</tr>
<tr>
<td>average</td>
<td></td>
</tr>
<tr>
<td>site A</td>
<td>—</td>
</tr>
<tr>
<td>[financial years]</td>
<td></td>
</tr>
<tr>
<td>site B</td>
<td>17.5 (11.9, 23.1)</td>
</tr>
<tr>
<td>[financial years]</td>
<td></td>
</tr>
<tr>
<td>good</td>
<td>25.0 (10.9, 39.1)</td>
</tr>
<tr>
<td>[financial years]</td>
<td></td>
</tr>
<tr>
<td>[1973/74, 1974/75]</td>
<td></td>
</tr>
</tbody>
</table>

Percentages with different superscripts within rows are significantly different (p < 0.05).

At site C, the highest percentage of herd bulls was removed in 1999/2000 (47.8%). This reflected the design of the primary beef cattle project, so analysis by opening seasonal conditions was not warranted.

Number of recorded herd bull deaths per financial year

The recorded mortality percentage of herd bulls (confirmed dead or euthanased) at site B did not vary significantly for financial years opening with average compared to poor/dry seasonal conditions (Table 4-5).

Table 4-5. Recorded mortality percentage of herd bulls, averaged per opening conditions of financial years at site B.

<table>
<thead>
<tr>
<th>Recorded herd bull mortality % (95% CI)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Opening seasonal conditions</td>
</tr>
<tr>
<td>poor/dry</td>
</tr>
<tr>
<td>site B [financial years]</td>
</tr>
<tr>
<td>[1991/92, 1994/95]</td>
</tr>
<tr>
<td>average</td>
</tr>
<tr>
<td>site B [financial years]</td>
</tr>
</tbody>
</table>
CHAPTER 4. HERD BULL RESULTS

Number of unconfirmed herd bull deaths per financial year
The unconfirmed mortality percentage of herd bulls was extrapolated per financial year, for two years at site B (1991/92: 6.5%; 1992/93: 5.5%). These extrapolated percentages did not meet the requirements for calculation of 95% CI with either normal approximation of a binomial distribution or with the exact binomial method. These extrapolated percentages were similar to the maximum annual recorded mortality percentage of herd bulls (1994/95: 5.5%).

SECTION 4.3. SUMMARY
In this chapter, aspects of bull percentage, plus recruitment and removal of herd bulls, have been highlighted for three sites.

Bull percentage
Wide ranges were reported: in the bull percentages (lowest: 4.1% at site B vs. highest: 8.2% at site C); in the ages of herd bulls at site B (2.5 to over 9 years old); and in the mean annual number of branded calves per herd bull at sites A and B (5–11.9 calves and 14–24.6 calves respectively).

Herd bull recruitment and removal
The recruited percentage of herd bulls was highest (p < 0.05) after average or good opening seasonal conditions at sites A and B (55.6% and 23.7% respectively). The major reasons for removal of herd bulls included selective culling based on excessive age, disease, injury or arthritis at sites A and B. Destocking was also a major reason for removal of herd bulls at sites A and C. For herd bulls at site B, the maximum annual recorded mortality percentage was 5.5% and the maximum annual extrapolated, unconfirmed mortality percentage was 6.5%.

In the following chapter, the reproductive performance and herd dynamics of cows at sites A, B and C are reported for the present study.
CHAPTER 5. COW RESULTS

SECTION 5.1. INTRODUCTION
In this chapter, the productive life of cows at one or more sites is described in terms of reproductive performance (conception, lactation, number and weight of calves produced) and breeding herd dynamics (culling, death and recruitment). These descriptions of reproductive performance and herd dynamics reflect the extensive management on the arid rangelands of three sites, as well as the considerations detailed in Section 3.3.3.3 for the present study.

SECTION 5.2. REPRODUCTIVE PERFORMANCE

5.2.1. Conception

*Monthly and annual conception percentage per financial year*

Monthly conception percentage was considered for sites A and B. The range was widest in a year opening with dry seasonal conditions (Table 3-2) at site A (1970/71: 0.7–24%) and site B (1994/95: 1.3–22%). The ranges of median and mean monthly conception percentages were similar for site A (medians: 6.7–10.5%; means: 8.0–9.3%) and site B (medians: 5.7–9.1%; means: 5.7–9.3%).

Annual conception percentage was considered by financial year and age-group for site B (Table 5-1). No significant difference was detected between the conception percentage of age-groups in the first two years of the study (1991/92, 1992/93). There was, however, a significantly lower (p < 0.05) conception percentage in the young cow group for years that opened with poor (84%) compared to average (94%) seasonal conditions (Table 3-2). Identification of significant differences in conception percentage between age-groups and years was limited either by an absence of data for the mature cow group (1991/92) or by a low number of individuals with conception data in the heifer group (1992/93).
For sites A and C, suitable data were not available for identification of individual cows with at least one conception in a financial year.

Table 5-1. Annual conception percentage per cow age-group: first two years at site B.

<table>
<thead>
<tr>
<th>Age-group [ages]</th>
<th>Annual conception % (95% CI)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Opening seasonal conditions (financial year)</td>
</tr>
<tr>
<td></td>
<td>poor (1991/92)</td>
</tr>
<tr>
<td>heifer [1.5–2.5 years old]</td>
<td>80 (59, 93)</td>
</tr>
<tr>
<td>young cow [3–5 years old]</td>
<td>84 (77, 89)</td>
</tr>
<tr>
<td>mature cow [5.5–7.5 years old]</td>
<td>—</td>
</tr>
<tr>
<td>aged cow [≥ 8 years old]</td>
<td>88 (83, 92)</td>
</tr>
</tbody>
</table>

**Monthly conception percentage vs. monthly rainfall and average monthly minimum temperature**

At site A, there was no linear correlation between monthly conception percentage and rainfall or temperature ($r = 0.05$, $p > 0.1$ and $r = 0.17$, $p > 0.1$ respectively).

At site B, there was a significant, but low, linear correlation ($p < 0.01$) between the monthly conception percentage and monthly rainfall ($r = 0.37$), as well as between the monthly conception percentage and average monthly minimum temperature ($r = 0.39$) (Figure 5-1, parts a. and b.).
Figure 5-1, parts a. and b. Monthly rainfall and average monthly minimum temperature, correlated with monthly conception percentage for site B.

Monthly conception percentage vs. time of musters and monthly rainfall
The mean monthly conception percentage was higher after recent rainfall events compared to periods with no recent rainfall at sites A and B, but was significantly higher (p < 0.05) only for site B (10.1%) (Table 5-2). Recent muster events did not have a significant effect on the mean monthly conception percentage for either site, and there was also no significant difference in the overall mean monthly conception of sites A and B (9.4% and 8.2% respectively).
CHAPTER 5. COW RESULTS

Table 5-2. Mean monthly conception percentage after muster and rainfall events at sites A and B.

<table>
<thead>
<tr>
<th></th>
<th>Monthly conception %</th>
<th>All records (95% CI)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Recent</td>
<td>Muster</td>
</tr>
<tr>
<td>Recent Rainfall</td>
<td>yes*</td>
<td>no</td>
</tr>
<tr>
<td>yes†</td>
<td>9.0</td>
<td>10.1</td>
</tr>
<tr>
<td>no</td>
<td>8.1</td>
<td>9.5</td>
</tr>
<tr>
<td>site A</td>
<td></td>
<td></td>
</tr>
<tr>
<td>All records (95% CI)</td>
<td>8.4 (6.4, 10.4)</td>
<td>9.9 (7.9, 11.8)</td>
</tr>
<tr>
<td>yes†</td>
<td>11.2</td>
<td>9.7</td>
</tr>
<tr>
<td>no</td>
<td>6.8</td>
<td>5.6</td>
</tr>
<tr>
<td>site B</td>
<td></td>
<td></td>
</tr>
<tr>
<td>All records (95% CI)</td>
<td>8.6 (6.4, 10.7)</td>
<td>8.0 (6.6, 9.4)</td>
</tr>
</tbody>
</table>

* 2-month period of influence attributed for potential conceptions.
† 1- to 2-month period of influence attributed for potential conceptions.

Weight-at-conception per age
For site A, the averaged reports on weight-at-conception for young-to-aged cows increased with each year of the study, but absence of data on variance prevented detection of a significant difference between years (Table 5-3).

For site B, the mean weight-at-conception for heifers was significantly higher (p < 0.05) in a year with average-to-poor seasonal conditions (1993/94) (Table 3-2), compared to a year with poor-to-average conditions (1991/92) (Table 5-3). Mean weight-at-conception for young-to-aged cows increased significantly (p < 0.05) with each year of the study.

For site C, the mean weight-at-conception for heifers was calculated in only one year (Table 5-3), and the mean weight-at-conception for young-to-aged cows varied significantly (p < 0.05) in the study.
Table 5-3. Weight-at-conception per cow age-category: financial year range for sites A, B and C.

<table>
<thead>
<tr>
<th></th>
<th>Annual weight-at-conception (kg (95% CI))</th>
<th>financial year</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>heifers</td>
<td></td>
</tr>
<tr>
<td>site B</td>
<td>range (kg (95% CI)) 371 (356, 385) to 408 (389, 428)</td>
<td>[1991/92]</td>
</tr>
<tr>
<td></td>
<td></td>
<td>[1993/94]</td>
</tr>
<tr>
<td>site C</td>
<td>range (kg (95% CI)) 343 (324, 363) ‡</td>
<td>[1998/99]</td>
</tr>
<tr>
<td></td>
<td>young-to-aged cows</td>
<td></td>
</tr>
<tr>
<td>site A</td>
<td>range (kg)* 321 † to 397 †</td>
<td>[1970/71]</td>
</tr>
<tr>
<td></td>
<td></td>
<td>[1974/75]</td>
</tr>
<tr>
<td>site B</td>
<td>range (kg (95% CI)) 405 (398, 412) to 496 (485, 506)</td>
<td>[1991/92]</td>
</tr>
<tr>
<td></td>
<td></td>
<td>[1995/96]</td>
</tr>
<tr>
<td>site C</td>
<td>range (kg (95% CI)) 362 (350, 373) to 410 (389, 431)</td>
<td>[1999/2000]</td>
</tr>
<tr>
<td></td>
<td></td>
<td>[2000/01]</td>
</tr>
</tbody>
</table>

* no liveweight variance reported for calculation of 95% CI.
† averaged weight-at-conception, may include heifers.
‡ liveweight data available in only one year.

Body condition score-at-conception per age

No data were available on BCS-at-conception for site A.

For site B, there was no significant difference (Mann-Whitney U test: p > 0.05) and no apparent descriptive or graphical difference (Table 5-4 and Figure 5-2 a.) between the BCS-at-conception for heifers and young-to-aged cows.

For site C, there were insufficient records for a Mann-Whitney U test, but there was an apparent descriptive and graphical difference (Table 5-4 and Figure 5-2 b.) between the BCS-at-conception for heifers and young-to-aged cows.

Table 5-4. Body condition score-at-conception per cow age-category: median and range for sites B and C.

<table>
<thead>
<tr>
<th></th>
<th>site B</th>
<th>site C</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>heifers</td>
<td>young-to-aged cows</td>
</tr>
<tr>
<td>BCS scale: 1–5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>median</td>
<td>2.5</td>
<td>2.5</td>
</tr>
<tr>
<td>range</td>
<td>1.5 to 4</td>
<td>1 to 5</td>
</tr>
</tbody>
</table>
Figure 5-2, parts a. and b.  Body condition score-at-conception, by percentage of cow age-category for sites B and C.

For sites B and C, the BCS-at-conception had a positive association with the mean weight-at-conception. For young-to-aged cows, the mean weight-at-conception rose: at site B, from 377 to 514 kg with increasing BCS-at-conception (range: BCS 1.5 to 4 (scale: 1–5)); and at site C, from 347 to 446 kg with increasing BCS-at-conception (range: BCS 2 to 4 (scale: 1–6)).
 CHAPTER 5. COW RESULTS

5.2.2. Lactation

Lactation per financial year

The lactation percentage of cows was significantly higher (p < 0.05) in financial years that opened with the better of two seasonal conditions recorded at a site, i.e. 96% with average conditions at site B, and 83% with good conditions at site C (Table 5-5).

Table 5-5. Lactation percentage averaged per opening conditions of financial years at sites B and C.

<table>
<thead>
<tr>
<th>Opening seasonal conditions</th>
<th>Lactation % (95% CI)</th>
</tr>
</thead>
<tbody>
<tr>
<td>poor/dry</td>
<td>average</td>
</tr>
<tr>
<td>site B</td>
<td>88 (86, 90)(^b)</td>
</tr>
<tr>
<td>site C</td>
<td>—</td>
</tr>
<tr>
<td>[financial years]</td>
<td>—</td>
</tr>
<tr>
<td></td>
<td>—</td>
</tr>
<tr>
<td></td>
<td>—</td>
</tr>
</tbody>
</table>

Percentages with different superscripts within rows are significantly different (p < 0.05).

Lactation per 6-months cumulative rainfall

At sites B and C there were significant differences (p < 0.05) in the lactation percentage of cows between different categories of 6-months cumulative rainfall, but increases were not linear (Table 5-6). In the category of ‘poor’ rainfall effectiveness, the percentage of cows that was lactating was lowest at site B (54%), but highest at site C (71%).
Table 5-6. Lactation percentage per 6-months cumulative rainfall at sites B and C.

<table>
<thead>
<tr>
<th>Rainfall effectiveness [6-months cumulative rainfall]</th>
<th>Lactation % (95% CI)</th>
</tr>
</thead>
<tbody>
<tr>
<td>poor [0–49mm]</td>
<td>54 (51, 57)(^a)</td>
</tr>
<tr>
<td></td>
<td>71 (63, 79)(^a)</td>
</tr>
<tr>
<td>short [50–99mm]</td>
<td>69 (66, 71)(^b)</td>
</tr>
<tr>
<td></td>
<td>45 (40, 50)(^b)</td>
</tr>
<tr>
<td>medium [100–199mm]</td>
<td>71 (70, 73)(^b)</td>
</tr>
<tr>
<td></td>
<td>41 (36, 47)(^b)</td>
</tr>
<tr>
<td>long [200–299mm]</td>
<td>78 (76, 80)(^c)</td>
</tr>
<tr>
<td></td>
<td>48 (40, 56)(^b)</td>
</tr>
<tr>
<td>prolonged [≥ 300mm]</td>
<td>70 (67, 73)(^b)</td>
</tr>
<tr>
<td></td>
<td>68 (62, 74)(^a)</td>
</tr>
</tbody>
</table>

Percentages with different superscripts within columns are significantly different (p < 0.05).

*Lactation per body condition*

The lactation percentage of cows differed significantly (p < 0.05) between three categories of body condition and was highest in the ‘store’ category at sites B and C (82% and 78% respectively) (Table 5-7).

Table 5-7. Lactation percentage per body condition at sites B and C.

<table>
<thead>
<tr>
<th>Body condition</th>
<th>Lactation % (95% CI)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>site B</td>
</tr>
<tr>
<td>store BCS (scale: 1–5)</td>
<td>82 (81, 84)(^a)</td>
</tr>
<tr>
<td>1.5–2</td>
<td>1.5–2</td>
</tr>
<tr>
<td>forward store</td>
<td>62 (58, 66)(^b)</td>
</tr>
<tr>
<td>fat BCS (scale: 1–6)</td>
<td>78 (69, 87)(^a)</td>
</tr>
</tbody>
</table>

Percentages with different superscripts within rows are significantly different (p < 0.05).

A supplementary Mann-Whitney U test indicated that overall, BCS was significantly lower (p < 0.05) for lactating compared to non-lactating cows at sites B and C.
CHAPTER 5. COW RESULTS

Lactation per age-group
The lactation percentage was lowest in the heifer group at sites B and C (52% and 45% respectively) (Table 5-8). However the percentage of cows that was lactating was only significantly different (p < 0.05) between some age-groups for site B, with the percentage being highest in the mature cow group (75%).

Table 5-8. Lactation percentage per cow age-group at sites B and C.

<table>
<thead>
<tr>
<th>Age-group [ages]</th>
<th>Lactation % (95% CI)</th>
<th>site B</th>
<th>site C</th>
</tr>
</thead>
<tbody>
<tr>
<td>heifer [1.5–2.5 years old]</td>
<td>52 (48, 55)(^c)</td>
<td>45 (34, 55)</td>
<td></td>
</tr>
<tr>
<td>young cow [3–5 years old]</td>
<td>71 (69, 72)(^b)</td>
<td>52 (49, 56)</td>
<td></td>
</tr>
<tr>
<td>mature cow [5.5–7.5 years old]</td>
<td>75 (73, 76)(^a)</td>
<td>52 (44, 60)</td>
<td></td>
</tr>
<tr>
<td>aged cow [≥ 8 years old]</td>
<td>72 (69, 73)(^{ab})</td>
<td>52 (41, 63)</td>
<td></td>
</tr>
</tbody>
</table>

Percentages with different superscripts within columns are significantly different (p < 0.05).

Lactation, body condition, age and subsequent pregnancy
The combined association of lactation status, body condition and age was considered with respect to recorded pregnancy at muster of continuously-mated cows at sites B and C (Appendix 13). At site B, the pregnancy percentage of lactating young, mature and aged cows (48–56%) was significantly lower (p < 0.05) than that of non-lactating individuals (range: 77–94%) in similar age-group and body condition categories. This significant difference was also recorded for heifers in ‘store’ and ‘forward store’ condition at site B and for young cows in ‘forward store’ and ‘fat’ condition at site C. The lower pregnancy percentage for lactating cows and heifers was consistent with the limited period for conception and subsequent pregnancy detection, while individuals were still lactating (before managed weaning) at sites B and C.
 CHAPTER 5. COW RESULTS

Within combined lactation status and age-group categories, a significant difference
(p < 0.05) in pregnancy percentage with body condition was recorded for non-lactating
young cows. In this group, the cows with ‘fat’ condition had the lowest pregnancy
percentage at site B (77%) and the highest pregnancy percentage at site C (94%).

_Lactation failure_

At site A, the level of lactation failure was not reported and no records were available to
determine this in the present study, however, there was loss of approximately 20 calves
during a 6-year period (Low & Wood c. 1980) that equated to 2.1% (1.3, 3.2) post-natal
death of the calves-to-brand (95% CI).

At site B, after first-trimester pregnancies in financial years that opened with average
seasonal conditions (Table 3-2), lactation failure indicated pre-natal and peri-/ post-natal
losses in the three older cow age-groups (Appendix 14). Only peri-/ post-natal losses
(4.5% of pregnancies) were identified in the heifer group. Overall losses were highest in
the aged cow group (10.3% of pregnancies), but there was no significant difference
(p > 0.05) between age-groups. Based on the combined data for all age-groups at site B,
first trimester losses (3.1% of pregnancies) were almost half of all indicated losses
(6.4% of pregnancies) (Appendix 14).

At site B, loss of 49 calves between calving and branding was recorded during a 5-year
period, and this equated to 1.0% (0.7, 1.3) post-natal loss of calves before branding
(95% CI). Although not significant (p > 0.05), this also equated to lower calf loss per
head of the young cow group (0.7% (0.4, 1.1)) and mature cow group (0.6% (0.3, 1.1))
compared to the heifer group (1.1% (0.4, 2.5)) and aged cow group (1.4% (0.8, 2.2)).

At site C, during two years with excellent seasonal conditions (Table 3-2), lactation
failure indicated pre- and post-natal loss (8.3% (1, 27)) for 24 pregnancies in the young
cow group.
CHAPTER 5. COW RESULTS

5.2.3. Calf Production

5.2.3.1. Numbers

Branded calves per financial year

For sites A and B, there was a significant difference (p < 0.05) of at least 21% between the lowest and highest branding percentage per financial year (Table 5-9). For site B, the branding percentage that was based on an extrapolated number of mated cows in 1991/92 was excluded from the analyses because it was unusual (> 100%). The average annual branding percentage at site A (64%) was significantly lower (p < 0.05) than the average at site B (87%).

No annual branding figures were available for site C.

Table 5-9. Branding percentage: average and financial year range for sites A and B.

<table>
<thead>
<tr>
<th></th>
<th>Branding % (95% CI)</th>
</tr>
</thead>
<tbody>
<tr>
<td>site A</td>
<td></td>
</tr>
<tr>
<td>5-year average</td>
<td>64 (62, 66)</td>
</tr>
<tr>
<td>range [financial year]</td>
<td>39 (34, 45) to 90 (87, 94)</td>
</tr>
<tr>
<td>[1971/72]</td>
<td>[1974/75]</td>
</tr>
<tr>
<td>site B</td>
<td></td>
</tr>
<tr>
<td>4-year average</td>
<td>87 (86, 88)</td>
</tr>
<tr>
<td>range [financial year]</td>
<td>79 (76, 81) to 100 (100, 100)</td>
</tr>
<tr>
<td>[1994/95]</td>
<td>[1995/96]</td>
</tr>
</tbody>
</table>

Weaned calves per calendar year

For sites B and C, the difference between the lowest and highest weaning percentage per calendar year (at least 22%) was significant (p < 0.05) (Table 5-10). The average annual weaning percentage was significantly higher (p < 0.05) at site B (84%) compared to site C (79%). The recorded male-to-female ratio of weaned calves was 1.01:1 over a 5-year period at site B, and 0.76:1 for a 1-year period (1999) at site C.

No annual weaning figures were available for site A, however weaner steers were regularly removed (Appendix 3).
Table 5-10. Weaning percentage: average and calendar year range for sites B and C.

<table>
<thead>
<tr>
<th>Site</th>
<th>4-year average</th>
<th>Range [calendar year]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Site B</td>
<td>84 (83, 85)</td>
<td>64 (61, 67) to 97 (96, 98) [1995, 1993]</td>
</tr>
<tr>
<td>Site C</td>
<td>79 (75, 83)</td>
<td>65 (57, 73) to 87 (82, 92) [2000, 1999]</td>
</tr>
</tbody>
</table>

5.2.3.2. Weight

Mean weight of weaner-age calves

For site A, the lowest mean weight of unweaned, weaner-age calves (6–12 months old) at muster was recorded after dry seasonal conditions (Table 3-2), and the highest mean weight was recorded after good conditions (Table 5-11). The significance of the difference (95 kg) between these means was not reported (Low & Wood 1979).

For sites B and C, the difference (at least 70 kg) between the lowest and highest recorded mean weights of weaned calves at muster was significant (p < 0.05) (Table 5-11).

At site B, the lower mean weights of weaned calves at muster were recorded: in late 1992 after poor seasonal conditions during 1991/92 (Table 3-2); and in late 1994 with early weaning for drought (as per Appendix 3). With the exception of late 1991, the mean weights of weaned calves at all other musters were significantly higher (p < 0.05) (Figure 5-3 a.).

At site C, the lower mean weights of weaned calves at muster were recorded: in late 1998 after poor seasonal conditions during 1997/98 (Table 3-2); in late 1999 with destocking of the mixed-age breeding herd; and in early 2000 with calves from the recruited first-calving cows (as per Appendix 3). The mean weights of weaned calves at all other musters were significantly higher (p < 0.05) (Figure 5-3 b.).
Table 5-11. Mean weight of weaner-age calves: range at muster for sites A, B and C.

<table>
<thead>
<tr>
<th>Site</th>
<th>Mean weight of weaner-age calves</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>165 to 260 [first muster in 1971] [first muster in 1974]</td>
</tr>
<tr>
<td>B</td>
<td>218 (205, 231) to 288 (276, 301) [last muster in 1994] [last muster in 1993]</td>
</tr>
<tr>
<td>C</td>
<td>185 (175, 194) to 262 (243, 281) [last muster in 1999] [first muster in 2001]</td>
</tr>
</tbody>
</table>

* reported mean weight of unweaned calves (mixed calves, 6–12 months old) (Low & Wood 1979).
† no liveweight variance reported for calculation of 95% CI.

5-3 a. Mean weight of weaned calves at musters for site B.

5-3 b. Mean weight of weaned calves at musters for site C.

Figure 5-3, parts a. and b. Mean weight of weaned calves at musters for sites B and C.


CHAPTER 5. COW RESULTS

Weight of weaned calves and reproductive efficiency of mated cows
The average weights of weaned calves per mated cow and per 100 kg of mated cows (compound measures of reproductive efficiency) were highest for years commencing with good seasonal conditions (Table 3-2) at sites B and C (mixed-age and young cows respectively) (Table 5-12).

Table 5-12. Average weight of weaned calves per head of mated cows and per 100 kg of mated cows: calendar year range for sites B and C.

<table>
<thead>
<tr>
<th></th>
<th>Average weight of weaned calves</th>
</tr>
</thead>
<tbody>
<tr>
<td>site B</td>
<td></td>
</tr>
<tr>
<td></td>
<td>range (kg per mated cow)</td>
</tr>
<tr>
<td></td>
<td>range (kg per 100 kg of mated cows)</td>
</tr>
<tr>
<td>[calendar year]</td>
<td>[1995]</td>
</tr>
<tr>
<td>site C</td>
<td></td>
</tr>
<tr>
<td></td>
<td>range (kg per mated cow)</td>
</tr>
<tr>
<td></td>
<td>range (kg per 100 kg of mated cows)</td>
</tr>
<tr>
<td>[calendar year]</td>
<td>[2000]</td>
</tr>
</tbody>
</table>

SECTION 5.3. HERD DYNAMICS

5.3.1. Removal of Cows

Reasons for removal
In general, cows were removed from all three sites through death, (selective) culling or (non-selective) destocking, as indicated in Appendix 7. Some cows were culled for multiple reasons.

At site A, the cattle manager selectively culled cows for excessive age (at 8–10 years old) or for poor reproductive performance. Removal of cows was also undertaken to adjust the stocking rate. Cows were partially destocked for drought and agisted in 1971. Removal of excess heifers in 1975 was indicated by the difference between the reported number of heifers that were introduced in December 1974 and the number that was still present after twelve months (Low 1978b).

At site B, removal of 948 cows from the herd was recorded over a 5-year period. These cows had either been found dead (18 head), euthanased (5 head), or otherwise
selectively culled (925 head). The sole and composite reasons for removal are summarised in Table 5-13. As a percentage of the removed cows, the major reasons for removal were excessive age (39%), undesirable phenotype (27%), and excessive body condition (24%).

Table 5-13. Reasons for removal: numbers of cows that were removed for sole and composite reasons at site B.

<table>
<thead>
<tr>
<th>Reason</th>
<th>Sole reason*</th>
<th>Composite reason†</th>
<th>Subtotal</th>
</tr>
</thead>
<tbody>
<tr>
<td>excessive age (1)</td>
<td>238 (25)</td>
<td>132 (14)</td>
<td>370 (39)</td>
</tr>
<tr>
<td>undesirable phenotype (2)</td>
<td>174 (18)</td>
<td>86 (9)</td>
<td>260 (27)</td>
</tr>
<tr>
<td>excessive body condition (3)</td>
<td>138 (15)</td>
<td>85 (9)</td>
<td>223 (24)</td>
</tr>
<tr>
<td>store movements (4)</td>
<td>135 (14)</td>
<td>5 (1)</td>
<td>140 (15)</td>
</tr>
<tr>
<td>disease (5)</td>
<td>39 (4)</td>
<td>24 (3)</td>
<td>63 (7)</td>
</tr>
<tr>
<td>undesirable temperament</td>
<td>15 (2)</td>
<td>45 (5)</td>
<td>60 (6)</td>
</tr>
<tr>
<td>unknown (6)</td>
<td>n/a</td>
<td>n/a</td>
<td>18 (2)</td>
</tr>
</tbody>
</table>

Total number of removed cows = 948

* cows selectively culled for this reason only.
† cows selectively culled for this reason, in addition to other reason(s).
n/a not applicable

(1) Aged and mature cows (from 5.5 years old) were recorded as removed for ‘excessive age’.
(2) Cows removed for ‘undesirable phenotype’ included 47% (122/260) culled solely for small frame size, 12% (30/260) culled solely for eye features (lack of pigment around the eyes or prominent eyes) and 8% (22/260) culled solely for evidence of a horn genotype (undesirable in a polled herd).
(3) Cows removed for ‘excessive body condition’ had a high level of body condition that was either inconsistent with regular calf production or opportunistic for the turnoff of cows with excessive age.
(4) Cows removed for ‘store movements’ included 49% (69/140) trucked for drought management and 47% (66/140) trucked to a breeding program.
(5) Cows removed for ‘disease’ included 54% (34/63) culled with ‘cancer eye’ (early clinical indications of ocular squamous cell carcinoma) and 8% (5/63) euthanased on account of urogenital or generalised disease.
(6) Cows were found dead, but the reason for death was unknown.

At site C, non-selective removal (destocking) of all mustered mixed-age cows in 1999/2000 reflected the design of the primary beef cattle project. Two young cows were also selectively culled in 2000/01 for poor reproductive performance (non-lactating and non-pregnant with excessive body condition).
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Number of removed cows per financial year (culling plus confirmed deaths)

At site A, annual turnoff (including cull cows) averaged 187 head (Low & Wood c. 1980). Extrapolated data indicated that the highest number of cows was removed in a year with dry opening seasonal conditions (Table 3-2) (1971/72: nett removal of 140 head). During that year, 99 cows were sent to agistment (Low 1978b) and were later sold (WA Low 2013, pers. comm.). After introduction of 400 yearling heifers in a year with good opening conditions (1974/75), there was indication that 75 heifers were removed within twelve months (Low 1978b).

At site B, the percentage of cows removed in financial years with poor/dry opening seasonal conditions (7%) was significantly lower (p < 0.05) than in years with average opening conditions (22%) (Table 5-14). The annual removed percentage of cows was lowest in 1994/95 (2.0%) with limited culling and post-drought death, and highest in 1992/93 (32.6%) with selective culling for excessive age.

At site C, cows were removed only in 1999/2000 (49.8%) and 2000/01 (1.4%).

Table 5-14. Removed percentage of cows, averaged per opening conditions of financial years at site B.

<table>
<thead>
<tr>
<th>Opening seasonal conditions</th>
<th>Cows - Removed % (95% CI)</th>
</tr>
</thead>
<tbody>
<tr>
<td>site B</td>
<td>7 (6, 8) (^b)</td>
</tr>
<tr>
<td>[financial years]</td>
<td>[1991/92, 1994/95]</td>
</tr>
<tr>
<td>average</td>
<td>22 (21, 24) (^a)</td>
</tr>
</tbody>
</table>

Percentages with different superscripts are significantly different (p < 0.05)

Number of recorded cow deaths per financial year

At site A, up to ten dead cows were seen in the paddock during one year (WA Low 2006, pers. comm.) and this equated to a reported mortality percentage of at least 2.4%.

At site B, the recorded mortality percentage (confirmed dead or euthanased) did not vary significantly for financial years under average compared to poor/dry opening seasonal conditions (Table 5-15). Deaths were recorded for cows that were euthanased...
CHAPTER 5. COW RESULTS

for medical reasons (5 head) or found dead (18 head). Of the latter, 44% (8/18) were aged cows. The highest recorded annual mortality percentage (1.3%) was in a financial year commencing with dry seasonal conditions (1994/95).

At site C, at least two dead cattle were seen in the paddock during the first eighteen months of the primary beef cattle project (Hill 2003, p.9), but no individually-identified cows were confirmed dead or euthanased.

Table 5-15. Recorded mortality percentage of cows, averaged per opening conditions of financial years at site B.

<table>
<thead>
<tr>
<th>Opening seasonal conditions</th>
<th>Recorded cow mortality % (95% CI)</th>
</tr>
</thead>
<tbody>
<tr>
<td>poor/dry</td>
<td>site B [financial years]</td>
</tr>
<tr>
<td>0.7 (0.3, 1.0)</td>
<td>0.2 (0.1, 0.4)</td>
</tr>
</tbody>
</table>

Number of unconfirmed cow deaths per financial year

For site B, the unconfirmed (extrapolated) mortality percentage (95% CI) was low for the first two years of the study (1991/92: 1.3% (0, 2.9); 1992/93: 1.8% (0, 3.8)). In the group of 56 individually-identified cows that were persistently absent from this period onwards, no particular age-group, lactation status or pregnancy trimester was over-represented (Table 5-16). The percentage that was mature or aged in this group (61% (48, 74)) was similar to that in the contemporary herd (54%).

Table 5-16. Summary of the last records for a group of 56 persistently absent cows from site B.

<table>
<thead>
<tr>
<th>Feature</th>
<th>Categories</th>
<th>Number of cows</th>
<th>% of persistently absent group (95% CI)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age-group</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>heifer &amp; young cow</td>
<td>22</td>
<td>39 (26, 52)</td>
<td></td>
</tr>
<tr>
<td>mature cow &amp; aged cow</td>
<td>34</td>
<td>61 (48, 74)</td>
<td></td>
</tr>
<tr>
<td>Lactation status</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>lactating</td>
<td>29</td>
<td>52 (39, 65)</td>
<td></td>
</tr>
<tr>
<td>non-lactating</td>
<td>27</td>
<td>48 (35, 61)</td>
<td></td>
</tr>
<tr>
<td>Pregnancy trimester</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>non-pregnant &amp; first trimester</td>
<td>19</td>
<td>34 (22, 46)</td>
<td></td>
</tr>
<tr>
<td>second &amp; third trimester</td>
<td>37</td>
<td>66 (54, 78)</td>
<td></td>
</tr>
</tbody>
</table>
CHAPTER 5. COW RESULTS

For site C, the unconfirmed (extrapolated) mortality percentage was low for the first year of the study (1998/99: 3.1% (0, 8.1)). Over half of the persistently absent cows (7/12) had been lactating and non-pregnant.

5.3.2. Recruitment of Cows

Number of recruited cows per financial year
At site A, cows were recruited in 1970/71, 1973/74 and 1974/75 (Low 1978b; Low, Müller & Dudzinski 1980; Low & Wood c. 1980). The introduction of 400 yearling heifers from other property paddocks (WA Low 2013, pers. comm.) in 1974/75 was equivalent to 50% recruitment in the cow herd. Of these, 325 head were retained (Low 1978b), in addition to other heifers and cows. It was extrapolated that 375 head of heifer progeny were retained in the paddock to recruit into the cow herd, and 186 head (nett) (including cows at the beginning of the primary beef cattle project) were recruited over the five years (WA Low 2006, pers. comm.).

At site B, the recruited percentage of cows was significantly lower (p < 0.05) in financial years that opened with poor/dry seasonal conditions (12%), rather than with average seasonal conditions (20%) (Table 5-17). The annual recruited percentage (95% CI) of cows was highest (27.8% (25.1, 30.4)) in 1993/94. Recruited cows comprised 191 heifers in the first year of the primary beef cattle project, plus 641 cows with calves-at-foot, and 119 heifers (extrapolated from retained 12- to 18-month-old heifer progeny) in the subsequent four years.

Table 5-17. Recruited percentage of cows, averaged per opening conditions of financial years at site B.

<table>
<thead>
<tr>
<th>Opening seasonal conditions</th>
<th>Cows - Recruited % (95% CI)</th>
</tr>
</thead>
<tbody>
<tr>
<td>poor/dry</td>
<td>site B [financial years]</td>
</tr>
<tr>
<td></td>
<td>12 (11, 14)</td>
</tr>
<tr>
<td></td>
<td>[1991/92, 1994/95]</td>
</tr>
<tr>
<td>average</td>
<td></td>
</tr>
<tr>
<td></td>
<td>20 (19, 22)</td>
</tr>
</tbody>
</table>

Percentages with different superscripts are significantly different (p < 0.05).

(- 100 -)
At site C, the 48.8% of cows recruited in one year (1999/2000) reflected the design of the primary beef cattle project. The mixed-age group of cows was replaced by a ‘first-calving’ heifer group.

### 5.3.2.1. Performance of Recruited Heifers

**Retention and removal**

At site B, 19 heifers were removed from the breeding herd through death or selective culling during a 5-year period. For a representative group, the retained percentage was significantly higher (p < 0.05) in heifers (97%) compared to young cows (95%) (Table 5-18).

**Reasons for removal**

Heifers and young cows of the representative group at site B were removed by selective culling for similar reasons and at similar percentages, i.e. for excessive body condition (37% and 38% respectively), store movements (21% and 22% respectively), and undesirable temperament (5% and 8% respectively). A higher percentage of heifers were euthanased for medical reasons (11%) or culled for evidence of a horn genotype (21%). A lower percentage of heifers were culled for a small frame (5%), and no heifers were culled for undesirable eye features.

**Suspected deaths**

Based on the records for 1.5-year-old heifers at site B, the repeat-muster percentage and the presumed survival percentage varied between years. After muster of 1.5-year-old heifers in late 1991 (44 head), 100% were re-yarded at the subsequent muster. In contrast, after muster of 46 head of 1.5-year-old heifers in 1993, only 37 were re-yarded within a 30-month period (four musters). This was a significantly lower (p < 0.05) long-term repeat-muster percentage (95% CI) (80% (69, 92)). The nine repeatedly-absent heifers had been in ‘forward store’ to ‘fat’ body condition (BCS 2.5 to 4, on scale: 1–5), non-lactating and at least 3.5-months pregnant when last recorded at musters in 1993.
Reproduction

For the representative group at site B, the lactation percentage was significantly lower (p < 0.05) in heifers compared to young cows (Table 5-18).

Table 5-18. Lactation percentage and retained percentage: heifers compared with young cows at site B.

<table>
<thead>
<tr>
<th>Age-group [ages]</th>
<th>Lactation % (95% CI)</th>
<th>Retained % (95% CI)</th>
</tr>
</thead>
<tbody>
<tr>
<td>heifer [1.5–2.5 years old]</td>
<td>52 (48, 55)\textsuperscript{a}</td>
<td>97 (96, 99)\textsuperscript{a}</td>
</tr>
<tr>
<td>young cow [3–5 years old]</td>
<td>71 (69, 72)\textsuperscript{b}</td>
<td>95 (94, 96)\textsuperscript{b}</td>
</tr>
</tbody>
</table>

Percentages with different superscripts within columns are significantly different (p < 0.05).

The lactation records of heifers indicated a range in the percentage that had lactated once or twice (95% CI). For 55 head of 1.5-year-old heifers repeat-mustered after twelve months, 13% (4, 22) had lactated twice, 82% (72, 92) had lactated once and 5% had not lactated. The conception percentage (95% CI) of 1.5-year-old (maiden) heifers averaged 76% (67, 85) in three years with poor or average opening seasonal conditions (Table 3-2) (1991/92: 44 head; 1992/93: 20 head; 1993/94: 27 head). On average, conception was lower (56% (32, 81)) for two years with dry, then average opening seasonal conditions, but with the low numbers of 1.5-year-old heifers retained during dry periods (1994/95: 10 head; 1995/96: 6 head) the difference was not significant.

For 172 head of 2-year-old heifers repeat-mustered after twelve months, 47% (40, 55) had lactated twice, 48% (40, 55) had lactated once and 5% (2, 9) had not lactated. The conception percentage of lactating 2-year-old heifers averaged 58% (44, 72) for two years with limited data (1991/92: 28 head; 1993/94: 22 head).

Over a 5-year period at site B, the pregnancy percentage at muster for the lactating heifer age-group in ‘store’ body condition (45%) was significantly lower (p < 0.05) than that of the lactating mature cow group in the same body condition (56%) (Appendix 13). On account of a wide 95% CI, the pregnancy percentage of lactating heifers in ‘fat’
condition (73%) was not significantly different from pregnancy percentages of other cow age-groups with the same lactation status and body condition.

SECTION 5.4. SUMMARY
In this chapter, aspects of conception, lactation, calf production, cow removal and cow recruitment have been highlighted for one or more sites.

Conception
The monthly conception percentage exceeded 20% after drought-breaking rain at sites A and B, and was significantly higher (p < 0.05) up to two months after rain (10.1%) compared with periods of no recent rain (6.2%) at site B. The annual conception percentage was significantly lower (p < 0.05) for the young cow group at site B in a year opening with poor (84%) compared to average (94%) seasonal conditions.

The averaged weight-at-conception of young-to-aged cows increased incrementally by year for sites A and B, and increased with BCS-at-conception at sites B and C. Mean weight-at-conception of young-to-aged cows was significantly lower (p < 0.05) in the first year of the study for sites B and C (405 kg and 362 kg respectively).

Lactation
The lactation percentage was significantly higher (p < 0.05) with years that commenced with the relatively better seasonal conditions at sites B and C (96% and 83% respectively), and with the lowest (‘store’) body condition category at sites B and C (82% and 78% respectively). For young cows in ‘forward store’ to ‘fat’ condition at sites B and C, pregnancy percentage at muster was higher (p < 0.05) for those not lactating (77–94%) compared to those lactating (41–51%). The pregnancy percentage was also significantly different (p < 0.05) for non-lactating young cows in different body condition categories. Pregnant cows that subsequently failed to lactate indicated foetal or calf loss (at least 4.5% of early pregnancies) for all examined cow age-groups at sites B and C.
CHAPTER 5. COW RESULTS

Calf production
The annual branding percentage varied by at least 21% at both sites A and B (ranges: 39–90% and 79–100% respectively). The average annual branding percentage differed significantly (p < 0.05) between sites A and B (64% vs. 87% respectively, over at least a 4-year period). The annual weaning percentage varied significantly (p < 0.05) between years at both sites B and C (ranges: 64–97% and 65–87% respectively). The average annual weaning percentage differed significantly (p < 0.05) between sites B and C (84% vs. 79% respectively, over at least a 3-year period).

The mean weight of weaner-age calves varied significantly (p < 0.05) between musters at sites B and C, and there was a difference of up to 95 kg in the mean weight of weaner-age calves at sites A, B and C (ranges: 165–260 kg, 218–288 kg and 185–262 kg respectively). For sites B and C, the lowest average weight of weaned calves per mated cow was 177 kg and 147 kg respectively. The lowest average weight of weaned calves per 100 kg of mated cows was similar for sites B and C (37.9 kg and 37.4 kg respectively). Between years, the difference in average weight of weaned calves per 100 kg of mated cows was over 25 kg at site B, but less than 7.5 kg at site C.

Cow removal
The major reasons for removal of cows included: selective culling at sites A and B based on excessive age, undesirable phenotype, excessive body condition, store movements, disease, undesirable temperament or poor reproductive performance; non-selective culling at sites A and C on account of project design or drought; and death at all three sites. The removed percentage of cows was elevated with agistment in a year of dry conditions at site A (99 head), and with a strategic cull for excessive age under average opening seasonal conditions at site B (22%). Recorded mortality of cows was infrequently reported. For site A, a single report equated to at least 2.4% mortality, and at site B, the confirmed (recorded) mortality percentage of cows was not significantly
different with varying opening seasonal conditions (range: 0.2–0.7%). The unconfirmed (extrapolated) mortality percentage of cows was low for sites B and C (up to 1.8% and 3.1% respectively), and the relevant persistently absent cows were not over-represented by any specific age, lactation or pregnancy status.

Cow recruitment

The recruited percentage of cows was highest in average to good seasonal conditions at sites A, B and C (equivalent to 50%, 20% and 49% of the cows respectively). For a representative group at site B, the lactation percentage was significantly lower (p < 0.05) in heifers (52%) compared to young cows (71%). Significantly more (p < 0.05) heifers (97%) than young cows (95%) were retained in this representative group, even though a significantly lower (p < 0.05) repeat-muster percentage (80%) suggested unconfirmed deaths of 1.5-year-old heifer cohorts. A lower conception percentage in 1.5-year-old heifers (56%) was associated with the years after a dry period. Limited data indicated no significant difference in the percentage of lactating 2-year-old heifers that conceived (58%) and the percentage of 2-year-old heifers that recorded a second lactation (47%). The pregnancy percentage of the lactating heifer age-group was not significantly different from the lactating cow age-groups.

In the following chapter, results of laboratory tests are reported for the present study, with reference to aspects of health and disease in cattle at sites B and C.
CHAPTER 6. LABORATORY TEST RESULTS

SECTION 6.1. INTRODUCTION
In this chapter, optimal and diagnostic values of blood biochemistry, haematology and faecal chemistry are reviewed. Other test results from preputial scrapings, blood and faecal samples (bacteriology, serology, biochemistry and faecal parasitology) allow comment to be made on indications of herd disease or deficiency. As detailed in Section 3.3.3.4 for the present study, these test results have been analysed with respect to variables of the cattle herds and arid rangeland pastures at sites B and C.

SECTION 6.2. BACTERIOLOGY

6.2.1. Preputial Scrapings

Culture for *Campylobacter fetus* subsp. *venerealis* vs. age and financial year
No positive cultures for *C. fetus* subsp. *venerealis* were recorded for herd bulls at site B (Appendix 15).

Culture for *Tritrichomonas foetus* var. vs. age and financial year
Positive cultures for *T. foetus* were recorded in 1992/93 for herd bulls in the ‘older-to-aged bull’ category at site B (Appendix 15). There was no significant difference in the percentage of positive cultures for *T. foetus* between financial year categories for the two categories of bull age.

SECTION 6.3. SEROLOGY

6.3.1. Serum Antibody to Leptospires

6.3.1.1. *L. sv. hardjo*

MAT titres to *L. sv. hardjo* vs. gender, age and 2-months cumulative rainfall
There was no significant difference in the percentage distribution of MAT titres to *L. sv. hardjo* between two categories of age (Appendix 16) and between two categories of 2-months cumulative rainfall (Appendix 17) for both genders at site B. Of the herd
bulls, only individuals in the ‘young-to-mature bull’ category had titres to \( L. \text{ sv. hardjo} \) that were as high as 1:800. However, these high titres were also recorded in each category of 2-months cumulative rainfall for both genders.

**MAT titres to \( L. \text{ sv. hardjo} \) vs. lactation and pregnancy**

The odds ratio indicated a significantly lower lactation percentage with positive titres to \( L. \text{ sv. hardjo} \) in the ‘young-to-aged cow’ category at site B. Chi-square tests showed tendencies for a lower lactation percentage \((p = 0.05)\) as well as a higher pregnancy percentage \((p = 0.09)\) with positive titres in this category (Appendix 18).

No significant differences in lactation and pregnancy percentages were shown with positive titres to \( L. \text{ sv. hardjo} \) in the ‘heifer’ category. However, following comparison with individuals matched on muster and reproductive status, the higher positive titres to \( L. \text{ sv. hardjo} \) (MAT \( > 1:400 \)) were found to be associated with reproductive failure in the ‘heifer’ category \((2/5)\), but not in the ‘young-to-aged cow’ category \((0/8)\).

### 6.3.1.2. \( L. \text{ sv. pomona} \)

**MAT titres to \( L. \text{ sv. pomona} \) vs. gender, age and 2-months cumulative rainfall**

Antibody titres to \( L. \text{ sv. pomona} \) were noted in herd bulls, but not in cows at site B. For herd bulls, there was no significant difference in the percentage distribution of MAT titres to \( L. \text{ sv. pomona} \) between two categories of age (Appendix 16) and between two categories of 2-months cumulative rainfall (Appendix 17), however, titres of 1:800 to \( L. \text{ sv. pomona} \) were recorded in all categories of age and 2-months cumulative rainfall.

### 6.3.1.3. \( L. \text{ sv. tarassovi} \)

**MAT titres to \( L. \text{ sv. tarassovi} \) vs. gender, age and 2-months cumulative rainfall**

There was no significant difference in the percentage distribution of MAT titres to \( L. \text{ sv. tarassovi} \) between two categories of age (Appendix 16) for both genders at site B. For herd bulls, there was no significant difference in the percentage distribution of titres to \( L. \text{ sv. tarassovi} \) between two categories of 2-months cumulative rainfall (Appendix
CHAPTER 6. LABORATORY TEST RESULTS

17), but for cows with higher titres (≥ 1:400), the percentage distribution was significantly higher in the ‘50+ mm’ category (21% (16, 28)) compared to the ‘< 50 mm’ category (10% (7, 15)). In herd bulls, titres to L. sv. tarassovi did not exceed 1:400.

MAT titres to L. sv. tarassovi vs. lactation and pregnancy
Given positive titres to L. sv. tarassovi, no significant difference or tendency (p > 0.1) was demonstrated with odds ratios and chi-squared tests for lactation and pregnancy percentages (Appendix 18) of cows in both age-categories at site B.

6.3.2. Serum Antibody to Viruses

6.3.2.1. Bovine Viral Diarrhoea Virus

AGID levels of antibody to BVDV vs. gender and age
There was no significant difference in the percentage distribution of AGID test levels of antibody to BVDV between two categories of age (Appendix 19) for both genders at site B. The only bull with a high level of antibody to BVDV (AGID = 3) was in the ‘young-to-mature bull’ category.

AGID levels of antibody to BVDV vs. lactation and pregnancy
Given positive titres to BVDV, no significant difference or tendency (p > 0.1) was demonstrated with odds ratios and chi-squared tests for lactation and pregnancy percentages (Appendix 20) of cows in both age-categories at site B.

6.3.2.2. Bovine Herpes Virus Type 1

SN titres to BHV1 vs. gender and age
There were significant differences (p < 0.05) in the percentage distribution of SN test titres to BHV1 between two categories of age (Appendix 19) for cows at site B. The percentage distribution was lower in the ‘heifer’ category (9% (4, 19)) compared to the ‘young-to-aged cow’ category (36% (24, 49)) at the higher titres (1:64–1:2048).
 Conversely for seronegative cows, the percentage distribution was higher in the ‘heifer’ category compared to the ‘young-to-aged cow’ category.

There was no significant difference in the percentage distribution of titres to BHV1 between two categories of age (Appendix 19) for herd bulls at site B. The only bull seronegative to BHV1 was in the ‘young-to-mature bull’ category and had been in the herd for less than 18 months.

**SN titres to BHV1 vs. lactation and pregnancy**

Given positive titres to BHV1, no significant difference or tendency ($p > 0.1$) was demonstrated with odds ratios and chi-squared tests for lactation and pregnancy percentages (Appendix 20) of cows in both age-categories at site B. However, in the ‘heifer’ category, all individuals in the first trimester of pregnancy were seronegative.

### SECTION 6.4. BIOCHEMISTRY AND HAEMATOLOGY

6.4.1. **Optimal Biochemical and Haematological Values**

There were significant differences ($p < 0.05$) between representative cattle groups at site B for either the means or the medians of most ‘optimal values’ of 16 serum biochemical tests and five haematological tests (Appendix 21). For many of these tests, the $10–90^{th}$ percentile range of values extended outside of the reference range of the testing laboratory, and in some instances also extended outside of the reference ranges of the selected key publications (Boyd 1984; Radostits et al. 2007).

The $10^{th}$ percentiles for serum P, gamma glutamyl transferase (GGT), globulin and blood platelets (both cow age-groups) were below the reference ranges of the testing laboratory. The $90^{th}$ percentiles for serum chloride (Cl), creatine phosphokinase (CPK), albumin and albumin-to-globulin ratio (all cattle groups), as well as for blood haemoglobin (Hb) (both cow age-groups), were above the reference ranges of the testing laboratory.
6.4.2. Variation in Biochemical Values

Biochemical values vs. financial year

For young cow groups at sites B and C, there was a significant difference (p < 0.05) between categories of financial years with serum P values. The ‘1991/92’ and ‘1999/2000’ years ranked lower than other years for sites B and C, respectively, and each had a 25th percentile value (serum P: 0.90 mmol/L and 0.82 mmol/L respectively) that indicated nutritional deficiency for the cattle groups.

There was a significant difference (p < 0.01) between years with serum vitamin A values for the young cow group at site B. The ‘1994/95’ year ranked lower than other years and had a 25th percentile value (serum vitamin A: 0.26 mg/L) that indicated nutritional deficiency for the cattle group.

This analysis of biochemical values, with the first examined variable (financial year) and reference ranges of the testing laboratory, is detailed as an example in Appendix 22.

Biochemical values vs. body condition score

For the young cow group at site B, there was a significant difference (p < 0.01) between categories of body condition with serum vitamin A values. The ‘BCS 1.5’ condition score ranked lower than other condition scores and had a 25th percentile value (serum vitamin A: 0.26 mg/L) that indicated nutritional deficiency for the cattle group.

Biochemical values correlated with liveweight

Significant correlations were demonstrated at site B, between liveweight and serum urea (p < 0.01) (aged cow group: r = -0.47; mature bull group: r = -0.49), as well as between liveweight and serum P (p < 0.05) (aged cow group: r = 0.35; older bull group: r = -0.52). The negative correlation between liveweight and serum P in the older bull group was associated with a significant positive correlation between liveweight and serum Ca (r = 0.48, p < 0.05).

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1 BCS for site B (scale: 1–5) was 1.5 to 3.5 for the young cow group.
Biochemical values vs. age
For the cows at site B, there was a significant difference (p < 0.01) between age-group categories with serum P and vitamin A values. The aged cow group ranked lower than other age-groups and had 25th percentile values (serum P: 0.92 mmol/L; serum vitamin A: 0.27 mg/L) that indicated nutritional deficiency for the aged cows.

Biochemical values vs. lactation
For the young cow group at site B, there was a tendency for difference (p < 0.1) between categories of lactation status with serum P values. The ‘lactating’ category ranked lower than the ‘non-lactating’ category and had a 25th percentile value (serum P: 1.09 mmol/L) that indicated nutritional deficiency for the lactating young cows. A chi-square test also indicated that, although not a recognised tendency, there was a trend ($\chi^2 = 4.35, p = 0.11$) for deficient levels of serum P to be associated with an absence of detectable conception in lactating young cows.

Biochemical values vs. pregnancy
For the young cow group at site B, there were significant differences (p < 0.05) between categories of pregnancy status with biochemical values, but no nutritional deficiency was indicated at 25th percentile values in the pregnancy categories.

SECTION 6.5. FAECAL CHEMISTRY

6.5.1. Variation in Faecal Chemistry Values

Faecal chemistry values vs. 2-months cumulative rainfall
For young cow groups at sites B and C, there was a significant difference (p < 0.01) between categories of 2-months cumulative rainfall with Faecal %P values. The ‘0–24mm’ rain category ranked lower than other rain categories; only the ‘25–49mm’ rain category ranked as low for site C. At the 25th percentile value in those lower ranked rain categories for sites B and C (Faecal %P: 0.15% and 0.12% respectively), dietary P-deficiency was indicated in the cattle groups.
There was a tendency for a difference (p < 0.1) between rain categories with Faecal %N values for the young cow group at site C. The ‘0–24mm’ rain category ranked lower than other rain categories and had a 25th percentile value (Faecal %N: 1.10%) that indicated dietary N-deficiency in the cattle group. In contrast, the ‘0–24mm’ rain category with Faecal %N values ranked significantly higher (p < 0.05) than the other (‘50–99mm’) rain category for the store steer\(^1\) group at site B.

For young cow groups at sites B and C, there was a significant difference (p < 0.01) between rain categories with Faecal %DM values. The ‘0–24mm’ rain category ranked higher than other rain categories, but had a quartile range of values for sites B and C (Faecal %DM: 15–20% and 16–18% respectively) that was within the physiologically-normal range for the cattle groups.

This analysis of faecal chemistry values with the first examined variable (2-months cumulative rainfall) is detailed as an example in Appendix 23, along with reference threshold values for maintenance (Faecal %P, Faecal %N) and reference values for the physiologically-normal range (Faecal %DM).

Faecal chemistry values vs. indicator grass greenness

For mature cow and store steer\(^2\) groups at site B, there was a significant difference (p < 0.01) between categories of indicator grass greenness with Faecal %P values. The ‘dry’ and ‘drying off’ greenness stages, respectively, ranked lower than other greenness stages and each had a 25th percentile value (Faecal %P: 0.15% and 0.19% respectively) that indicated dietary P-deficiency in the cattle groups.

There was a significant difference (p < 0.05) between greenness stages with Faecal %N values for the store steer group at site B. The ‘greening up’ greenness stage ranked lower than the other (‘drying off’) greenness stage, but neither had a 25th percentile value that indicated dietary N-deficiency.

\(^1\) The store steer group had faecal chemistry data for only two cumulative rainfall categories.

\(^2\) The store steer group had faecal chemistry data for only two indicator grass greenness categories.
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For the mature cow group at site B, there was a tendency for a difference (p < 0.1) between greenness stages with Faecal %DM values. The ‘flush green’ greenness stage ranked higher than other greenness stages, but had a quartile range of values (Faecal %DM: 13–16%) that was within the physiologically-normal range for the cattle group.

*Faecal chemistry values vs. indicator grass recruitment*

For the mature cow group at site B, there was a significant difference (p < 0.01) between categories of indicator grass recruitment with Faecal %P values. The ‘nil’ recruitment level ranked lower than other recruitment levels and had a 25\textsuperscript{th} percentile value (Faecal %P: 0.17%) that indicated dietary P-deficiency in the cattle group. Paradoxically, deficiency in this cattle group was also indicated at the 25\textsuperscript{th} percentile value in the ‘moderate’ recruitment level (Faecal %P: 0.17%).

There was a significant difference (p < 0.05) between recruitment levels with Faecal %N values for the mature cow group at site B. The ‘moderate’ recruitment level ranked lower than other recruitment levels and had a 25\textsuperscript{th} percentile value (Faecal %N: 1.05%) that indicated dietary N-deficiency in the cattle group.

For the mature cow group at site B, there was a significant difference (p < 0.05) between the recruitment levels with Faecal %DM values. The ‘abundant’ recruitment level ranked higher (p < 0.05) than other recruitment levels, but had a quartile range of values (Faecal %DM: 13–16%) that was within the physiologically-normal range for the cattle group. As a corollary, the 25\textsuperscript{th} percentile value in the ‘moderate’ recruitment level (Faecal %DM: 10%) indicated some abnormally loose faeces for this cattle group.

*Faecal chemistry values correlated with serum biochemistry*

For cows at site C, there were significant (p < 0.01) correlations that were positive between Faecal %P and serum P (r = 0.48), but negative between Faecal %DM and serum P (r = -0.46). In contrast, there was a significant (p < 0.05) positive correlation between Faecal %DM and serum P (r = 0.39) for store steers at site C.
For cows at site B, there were significant (p < 0.05) correlations between Faecal %P and serum P (r = 0.23), as well as between Faecal %N and serum urea (r = 0.22).

**Faecal chemistry values vs. age**

For cows at site B, there were no significant differences or tendencies (p > 0.1) between age-group categories with Faecal %P and Faecal %N values.

There was a tendency for a difference (p < 0.1) between age-groups with Faecal %DM values for cows at site B. The ‘heifer’ group ranked higher than other age-groups, but had a quartile range of values (Faecal %DM: 13–17%) that was within the physiologically-normal range for the cows. As a corollary, the 25th percentile value in the ‘aged cow’ group (Faecal %DM: 11%) indicated some abnormally loose faeces for these cows.

**Faecal chemistry values vs. ‘wet/ dry’ cattle class**

For cattle at sites B and C, there was no significant difference or tendency (p > 0.1) between two categories of ‘wet/ dry’ cattle class\(^1\) with Faecal %P values.

There was a significant difference (p < 0.01) between ‘wet’ and ‘dry’ cattle with Faecal %N values at site C. The ‘wet’ cattle ranked lower than the ‘dry’ cattle and had a 25th percentile value (Faecal %N: 1.23%) that indicated dietary N-deficiency for the cattle.

For cattle at sites B and C, there was a tendency for a difference (p < 0.1) and a significant difference (p < 0.01), respectively, between ‘wet’ and ‘dry’ cattle with Faecal %DM values. The ‘dry’ cattle ranked higher than the ‘wet’ cattle, but had a quartile range of values for sites B and C (Faecal %DM: 15–20% and 15–18% respectively) that was within the physiologically-normal range for the cattle.

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\(^1\) ‘wet’ cattle class (lactating young cows); ‘dry’ cattle class (store steers).
SECTION 6.6. FAECAL PARASITOLOGY

6.6.1. Identity of Intestinal Parasites
The genera of the intestinal nematode eggs and larvae identified in faecal samples of cattle from site B are summarised in Appendix 24. Up to 150 *Cooperia* spp.-type eggs and 480 *Oesphagostomum* sp./*Haemonchus* sp.-type eggs were identified per gram of faeces. Nematode larvae cultured in faecal samples were *Cooperia* spp. (up to 100% of larvae in some samples), *Oesphagostomum* sp. (up to 75% of larvae in some samples) and *Haemonchus* sp. (up to 70% of larvae in some samples). It was recognised that because there may have been differences between nematode genera, in the fecundity of adults and in the success of larval cultures, these percentages of nematode larvae would not necessarily have indicated the abundance of adult intestinal nematodes in the cattle. Oocysts in the faeces of two male, weaned calves at site B were identified as *Eimeria bovis* and *E. canadensis*.

6.6.2. Variation in Faecal Egg Counts and Oocyst Counts

*Faecal egg and oocyst counts per financial year*
For the mixed, weaned-calf group at site B, there was a significant difference (p < 0.01) between categories of financial years with transformed faecal egg counts. The ‘1994/95’ year ranked higher than other years and had a 90\(^{th}\) percentile count (889 epg) that exceeded the reference threshold for clinical intestinal nematodiasis in the cattle group. The maximum faecal egg count for the mixed, weaned-calf group (1,920 epg in the ‘1993/94’ year) and the mature-to-older bull group (720 epg in the ‘1992/93’ year) exceeded the reference threshold for clinical intestinal nematodiasis. Based on the total number of herd bulls sampled in the mature-to-older bull group (n = 81) and a 95% level of confidence to predict the true prevalence of disease (Cameron 1999) (i.e. an indication of clinical intestinal nematodiasis), up to 6% of bulls in this group could have had faecal egg counts as high as the recorded maximum.
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For the mixed, weaned-calf group at site B, there was a significant difference (p < 0.01) between years with transformed faecal oocyst counts. The ‘1994/95’ and ‘1995/96’ years ranked higher than other years but each had a 90\textsuperscript{th} percentile count (980 opg and 240 opg respectively) that did not exceed the reference threshold for clinical coccidiosis in the cattle group.

The maximum faecal oocyst count for the mixed, weaned-calf group (15,050 opg in the ‘1992/93’ year) exceeded the reference threshold for clinical coccidiosis.

Aspects of this analysis of faecal egg and oocyst counts, together with the first examined variable (financial year) and reference threshold faecal counts for intestinal parasitic disease, are detailed as an example in Appendix 25.

\textit{Faecal egg and oocyst counts per indicator grass greenness}

There were no significant differences or tendencies (p > 0.1) between categories of indicator grass greenness with transformed faecal egg counts for cattle at site B.

For the mixed, weaned-calf group at site B, there was a significant difference (p < 0.01) between categories of indicator grass greenness with transformed faecal oocyst counts. The ‘drying-off’ greenness stage ranked higher than the other (‘greening up’) greenness stage but had a 90\textsuperscript{th} percentile count (300 opg) that did not exceed the reference threshold for clinical coccidiosis in the cattle group.

\textit{Faecal egg and oocyst counts per body condition score}

For the mature cow group at site B, there was a significant difference (p < 0.05) between categories of body condition with transformed faecal egg counts. The ‘BCS 3’ condition score ranked higher than other condition scores\textsuperscript{1} but had a 90\textsuperscript{th} percentile count (53 epg) that did not exceed the reference threshold for clinical intestinal nematodiasis in the cattle group.

\textsuperscript{1} BCS for site B (scale: 1–5) was 1.5 to 3.5 for the mature cow group.
CHAPTER 6. LABORATORY TEST RESULTS

For the mature-to-older bull group at site B, there was a significant difference (p < 0.05) between condition scores with transformed faecal oocyst counts. The ‘BCS 2.5’ condition score ranked higher than other condition scores\(^1\) but had a 90\(^{th}\) percentile count (10 opg) that did not exceed the reference threshold for clinical coccidiosis in the cattle group.

_Faecal egg and oocyst counts compared per liveweight_

For the mixed, weaned-calf group and the mature-to-older bull group at site B, odds ratios indicated that the percentage with positive faecal egg or oocyst counts was not significantly higher in the lower-weight, weaned calves (≤ 250 kg\(^2\)) or lower-weight bulls (≤ 750 kg\(^3\)), compared to their respective higher-weight cohorts.

_Faecal egg and oocyst counts per age_

The maximum faecal egg and oocyst counts in age-group categories for cows and herd bulls\(^4\) did not exceed reference thresholds for clinical intestinal nematodiasis or clinical coccidiosis.

**SECTION 6.7. SUMMARY**

In this chapter, results of laboratory tests on samples from cattle at one or more sites have highlighted aspects of bovine infections (\_C. fetus\_ subsp. \_venerealis\_, \_T. foetus\_), leptospires, BVDV, BHV1), infestations (intestinal parasites) and diagnostic tests of cattle nutrition (biochemistry, haematology and faecal chemistry) on arid rangelands.

_Campylobacter fetus subsp. venerealis_

Collection and culture of preputial scrapings during a 5-year period did not detect vibriosis in the breeding herd at site B.

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\(^1\) BCS for site B (scale: 1–5) was 1.5 to 3.5 for the mature-to-older bull group.

\(^2\) Cut-off weight = median recorded weaned-calf weight (250 kg).

\(^3\) Cut-off weight ~ median recorded bull weight (768 kg).

\(^4\) Herd bull age-groups (Appendix 10), not including young bulls.
CHAPTER 6. LABORATORY TEST RESULTS

*Tritrichomonas foetus var.*
Collection and culture of preputial scrapings during a 5-year period detected trichomoniasis in the breeding herd at site B, but no significant association was demonstrated with bull age or financial year.

*Leptospires*
Micro-agglutination test titres indicated that in the breeding herd at site B, there was serological evidence of *L. sv. hardjo* and *L. sv. tarassovi*, but not of *L. sv. pomona*. With positive titres (MAT titre $\geq 1:100$) to *L. sv. hardjo* in the ‘young-to-aged cow’ category, the lactation percentage tended to be lower ($p = 0.05$) and the pregnancy percentage tended to be higher ($p = 0.09$). No significant association or tendency was demonstrated between positive titres to *L. sv. tarassovi* and the percentage lactating or pregnant, but the percentage distribution of cows with higher titres to *L. sv. tarassovi* ($\geq 1:400$) was significantly higher ($p < 0.05$) in the ‘50 mm+’ category of 2-months cumulative rainfall.

*Bovine viral diarrhoea virus*
Agar gel immunodiffusion test levels of antibody to BVDV indicated serological evidence of this virus in the breeding herd at site B. No significant association or tendency was demonstrated between positive titres to BVDV (AGID $\geq 1$) and the percentage lactating or pregnant.

*Bovine herpes virus type 1*
Serum neutralisation test titres to BHV1 indicated serological evidence of this virus in the breeding herd at site B. There was more than 95% seroprevalence in the herd bull categories. Compared to the ‘heifer’ category, there was a significantly higher (36%, p < 0.05) percentage distribution of the higher titres (1:64–1:2048) in the ‘young-to-aged cow’ category. No significant association or tendency was demonstrated between positive titres to BHV1 (positive SN titre) and the percentage lactating or pregnant.
Biochemistry and haematology
Based on two cow age-groups under ‘optimal’ seasonal conditions on arid rangelands at site B, the 10–90th percentile ranges of test values that extended outside of the reference ranges of the testing laboratory were considered for creation of regional reference ranges, i.e. six biochemical tests (Cl, GGT, CPK, albumin, globulin, albumin-to-globulin ratio) and two haematological tests (Hb, platelets).

Below-normal serum P values at the 25th percentile (range: 0.82–1.09 mmol/L) were associated with poor rangeland conditions and aged or lactating cows at sites B and C. Correlation of liveweight with serum P at site B was low for aged cows ($r = 0.35$, $p < 0.05$) and negative for the older bulls ($r = -0.52$, $p < 0.05$).

Below-normal serum vitamin A values at the 25th percentile (range: 0.26–0.27 mg/L) were associated with dry seasonal conditions, aged cows and low body condition (BCS 1.5) at site B.

Faecal chemistry
Low Faecal %P values at the 25th percentile (range: 0.12–0.19%) suggested that dietary P-deficiency on arid rangelands at sites B and C was associated with low 2-months cumulative rainfall, dry indicator grass and nil indicator grass recruitment. Correlation of Faecal %P with serum P was highest for cows at site C ($r = 0.48$, $p < 0.01$).

Low Faecal %N values at the 25th percentile (range: 1.05–1.23%) suggested that dietary N-deficiency on arid rangelands at sites B and C was associated with low 2-months cumulative rainfall, moderate indicator grass recruitment, and lactating young cows. Correlation of Faecal %N with serum urea was highest for cows at site B ($r = 0.22$, $p < 0.05$).

Quartile ranges of Faecal %DM at sites B and C were within the physiologically-normal range. Low Faecal %DM was recorded at the 25th percentile for aged cows (11%) and with moderate indicator grass recruitment (mature cows: 10%). The most significant
differences (p < 0.01) in Faecal %DM values were associated with 2-months cumulative rainfall, and store steers at sites B and C. Correlations of Faecal %DM with serum P were inconsistent between steers (r = 0.39, p < 0.05) and cows (r = -0.46, p < 0.01) at site C.

**Intestinal parasites**

Culture of *Cooperia* spp., *Oesphagostomum* sp. and *Haemonchus* sp. larvae in faecal samples from site B confirmed not only infestations by these intestinal nematodes in adult cattle and weaned calves, but also the resilient nature of *Cooperia* spp. larvae. Up to 100% of cultured larvae were identified as *Cooperia* spp. in some faecal samples. The maximum faecal egg counts in the mixed, weaned-calf group (1,920 epg) and mature-to-older bull group (720 epg) indicated clinical intestinal nematodiasis. For the mixed, weaned-calf group, the 90th percentile faecal egg count exceeded the reference threshold for clinical intestinal nematodiasis in two financial year categories (‘1994/95’: 889 epg; ‘1992/93’: 720 epg).

*Eimeria bovis* and *E. canadensis* oocysts were identified in the faeces of two weaned calves at site B. Although the maximum faecal oocyst count in the mixed, weaned-calf group (15,050 opg) exceeded the reference threshold for clinical coccidiosis, this was not reflected by the 90th percentile faecal oocyst counts.

In the following chapter, the results from the present study are reviewed and compared with literature that is relevant to cattle grazed on arid rangelands.
CHAPTER 7. DISCUSSION

SECTION 7.1. INTRODUCTION
In this chapter, the results from the present study are reviewed. This study was based on three arid rangeland sites with primary beef cattle projects in the northern Alice Springs district of the Northern Territory. Conclusions are made with respect to results for herd bulls, cows, serology, biochemistry and haematology, faecal chemistry and faecal parasitology.

SECTION 7.2. REVIEW OF HERD BULL RESULTS
An adequate number of physically and reproductively functional herd bulls is a basic requirement for a beef cattle breeding herd. In the present study, management of herd bulls was described with respect to their number and age, as well as recruitment, culling and deaths.

7.2.1.1. Herd Bulls in Paddock

Bull percentages
The maximum bull percentages calculated for the three sites (range: 5.8–8.2%) in the present study (Table 4-1) were within a range reported by cattle managers in the Alice Springs district (2–10%) (Leigo c. 2006). Calculation of the mean annual number of branded calves per herd bull at two sites (range: 5–24.6 calves) (Table 4-2) indicated that the lowest number of calves per bull was associated with the highest bull percentage and by default, potentially the highest bull cost per calf. Modelling reported for the breeding herd at site B has indicated an average of $36.75 +/- $14.77 bull-cost per calf branded (+/- standard error) (Coventry, Taylor & Pinch 2002a), however DNA typing of calves to determine paternity in herds with multiple-sire mating has indicated a wide range in the mating success of individual bulls in northern Australia (Holroyd et al. 2002). This latter report suggests that the physical, seminal and behavioural traits of
bulls, in addition to bull percentage, can have a large influence on the bull-cost per calf for individual sires. Studies in other extensive areas of northern Australia have demonstrated that bull percentages in excess of 6% are also associated with fence damage, fighting, injury and increased numbers of non-working bulls (Fordyce et al. 1998). As a corollary, those studies have demonstrated that where open paddock terrain and controlled water-points facilitate access of bulls to the cows, an equivalent of 2% bulls has been sufficient to sire 80% of calves. In line with these findings, the use of 2.5% reproductively sound bulls has been recommended for breeding herds of northern Australia (Holroyd et al. 2000).

Reasons for the use of higher bull percentages at sites A and C (8.1% and 8.2% respectively) may have included allowance for the three considerations detailed in Section 2.1.4.2, i.e. mating behaviour of *Bos indicus* bulls; loss of bull breeding soundness; and lack of access to cows in paddocks with hilly terrain or uncontrolled waters. At all three sites, uncontrolled surface waters were recorded after rain in some years, and rough or thickly vegetated rangeland was represented by one or more landsystems at each site (Appendix 1). These paddock conditions were not consistent with those identified as suitable for the recommended 2.5% reproductively sound bulls. This indicates scope for further studies to quantify a cost-effective bull percentage under conditions of arid rangeland grazing and extensive cattle management.

### 7.2.1.2. Recruitment of Herd Bulls

*Source and selection criteria*

The frequency of recruiting young bulls for each site reflected the different management style and objectives of each primary beef cattle project. Some or all of the recruited herd bulls were sourced externally, as previously reported for beef cattle properties in the Alice Springs district (Leigo c. 2006; NT-DPI&F 1995c). For site A, herd bulls were also recruited from the ‘exceptional’ station-bred bull calves (Appendix 3). During the
1970s, 23% of properties in the district purchased all herd bulls from interstate studs and 14% of properties bred their herd bulls by not castrating the phenotypically-desirable male calves (Petty, Holt & Bertram 1979). These management practices have influenced the rate of herd bull improvement in the district.

More recently it has been recommended that selected bulls should meet threshold criteria for general physical and reproductive soundness (Holroyd et al. 2002). Although little information on the bull selection criteria was recorded for the sites, some external sourcing of bulls for all three sites implied that introduction of young, genetically-improved, breed-specific bulls was important. No information was reported on the breeding soundness of these introduced bulls prior to use in the primary beef cattle projects. As noted in Section 2.1.4.2, cattle managers in the Alice Springs district have considered a ‘fertility test’ to be an aspect of a bull breeding soundness examination (BBSE) that is both important for the selection of herd bulls and the responsibility of a vendor stud prior to the sale of bulls.

### 7.2.1.3. Removal of Herd Bulls

**Selective culling**

In the 20 years between completion of data collections at sites A and B (1975–1996), increasing emphasis in technical and extension manuals has been placed on the use of a standardised BBSE to assist selection, culling or retention of herd bulls (Bertram 2003, pp.17-32; Entwistle & Fordyce 2003, pp.7-9; McGowan et al. 1995, pp.9-12). Some criteria of a BBSE were assessed at site B, but not at sites A and C. The objectives of the primary beef cattle projects at the latter two sites did not include a BBSE (Appendix 12 a.). The herd bull management activity reported for these sites only reflected district practices such as the purchase and introduction of new bulls (NT-DPI&F 1995b) and visual inspections during a bore run or muster to identify unsound or unsuitable bulls (NT-DPI&F 1995c). Failure to yard all herd bulls at muster would reduce the capacity...
to assess each bull for selective culling. A (complete) BBSE has been perceived as impractical under pastoral property conditions (NT-DPI&F 1994a), however, a limited number of assessments can still assist selective culling of bulls that are unsuitable or poor contributors to calf production (Bertram 2003, p.29; Holroyd et al. 2002). At sites A and B, selective culling of herd bulls focused on limitations to physical soundness (excessive age, disease, injury and arthritis) (Section 4.2.3), similar to findings from surveys of other arid areas of northern Australia (Bortolussi et al. 1999a,b; Clarke 1991, p.25). The age at which herd bulls were culled for excessive age at site A was not reported. However at site B, 80% of culled bulls were greater than 8 years old (Coventry, Leigo & Saville 2007, p.5), and the earliest cull for excessive age was undertaken at 7.5 years old. The latter is consistent with culling for excessive age, as recommended for bulls in northern Australia from 6 years old (Fordyce 1992), and as undertaken in the Alice Springs district at 6 to 8 years of age (Section 2.1.4.1).

Issues relating to physical disease or injury during herd bull acclimatisation and mating occurred at sites A and B. For 22% of the bulls removed from site B, reasons for culling included abnormalities of the reproductive tract. Although recruited herd bulls had no abnormalities of the penis, preputial sheath or seminal vesicles when first inspected and recorded at 3 years old, at least 7% of 4-year-old bulls had some abnormality within two years of introduction (Coventry, Leigo & Saville 2007, p.7). Additional examination of the reproductive tract, including interpretation of scrotal circumference and testicular tone in herd bulls at site B (Coventry, Taylor & Pinch 2002b), has demonstrated how reproductive tract measures can assist with the culling of low-fertility or geriatric bulls. The other issue of note at site B was euthanasia of a young herd bull (3.5 years old) on account of a dislocated stifle, which may have been sustained during mating or inter-bull aggression in the year of introduction (1996). As noted in Section 2.1.4.1, the high-risk period for new bulls is during or shortly after introduction. For site A, removal of
three introduced herd bulls on account of behavioural problems in late 1973 was reported by a research officer from the primary beef cattle project (WA Low 2006, pers. comm.) (Section 3.3.3.1). This removal may have been associated with unsuccessful acclimatisation of the introduced bulls. In comparison, retention of ‘exceptional’ male calves for recruitment as herd bulls at site A may have circumvented analogous acclimatisation problems.

**Total number removed**

High annual variability in the percentage of herd bulls that was removed reflected seasonal factors and long-term breeding objectives, but this was less obvious when averaged on a seasonal basis (Table 4-4). At site A, the highest annual percentage of herd bulls that was removed (50%) coincided with restructuring of the breeding herd and the return of average-to-good seasonal conditions in 1973 (Table 3-2). At site B, the highest annual percentage of herd bulls that was removed (21%) represented opportunistic removal of older bulls under good seasonal conditions. These herd bulls had been introduced in a large consignment during a period of herd-building in 1987 (Coventry, Leigo & Saville 2007, p.5).

**Recorded and unconfirmed deaths**

Herd bull deaths in an extensively-grazed cattle herd are difficult to detect if there is confounding, either by a relatively low number of bulls, a low mustering percentage or limited data recording (Section 2.1.3.3). Low mustering percentages were noted for herd bulls at one or more musters for each of the three sites, and limited data were noted for herd bull groups at sites A and C (Table 3-3).

The recorded and unconfirmed (extrapolated) herd bull mortality percentage data were only examined for site B. The range of recorded annual mortality (0–5.5%) equated to less than 5% herd bull mortality in years opening with average and poor/dry seasonal conditions (Table 4-5). Limited extrapolation indicated up to 6.5% unconfirmed herd
CHAPTER 7. DISCUSSION

bull mortality. This was similar to that of recorded deaths and inferred that for every bull that was recorded (confirmed) as ‘dead’, there was another bull death that could not be confirmed, i.e. a confirmed-to-unconfirmed bull death ratio of 1:1. This is not as low as a previous estimate of 1:2 for extensively-grazed cattle on open grassland (K de Witte (NT-DPI&F, Katherine, N.T.) 2000, pers. comm.).

Mortality percentages for bulls in the Alice Springs district have not been recorded, however the sum of maximum recorded herd bull mortality and unconfirmed (extrapolated) herd bull mortality at site B suggests an annual mortality potentially exceeding 10%. This is consistent with the level of herd bull deaths presumed for one year in an arid area of Western Australia (Thomson 1999, p.39).

7.2.1.4. Conclusions on Herd Bulls

Effective herd bull groups
Although limited for herd bulls in the present study, analysis and discussion of direct and derived data from the three sites enabled examination of herd bull group dynamics for extensively-managed beef cattle breeding herds. This highlighted the potential for a lower reported bull percentage (4.1%) to maximise the mean annual number of branded calves per herd bull (24.6 calves). Also highlighted was the potential to identify higher risk herd bulls for culling, based on appraisal of bull ages, numbers and soundness at muster. A combination of confirmed and unconfirmed annual mortality data suggested that 10% of herd bulls were at risk of dying on arid rangelands.

7.2.2. REVIEW OF COW RESULTS
Optimal production by a beef cattle breeding herd requires management of nutrition, plus timely recruitment and culling of cows. In the present study, the production efficiency of cows was described with measures of reproductive performance and herd dynamics: conception; lactation; number and weight of calves produced; recruitment; culling; and deaths.
7.2.2.1. Conception

Variable conception percentages

A link exists between the highly variable seasonal nutrition and cow production efficiency on arid rangelands (Section 2.1.5.1). This was demonstrated in the present study with the number of calculated monthly conceptions. The range of calculated monthly conception percentage was widest in a year opening with poor/dry seasonal conditions at sites A and B (0.7–24% and 1.3–22% respectively). Also a significantly lower (p < 0.05) percentage of individuals in the young cow group at site B conceived in a year opening with poor (84%) compared to average (94%) seasonal conditions (Table 5-1). At least 89% annual conception (based on the lower 95% CI) was calculated for young, mature and aged cow groups in a year opening with average seasonal conditions (1992/93). This apparent level of conception was boosted by the good seasonal conditions for the second part of that year and calculations based on cows recorded at three consecutive musters. By default, cows removed from calculations included those culled for ‘fat’ and some of these may have been infertile. However, extrapolation on this is confounded by the strategic culling for excessive age undertaken during good seasonal conditions at site B. The latter is described in Section 7.2.2.4 below.

At site A, no significant relationship was demonstrated between the monthly conception percentage and monthly rainfall or recent effective rainfall (Section 5.2.1 and Table 5-2), however in the primary beef cattle project it was concluded that forage abundance had the strongest influence on the rate of conception. A low number of conceptions were identified under poor forage conditions, resulting in 20% of those cows over 2 years old conceiving in each 3-month period (monthly conception averaging 6.6%). During good forage conditions, approximately 30% of cows conceived in each 3-month period (monthly conception averaging 10%) and forage growth after heavy rains was
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sufficient for good forage (conditions) to carry-over into drought years (Low & Wood c. 1980).

At site B, the monthly conception percentage was significantly correlated (p < 0.01) with both average monthly minimum temperature and monthly rainfall (Section 5.2.1). These correlations are consistent with a previously noted positive response in pasture grasses (Section 2.1.1.3) that occurs when requirements for temperature and rainfall are met for growth. The mean monthly conception percentage was also significantly higher (p < 0.05) (10.1% vs. 6.2%) after the extended (1- to 2-month) influence of recent effective rainfall (Table 5-2). This examination of an extended rainfall influence made allowance for the noted lag period between a flush in rangeland pasture growth and stimulation of oestrus (Section 2.1.6.1).

Although no statistically significant increase in conception was demonstrated in the two months after musters with limited weaning of mixed-age cows at site B (Table 5-2), this is consistent with the understanding that the greatest benefit of weaning for a continuously-mated herd is in the improvement of post-weaning body condition of pregnant cows and subsequent reduction in the next calving-to-conception interval. However, a more immediate positive outcome from weaning has been demonstrated with a significant increase in conceptions for first-calved cows south of Alice Springs (Schatz 2011, pp.48-50).

In the primary beef cattle project at site A, cows lactated for two to six months before conceiving (Low & Wood c. 1980), i.e. the calving-to-conception interval of some cows exceeded the critical 85 days described by Entwistle (1984). Managed weaning was limited to steer progeny (Appendix 3), so prolonged lactating by the cows with female calves may have contributed to an extension of the average calving-to-conception interval. Other issues related to lactation and weaning are discussed below in Section 7.2.2.2.
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Pre-natal conception losses
In arid/semi-arid regions, pre-natal conception losses may result from venereal disease (Entwistle 1974). For example, pre-natal losses from venereal disease (trichomoniasis) have been reported to cause a 35% drop in pregnancy in naïve cows on the Barkly Tablelands of the Northern Territory (Andrews 1976, p.131). Pre-natal losses may also be the result of dietary factors associated with drought (Entwistle 1974), including increased consumption of dietary tannins (Holloway et al. 2002).

For the primary beef cattle project at site A, reports of 2.5% abortions (Low 1978b) and 11% conception loss (based on consecutive conceptions less than 240 days apart) (Low & Wood c. 1980) suggest an equivalent of 8.5% early pre-natal loss. At the time of the primary beef cattle project at site A, brucellosis had been detected in up to 1% of the property cohorts (Low 1978b) and cattle were subjected to blood testing as a part of the BTEC program (Low & Wood c. 1980). Although bovine brucellosis may have been a differential diagnoses for conception losses, the cattle at site A were not in the paddock that was considered to be the source of brucellosis infection on the property, and none had to be removed on account of positive brucellosis blood test results (WA Low 2013, pers. comm.). Testing for other venereal pathogens was not undertaken during the primary beef cattle project at site A.

For site B, pre-natal losses (3.9% of pregnancies) were determined (Appendix 14), but evidence of infectious causes was elusive. Testing for pathogens such as *Neospora caninum* was not a part of the primary beef cattle project at site B. Serological evidence of infection with BVDV, *L. s.v.* hardjo or BHV1 in the herd was insufficient to attribute these pathogens to the reported pre-natal losses. In the ‘heifer’ category, higher titres to *L. s.v.* hardjo (MAT ≥ 1:400) were associated with reproductive failure (Section 6.3.1.1) and the pregnancy percentage was lower with positive titres to BHV1 (44%) (Appendix
20), however the numbers of individuals in compared groups were too small to demonstrate a significant difference.

With regards to bacteriology, testing of herd bulls from site B for *Campylobacter fetus* subsp. *venerealis* and *Tritrichomonas foetus* was either inconclusive or had low sensitivity (Section 7.3.1). In addition, the primary beef cattle project did not include serological or PCR testing for either pathogen.

For both sites A and B, it is not possible to say how dietary factors contributed to the reported pre-natal losses. However, dry periods occurred at both sites (Table 3-2) and these periods on arid rangelands have been associated with a decrease in the quality of available feed (Section 2.1.1.3), as well as with an increase in consumption of poisonous plants (Section 2.1.3.2). In addition to the suppressive effect on oestrus from poor cow nutrition (Section 2.1.6.1), it is possible that poor seasonal quality of available feed or compounds in some eaten plants may have had a negative impact on conceptions.

In the Alice Springs district, no data have been previously collated on the pre-natal proportion of conception losses. Review of research into reproductive efficiency in northern Australia has recognised the difficulty in identifying pre-natal losses and their causes in extensively-grazed cattle herds. These causes may include: fertilisation failure, infectious disease, stress, heat adaptation, age, nutritional deficiencies and toxins (Burns, Fordyce & Holroyd 2010).

From research in northern Australia, benchmarks have been proposed for pre-natal losses before a confirmed pregnancy (fertilisation failure: 10%; early embryonic loss: 20%; late embryonic loss: 5%), and for the pre-natal losses after a confirmed pregnancy (3%) (Fordyce, Burns & Holroyd 2006, p.4). The latter is similar to the pre-natal losses noted above for site B (3.9%) but not for site A (11%). The difference in analysis for
site B (lactation after confirmed (1st trimester) pregnancy), compared to that described by Low and Wood (c. 1980) for site A, may have contributed to the noted differential.

*Influences on weight-at-conception*

Interacting factors that influence cow liveweight were reflected in the annual weight-at-conception for site A (averages of young-to-aged cows), plus sites B and C (means of heifers and young-to-aged cows) (Table 5-3). In the present study, a progressive annual increase in weight-at-conception was noted in the young-to-aged cows at sites A and B (from 321 to 397 kg, and from 405 to 496 kg respectively). This annual increase in weight may have been a result of either marked changes in the herd genetics or above-average seasonal conditions.

Changes to herd composition did occur with destocking for drought at site A (Low 1978b), as well as with culling of cows with lower frame scores, and recruitment of heifers with higher frame scores at site B (Coventry, Leigo & Saville 2007, p.8). If the consequent change in herd genetics was initiating increased frame score and mature weight, this could increase both the age of puberty (Vargas et al. 1999) and the maintenance requirements. Both of these outcomes can impact negatively on reproductive performance, in particular as a result of reduced drought tolerance (Fahey et al. 2000, p.27; Phillips & Coventry 2004). Increasing average weight could also be related to genetic gains with improved feed conversion efficiency and an increased percentage of body muscle relative to body fat. Analysis of carcase traits has shown that the percentage of fat in steers has a positive genetic correlation with calving rate in related female cattle (Splan, Cundiff & Van Vleck 1998), so herd genetics that increase the proportion of body muscle to fat would appear to have the potential to impact negatively on aspects of female reproductive performance. Notwithstanding this, trials have demonstrated that, firstly it is possible to select for improved yearling weight without significantly impacting on days-to-calving or calving success (Mercadante et al.
and secondly it is possible to select heifers with increased muscling without detrimental effect on early female fertility (McKiernan, Richardson & Wilkins 2004). Increase in annual weight-at-conception in the study was also associated with improvement in seasonal feed conditions at sites A and B (young-to-aged cows) and increasing BCS at sites B and C (Section 5.2.1). This indication of a seasonal influence mitigated some concern for sites A and B, regarding a genetically-increased mature cow liveweight and the potential for an adverse effect on reproductive efficiency.

Post-pubertal nutrition and growth contributed to the significant differences (p < 0.05) in annual weight-at-conception between heifers and young-to-aged cows at site B, and between years for young-to-aged cows (‘first-calving’ heifers) at site C (range: 362–410 kg). At sites B and C, liveweight data analysed for heifers were inclusive of first-calf heifers, so the means of annual weight-at-conception did not reflect the critical mating liveweights of maiden heifers for breeds of the *Bos taurus*-type (range: 270–290 kg) (Withers 1984) and *Bos indicus*-type (range: 280–320 kg) (Holroyd 1985, p.vi).

**Recommended body condition score-at-conception**

With the exception of disease, most factors influencing the conception percentage of cows may be related to nutrition and changes in body condition. The body condition of cows at calving determines the percentage that exhibit oestrus and subsequently conceive when re-mated (Herd & Sprott 1988). This positive relationship between cow body condition and pregnancy percentage has been reported in northern Australia (Donaldson 1969; Lamond 1969), and has been documented for continuously-mated cows in the Alice Springs district (NT-DPI&F 2001b). The latter has shown higher pregnancy percentages in non-lactating cows and cows with higher body condition.

Body condition scoring has been promoted as a tool to manage nutrition for the beginning of a defined mating period (Herd & Sprott 1988). On the Barkly Tablelands of the Northern Territory, body condition scoring has been used with regression analysis
(Savage 2004, p.xiv) to predict the pregnancy percentage and monthly conceptions in a seasonally-calving herd. This supported recommended use of body condition scoring at biannual musters to assess and managed future herd fertility.

At calving it is recommended that body condition be a minimum of BCS 5 (scale: 1–9) for young-to-aged cows and a minimum of BCS 6 for first-calving heifers (Spitzer et al. 1995). In order to avoid dystocia, heifers at first-calving should also be well-grown and without excessive fat. On the scale of 1 to 5 used at site B, equivalent recommendations for young-to-aged cows and heifers (BCS 2.5 to 3) (Withers 1984) are higher than recommendations of Graham (2006) (BCS 2 to 2.5). On the scale of 1 to 6 used at site C, the equivalent recommendations might be advanced to between BCS 3 and 4.

At site B, the medians of calculated (extrapolated) BCS-at-conception for young-to-aged cows and heifers (both BCS 2.5) were consistent with the recommendations of Withers (1984). At site C, the medians of BCS-at-conception for young-to-aged cows and heifers (BCS 3 and BCS 4 respectively) presented equivalent recommendations, based on a scale of 1 to 6. The slightly higher median of calculated BCS-at-conception for heifers was in line with the age differential in recommendations by Spitzer et al. (1995). The difference in medians of calculated BCS-at-conception at sites B and C reflected the divergence in their two scoring scales for the cows in ‘fat’ body condition.

For continuously-mated herds in northern Australia, the relationship between body condition and point-in-time measures of conception are not always positive. Monthly observations have been required to correlate fertility with body condition (Holroyd, Arthur & Mayer 1979). Loss of a positive relationship between body condition and pregnancy percentage has been documented, particularly for non-lactating cows and recently-weaned cows in ‘poor’ or ‘store’ condition (Donaldson 1969; Lamond 1969).

In the present study for site B, the pregnancy percentage of lactating mature and aged cows was highest, although not significantly different, for individuals in ‘store’ body
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condition. For non-lactating heifers, mature cows and aged cows, findings demonstrated a lack of correlation between body condition and pregnancy percentage at muster, as well as a lack of significant difference in pregnancy percentage between the body condition categories (Appendix 13).

Effective use of body condition as a management tool is not as clear-cut for mixed-age cows in a continuously-mated breeding herd. With exception of heifers that are entering the breeding cycle, the cows will be in a range of reproductive stages and have a range of nutritional needs that may reflect maternal growth, late pregnancy or lactation. In general, assessment of body condition is thus of most benefit where used to monitor management of herd nutrition, with respect to weaning and the nutritional strategies described in Section 2.1.3.1. Ideally, heifers and lactating cows would be maintained in ‘fat’ and ‘forward store’ condition respectively, i.e. above or at the recommended BCS-at-conception (BCS 2.5 on scale: 1–5). As a corollary, individual assessment of body condition can also promote seasonal culling, as described in Section 2.1.5.1 for non-lactating cows in excessive (‘fat’) body condition, especially where the absence of detectable pregnancy indicates poor reproductive efficiency.

As a final point of note, correlation between body condition and pregnancy percentage at muster was only recorded for non-lactating young cows in the present study. For those individuals in ‘forward store’ condition at sites B and C, the pregnancy percentage (87% and 80% respectively) (Appendix 13) was similar to an averaged reproductive parameter at site B (87% branding percentage) (Table 5-9) and site C (79% weaning percentage) (Table 5-10). This suggests that the pregnancy percentage of non-lactating cows in ‘forward store’ condition might be used as an indicator of reproductive efficiency in a continuously-mated herd under analogous conditions.
7.2.2.2. Lactation

Association with rain, body condition and age
In the primary beef cattle project at site A, it was reported that the lactation percentage averaged 68% for mustered cows over 2 years of age (Low & Wood c. 1980). This was most similar to the percentage that was lactating in the young cow group (71%) at site B. At this latter site, the lactation percentage of the young cows was significantly different (p < 0.05) from the lactation percentages of the heifer and mature cow groups (52% and 75% respectively) (Table 5-8). Interrupted lactation records of the older age-groups at site C prevented meaningful comparison of the percentages that were lactating.

Assessment of the lactation percentage of cows at sites B and C suggested that there was an indirect relationship between rainfall and lactation in the continuously-mated breeding herds. Significantly more (p < 0.05) cows were lactating in years commencing with average opening seasonal conditions (site B: 96%) or good opening conditions (site C: 83%) (Table 5-5), but this was not associated with recent (6-months cumulative) rainfall (Table 5-6). This was more likely to be associated with successful calf-raising, extended capacity of the cows to lactate, and reduced seasonal need for managed weaning to maintain cow body condition for reproductive efficiency.

Based on descriptive body condition categories, the percentage of cows that was lactating was inversely related to body condition of cows at both sites B and C (Table 5-7). This supports recommended management strategies that limit the nutritional stress of lactation (Section 2.1.5.1).

Assessment and management of lactation
The presence or absence of lactation is one determinant of cow reproductive performance. As a corollary for individual cows in a continuously-mated herd, it is noted that two lactation status records from biannual musters have provided a more
accurate indication of annual reproductive performance than has one lactation status record from a single annual muster.

Absence of lactation within an expected period (lactation failure) may be used with records of cow pregnancy to determine failure to rear a calf (Entwistle 1984). In the present study, lactation failure was used to determine pre-, peri-/post-natal losses at sites B and C (Section 5.2.2). The presence and absence of lactation is a foremost consideration for management of a breeding herd: to selectively manage nutrition (as per Section 2.1.5.1); to manage for drought (as per Section 2.1.3.1); to reduce potential causes of mortality (as per Section 2.1.3.3); for selective culling; and to plan the time of controlled mating. The relationship between nutrition and lactation percentage at sites B and C was demonstrated by the correlations with seasonal conditions and body condition that are described above.

7.2.2.3. Calf Production

Number of Calves

Variable branding and weaning percentages

The annual branding percentages for the present study varied by at least 21% at sites A and B (ranges: 39–90% and 79–100% respectively) (Table 5-9). This variation is consistent with previous reports for poor-to-good seasons in the Alice Springs district (range: 25–90%) (NT-DPI&F 1994a,b; 1995a,b,c). The average annual branding percentage at site A (64%) was less than the range reported elsewhere on arid rangelands of northern Australia (72–78%) (Kok, Collopy & Stretch 1987; O'Rourke, Winks & Kelly 1992; Stone & Burnside 1987), and was also less than 70%—a level at which fertility is likely to have been a major factor affecting the economics of the herd (Entwistle 1984). The minimum annual branding percentage in 1971/72 (39%) substantially suppressed the average annual branding percentage at site A. This minimum occurred in a second consecutive year with dry opening seasonal conditions,
and after a year (1970) with no managed weaning (Appendix 3). Consequently, in the early years of the primary beef cattle project at site A, there was also a noted delay in conception for lactating cows (Section 7.2.2.1), plus delayed first-calving of heifers, as discussed in Section 7.2.2.5 below. In subsequent years, managed weaning of steer calves, together with improved seasonal conditions, was associated with more than doubling of the annual branding percentage.

In contrast, the average annual branding percentage at site B (87%) exceeded the equivalent (‘calf crop’) percentages reported for conservative stocking rates on arid rangelands of the USA (82–85%) (Holechek, Pieper & Herbel 2004, p.226; Winder et al. 2000). The average branding percentage at site B was high, without even including branding figures for the first year (1991/92) when the number of branded calves exceeded the extrapolated number of mated cows. Speculated reasons for the unusual branding percentage in 1991/92 implicate compounding of paddock, management and seasonal factors. For example, in mid-1991, there may have been loss or escape of cows that left behind unbranded weaner-aged calves. Alternatively, the large seasonal break in January and February 1991 (>300 mm of rain) may have resulted in a delay of branding for recently-born calves and rapid reconception in the recently-calved cows. Together with the late branding-muster in the first half of 1992, this could have enabled for 1991/92, branding and counting of calves that had been born over a 13-month period. The need to exclude the branding percentage calculation for the first year of the study highlights one of the challenges for calculations based on an extensively-managed and continuously-mated herd (Section 2.1.6.2).

The annual weaning percentages in the study varied by at least 22% at sites B and C (ranges: 64–97% and 65–87% respectively) (Table 5-10). The average annual weaning percentage for sites B and C (84% and 79% respectively) was above that reported by cattle managers in the Alice Springs district (76%) (Leigo c. 2006). Those average
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annual percentages were also above a level that would indicate infertility of economic importance (70%) (Entwistle 1984) and would meet an enterprise requirement for optimum steer turnoff at 3.5 to 4.5 years of age (Burns, Sullivan & Holmes 1990). It is recognised that accurate collection of data on cow and calf numbers may exceed the day-to-day capacity of cattle managers of continuously-mated, extensively-grazed herds on the arid rangelands of the Alice Springs district and the Pilbara (McCosker, McLean & Holmes 2010, pp.55,56), and calculated reproductive indices (branding and weaning percentages) may be inaccurate where the number of mated cows is estimated (Entwistle 1984). However, calculation of these indices with five years of data (McCosker, McLean & Holmes 2010, p.16; O'Rourke & Howitt 1986) under formal reporting methods (beef cattle research projects, benchmarking groups or collated regional survey data) does provide a platform for discussion and comparison of data that are collected and collated with similar methods.

Peri- and post-natal calf losses
The post-natal calf loss at site A (2.1%) that was based on approximated losses in the primary beef cattle project (Low & Wood c. 1980), was similar to reported post-natal loss (2%) from herds of heifers and young cows in the dry tropics of central and north-west Queensland (Fordyce, Burns & Holroyd 2006, p.13). Consistent with reports about pre-, peri- or post-natal calf losses in first- and second-calving cows south of Alice Springs (Schatz 2011, pp.38,44) and on arid rangelands of Arizona (Ray et al. 1989), calf losses at site A were associated with first-calf heifers, poor rangeland conditions (climate or feed) and predation (Low 1978b; Low & Wood c. 1980). As noted in Sections 2.1.3.3 and 2.1.6.4, predation has been a commonly reported cause of peri- and post-natal calf losses in the Alice Springs district, and can result in 5 to 20% calf loss on arid rangelands of south-west Africa (Latimer 2002) and south-west USA (USDA, APHIS & ADC c. 1999).
Based on consecutive conceptions less than 240 days apart in the primary beef cattle project at site A, pre-natal conception losses were estimated to be 11% (Low & Wood c. 1980). This suggests 13.1% foetal and calf loss between pregnancy testing and branding. Together with reported abortions in the primary beef cattle project (2.5%) (Low 1978b), there is assumed to have been 4.6% peri-/ post-natal loss at site A.

For site B, the post-natal loss of 49 calves recorded between calving and branding indicated 1% loss of calves before branding (Section 5.2.2). It is assumed that this loss would be included in the 2.5% peri-/ post-natal loss of confirmed early pregnancies that was determined in the present study (Appendix 14). Together with the 3% post-branding calf loss that is indicated by a difference between the long-term branding (87%) and weaning (84%) percentages (Table 5-9 and Table 5-10), this suggests 5.5% peri-/ post-natal loss before weaning, or 4% post-natal loss before weaning at site B. If the herd conception percentage averaged 93% for the five years, then together with the pre-natal (3.9%) and peri-/ post-natal (2.5%) loss of confirmed early pregnancies (Appendix 14), the raw post-branding calf loss would suggest 9.4% foetal and calf loss between pregnancy testing and weaning at site B.

The overall peri-/ post-natal reproductive loss in the study for site B is consistent with an annual report (1992) of lactation failure equating to 2.6% foetal or calf loss per head of mustered cows in the primary beef cattle project. Reported causes of that loss included stress-related abortions, mismothering and predation before, during or after musters (Coventry, Leigo & Saville 2007, p.10). In addition to a management review to address these causes, selective culling for excessive age in 1992/93 may have, by default, helped to minimise reproductive losses in the herd at site B. Although not significant, records of pre-natal losses based on lactation failure plus records of post-natal calf loss prior to branding indicate that losses are higher in the aged cow group.
(6.9% of confirmed early pregnancies and 1.4% calf loss per head respectively) (Section
5.2.2).

The apparent foetal and calf losses determined in the study after pregnancy testing at
sites A and B (13.1% until branding and 9.4% until weaning respectively) are similar to
mean total losses and minimum total losses that have been reported for cattle in the
semi-arid tropics of northern Australia (13.5% and 9.4% respectively) (Holroyd 1987).
This is not dissimilar to a report of average calf losses based on conception and lactation
records for first- and second-calving cows south of Alice Springs (12% and 8.7%
respectively) (Schatz 2011, pp.38,44).

A review of research into reproductive efficiency in northern Australia has recognised
the potential role of infectious disease, nutritional deficiency, cow mortality, dystocia,
environmental adaptation and predation for peri- and post-natal losses in extensively-
grazed cattle herds (Burns, Fordyce & Holroyd 2010). From research in northern
Australia, it has been found that losses between confirmed early pregnancy and weaning
average approximately 9% under ideal situations (Fordyce, Burns & Holroyd 2006,
p.3). The benchmarks that have been subsequently proposed include peri-natal loss (5%
of calving cows) and post-natal loss (1% of surviving neonates). These benchmarks are
comparable to the reports from site A (4.6% combined peri-/ post-natal loss to branding)
(Low 1978b; Low & Wood c. 1980) and the study findings for site B (5.5% combined
peri-/ post-natal loss to weaning). These benchmarks by Fordyce, Burns and Holroyd
(2006) are also within the range of reports from arid rangelands of the USA (2.5–5.9%
calf loss by age, from birth to weaning) (Ray et al. 1989) and Namibia (3.5–9.4% calf
loss by breed, from birth to weaning) (Schoeman 1989).
Weight of Calves Produced

Seasonal weaning weights
The mean weights of weaner-age calves at each of the three sites were consistent with a report on average weaning weights for beef cattle properties in south-west Queensland (range: 145–250 kg) (Bortolussi et al. 1999b). At all three sites, the highest mean weight of weaner-age calves (range: 260–288 kg) (Table 5-11) was recorded for a muster that followed good seasonal conditions (Table 3-2). These weights were equivalent to the reported upper limit for first round, minimum weaning weight in the Alice Springs district (280 kg) (Oxley et al. c. 2006). The lowest mean weight of weaner-age calves was recorded either for a muster after poor/dry conditions at sites A and B (165 kg and 218 kg respectively), or for destocking at site C (185 kg at muster 04) following average conditions and removal of some weaner-age calves only two months before. This indicates that three factors are potentially associated with high variability in the liveweight (and age) of calves at weaning in a continuously-mated breeding herd on arid rangelands. The first factor (seasonal availability of rangeland feed) is consistent with research findings in New Mexico (Thomas et al. 2007; Thomas, Bailey & Holechek 2000) and western Texas (Holloway et al. 2002). The other two factors (destocking and early weaning during drought) were noted in Section 2.1.6.3 to be an aspect of cattle management in response to seasonal conditions in the Alice Springs district.

Total weight of calves produced and reproductive efficiency
Annual weaning percentage and weights of weaned calves can be incorporated into a compound measure of reproductive efficiency, such as the average weight of weaned calves per mated cow (Cundiff et al. 1992; Fahey et al. 2000, p.15; McCosker 1986). In the present study, a range of values were recorded at sites B and C for the average weight of weaned calves per mated cow (147–271 kg) and the average weight of weaned calves per 100 kg of mated cows (37.4–64 kg) (Table 5-12). For cows of
different breeds and mature weights from arid rangelands of south-west Africa, the average (adjusted) 205-day weights of weaned calves has varied, per 100 kg of cow weight in Namibia (range: 25.9–38.9 kg) (Schoeman 1989), and per 100 kg of mated cows in the North-West province of South Africa (range: 29.5–46.5 kg) (du Plessis 2004, p.55).

In the study, the continuous-mating system and variable seasonal nutrition influenced the mean age and weight of calves at weaning, as well as the mean liveweight of mated cows (heifers and young-to-aged cows) at the first (weaning) muster of the calendar year (Section 3.3.3.3). The weight of individual mated cows would have been influenced by the period of lactation before weaning, the stage of pregnancy, age and mature weight. These related seasonal, management and individual cow factors restricted comparison between the compound measures of reproductive efficiency in the study and the equivalent measures reported in south-west Africa. Never-the-less, the measures in the study have not been previously reported in the Alice Springs district. They provide a means of describing the nett effect of multiple factors that influence calf production, interpretation of which does require recording of related factors. In the present study, ancillary records indicated that the measures had been influenced by seasonal rangeland nutrition, the timing of managed weaning, age and mature liveweight of cows at both sites B and C, as well as reproductive losses before weaning at site C.

7.2.2.4. Removal of Cows

Selective and strategic culling

Selective culling was used to maintain the production efficiency of the breeding herds at the three sites. Reasons for culling in the present study focused on criteria of reproductive performance and physical soundness (poor reproductive performance, excessive body condition, excessive age and disease) (Section 5.3.1), which were
consistent with the reasons summarised in Section 2.1.5.1 for the Alice Springs district and other arid areas of northern Australia.

In a report from the primary beef cattle project at site A, it was observed that culling was well founded, where cows with excessive body condition were culled as poor-performing (non-productive) cows (Low & Wood c. 1980). At site C in 2000/01, two cows were also culled on account of excessive body condition combined with an absence of lactation and pregnancy (Section 5.3.1).

During a 5-year period at site B, 15% of the removed cows (138/948) were culled solely for excessive body condition. The need to remove cows that have a body condition that is both high and inconsistent with regular calf production (Table 5-13) was confirmed by combined analysis of lactation, body condition, age and pregnancy at site B (Appendix 13). By default, this identified that non-lactating young cows in ‘fat’ condition had a significantly lower (p < 0.05) pregnancy percentage than individuals in ‘forward store’ condition (77% vs. 87% pregnant at muster).

Excessive age was also a major reason for strategic culling at site B. During the 5-year period, 25% of the removed cows (238/948) were culled solely for excessive age. This reduced the need to non-selectively destock or agist during drought, as occurred at site A (Low 1978b). Culling for excessive age reduces the risk of retaining geriatric cows that have an escalating chance of reproductive inefficiency, incapacity or death, especially with respect to death during drought (Hodge 1978; Niethe & Holmes 2008).

Strategic culling for excessive age has been supported by modelling of beef cattle management for arid rangelands of South Africa. This modelling focused on the stabilisation of production, avoidance of cattle losses during dry periods, and sale of old or non-pregnant cows (du Plessis & van der Waal 2004).
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Total number removed
The overall culling pressure, and by default selection pressure, on a breeding herd should be based on objectives for herd size, genetics and production efficiency (Fahey et al. 2000, p.24), as well as market prices and sustainable seasonal stocking rates. High rates of mortality and low rates of reproduction will limit the number of cows that either should be removed to maintain sustainable stocking rates, or could be selectively culled to improve the herd genetic pool.

For each site in the present study, there were musters at which removal of a large percentage of the cows brought about a substantial change in the breeding herd genetic pool. At site A, 28.9% of cows were strategically, but non-selectively removed with calves and herd bulls at a single-purpose muster (muster 04) to agist for drought management in late 1971 (Appendix 9). At site B, 32.6% of cows were strategically and selectively removed in 1992/93 with an emphasis on culling for excessive age. At site C, 49.8% of cows were non-selectively removed in 1999/2000. Lower levels of annual culling have been reported in the Alice Springs district (average: 18% of cows) (Schatz 2011, p.89) and on arid rangelands of Arizona (range: 21–29% of cows) (Kattnig & DeNise 1992). The latter has involved removal of unproductive or physically unsound cows, however up to 50% culling has also been reported in response to drought conditions in south-east Arizona (Eakin & Conley 2002). For one year during a decade of drought in Chihuahua, a 62% reduction in the regional breeding herd was associated with increases in cattle exports and deaths (Ortega-Ochoa et al. 2008).

Recorded deaths
Recorded deaths at each site provided a temporal indication of mortality in the present study. Outside of poor/dry seasonal conditions, few cows were found dead. The recorded mortality percentages of cows (Section 5.3.1) were at the lower end of published levels for average seasons in the Alice Springs district (range: 3–5%)
Aspects of seasonal nutrition were implicated in cow deaths. At site A, cattle deaths appeared unimportant (Low 1978b), but a single observation equating to at least 2.4% cow mortality did suggest that potential causes of mortality were related to aspects of seasonal nutrition (poisonous plants or starvation during droughts) (Low 1978b). At site B, only four cows were found dead and five cows were euthanased (for medical reasons) during years with a period of average seasonal conditions (1991/92, 1992/93, 1993/94, 1995/96). The annual recorded mortality percentage of cows was highest following poor seasonal nutrition associated with drought (1994/95: 1.3%), especially for the aged cow group (4.6%) (Coventry, Leigo & Saville 2007, p.9). The latter is consistent with a recognised potential cause of mortality in aged cows in a harsh environment (O'Rourke, Sullivan & Neale 1995), especially during nutritional stress in north Australia (Andrews 1976, p.108).

At site C, at least two dead cattle were reported early in the primary beef cattle project (Hill 2003, p.9) after poor and average seasonal conditions, but not later during the good and excellent conditions. The identity of the dead cattle was not reported.

Strategies that have been used to reduce cow mortality in northern Australia (Bolam, Jubb & Kerr 1998; Entwistle 1984) and arid Australia (Agriculture Western Australia 1999; Kok, Collopy & Stretch 1987) include reduced stocking rates, stock segregation, strategic supplementation, weaning and annual vaccination against botulism. All of these strategies were undertaken for site B (Appendix 3), and it is of note that no Clostridium botulinum type C or D bacteria were cultured out of the faecal samples from herd bulls, cows and weaned calves (Coventry, Leigo & Saville 2007, p.14).
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Most of those management strategies to reduce cow mortality were also used at sites A and C, but annual vaccination against botulism was not a standard management practice. Early in the primary beef cattle project at site C, a report of more than ten dead cattle in the adjacent paddock that had no year-round urea and P supplementation (Hill 2003, p.9), highlighted the potential risk of botulism poisoning. The difference in botulism vaccination policy across the three sites reflected a historical increase in awareness of botulism poisoning (NT-DPI&F 1994a,c; O'Rourke, Winks & Kelly 1992) and general adoption of vaccination for routine cattle management (Brown et al. 1999; Gregory et al. 1996).

*Unconfirmed (extrapolated) deaths*

As noted in Section 2.1.3.3, detection of cattle deaths in an extensively-grazed breeding herd can be confounded when either there is less than 100% recording of individual cattle, mustering percentage is low or paddock security is poor. These issues were occasionally noted for cows in the present study for sites B and C.

At site B, recording was possibly confounded by ear-tag loss in the first years (1991, 1992), and a low mustering percentage after autumn rain in early 1992 (muster 02). Confounding issues of paddock security were noted for site B after cattle that had strayed were returned from a neighbouring beef cattle property in late 1993 (up to 10 head) and in 2004 (approximately 40 older cows). The return of cows in 2004 impacted on the extrapolation of unconfirmed mortality at site B in 1992/93 (1.8%), but did not impact on the extrapolation for 1991/92 (1.3%). This earlier extrapolation was thus reasonable and inferred a low ratio between the number of cattle that were confirmed ‘dead’ and the number of cattle that were absent and assumed, but not confirmed to be ‘dead’. This is expressed as a confirmed-to-unconfirmed cattle death ratio of 1:13. This is lower than previous estimates for extensively-grazed cattle on open grassland (1:2) or in heavily wooded and long-grass country (1:6) (K de Witte (NT-
DPI&F, Katherine, N.T.) 2000, pers. comm.), but it is not as low as an estimate of 1:35 for mixed arid rangelands in Western Australia (Thomson 1999, p.12). A potential cause of unconfirmed deaths in the heifer and young cow groups is discussed in Section 7.2.2.5.

At site C, dead cattle were reported in the paddock (Hill 2003, p.9), however recording was limited by a lack of details on the year of death and individual cattle identification (gender, age and ear-tag number). If these had been individually-identified cows, there may have been a reduction in the recorded number of mustered cows, absent from next 5 musters at site C (Appendix 7). Low mustering percentages in the paddock after exceptional summer rainfall in early 2000 and late 2001 (Hill 2003, p.12) (musters 05 and 08) also increased the chance (to 1 in 50,000) for missing cows that had been persistently absent from five consecutive musters at site C.

7.2.2.5. Recruitment of Cows

Number of recruited cows

The number of recruited cows needs to be balanced against available seasonal feed and breeding objectives for desirable herd genetics or production. In the present study, a high level of cow recruitment was recorded during one year at each site, either on account of substantial culling and subsequent growth of good seasonal feed at site A (1974/75: est. 50% of cows was recruited) and site B (1993/94: 28% of cows was recruited), or on account of the design of the primary beef cattle project at site C (Section 5.3.2).

In the semi-arid tropics of the Northern Territory, 16% annual recruitment with 2-year-old heifers has maintained breeding herd numbers (O'Rourke, Sullivan & Neale 1995). In the present study, retention of heifers did not serve as the sole means of recruiting cows at any site. Over 50% of the recruited cows at both sites B and C were young-to-mature cows sourced from other areas of the respective beef cattle properties.
Consequently there were no critical observations at the three sites regarding how heifer retention related to either culling for excessive age, cow mortality or the branding percentage.

Fate of recruited heifers
With the exception of store movements for a breeding program, the reasons for selective culling of heifers at site B (excessive body condition, small frame, undesirable temperament, horn genotype and undesirable eye features) (Section 5.3.2.1) were consistent with previously reported criteria for removal of heifers in northern Australia (Entwistle 1984; Fahey et al. 2000, p.24; Hodge 1978). Culling pressure (or by default, selection pressure) changed as the recruited heifers matured. Although selective culling of heifers and young cows was similar with respect to excessive body condition, store movements and undesirable temperament, heifers were culled less than young cows for undesirable eye features and frame, and significantly less (p < 0.05) as a percentage of the group (2.5% of heifers) (Table 5-18).

Dystocia was suspected to have caused unconfirmed death of recruited cows in the present study. At site B, persistent absence at muster for 20% of a pregnant heifer group (9 out of 46 head) after good seasonal conditions in 1993 and poor conditions in 1994 suggested deaths related to early conceptions in unweaned heifers and subsequent dystocia of small, excessively-fat or nutritionally-weakened heifers (Section 5.3.2.1). At site C, 13% of the ‘first-calving’ cow group (19 young cows) was missing after the first yarding in late 1999 (muster 04). After the fourth consecutive absence from muster (muster 08) at the end of the primary beef cattle project, there was a chance of less than 1 in 650 that these cows remained alive in the paddock (Hill 2003, p.12). In this group, nine young cows had been in the second or third trimester of pregnancy. Given this limited repeat-muster data, this suggested that up to 6.3% mortality may have occurred as a result of dystocia (9 out of 142 ‘first-calving’ cows) during the good seasonal
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conditions at the end of 1999. The unconfirmed mortality of first-calving heifers and young cows in the study is comparable to reported heifer loss on the arid rangelands of Western Australia. Compared to a non-pregnant group, 9% more of a pregnant heifer group was missing (absent from muster) after a ‘failed growing season’ in the Pilbara (Smith et al. 2010a, p.20).

As noted in Section 2.1.6.4, dystocia is rarely reported but can be managed on arid rangelands (Sprinkle 2001a). The association of dystocia with unreported deaths, maiden heifer deaths (de Witte, Jubb & Hedlefs 1998; Entwistle 1978) and peri-natal calf loss has been reported in the Alice Springs district (Perry 1962, p.267) and in south-west Queensland (Clarke 1991, p.63). Issues about heifer growth (e.g. excessively-fat heifers, or early puberty in heifers after supplementation or good seasonal pasture conditions) have been common elements in the latter reports. Even in the absence of these factors, the peri-natal risks in heifer reproduction are highlighted by a higher level of calf loss in the heifer age-group. For example, the highest level of peri-/ post-natal reproductive loss has been reported for the heifer group in the study for site B (4.5% loss of confirmed early pregnancies) (Appendix 14), and for 3-year-old, first-calving heifers on the arid rangelands of Arizona (5.9% loss of calves) (Ray et al. 1989).

Reproductive performance of recruited heifers
For the primary beef cattle project at site A, maiden heifer conceptions followed mating between 12 to 24 months of age (Low 1978b). Yearling heifer pregnancies were reported in association with favourable seasonal feed and the absence of weaning for female calves. This resulted in a higher number of calves from yearling heifers in 1971 and 1974 (Low 1978b; Low & Wood c. 1980).

At site B, the lactation percentage for a representative group was significantly higher (p < 0.05) in young cows (71%) compared to heifers (52%) (Table 5-18). This
improvement in reproductive performance, as recruited cows matured, followed
previous observations about age-related differences in the lactation percentage.
Prospective examination of the lactation records for a sub-group of 1.5-year-old
recruited heifers at site B indicated that by 2.5 years of age, 13% had entered a second
lactation period and thus had commenced reproductive activity before 12 months of age
(Section 5.3.2.1). This occurred when pubescent heifers were exposed to herd bulls,
either when well-grown weaner heifers were retained for blood sampling in the primary
beef cattle project (late 1991), or when rain limited a weaning muster (early 1992), or
when good seasonal feed conditions promoted early puberty (1993).
The reporting for sites A and B regarding yearling heifer conceptions versus delayed
puberty is consistent with the wide age-range noted in Section 2.1.5.1 for controlled and
uncontrolled maiden heifer joining (range: 8–18 months old) under the variable seasonal
conditions in the Alice Springs district. The inferred influences of seasonal nutrition and
early exposure to bulls are consistent with the wide range of pregnancy percentage
reported in yearling heifers on arid rangelands of Western Australia (22–64%) (Smith et
al. 2010a, p.38). In the North-West province of South Africa, controlled-mating of
heifers with different breeds and mature weights has resulted in a similarly wide range
of heifer conception (8–62%) (du Plessis 2004, p.53).
In the primary beef cattle projects at sites A and B, the reported mean weight-at-
conception (95% CI) for maiden heifers up to 1.5 years old was 273 kg (267, 279) (Low
& Wood c. 1980) and 280 kg (272, 288) (Coventry 2000) respectively. These mean
weights are higher than the average joining weight reported by cattle managers for
maiden heifers in the Alice Springs district (265 kg) (Oxley et al. c. 2006), but similar to
an average estimated conception weight of mixed-age maiden heifers south of Alice
Springs (284 kg) (Schatz 2011, pp.38,41). Given a period of poor seasonal conditions in
the primary beef cattle projects at sites A and B, delayed puberty of maiden heifers was
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assumed to occur: with a subsequent delay in first-calving until 3.5 years old at site A (Low & Wood c. 1980); and with an even higher average weight-at-conception (312 kg (289, 335)) at site B (Coventry 2000). The latter is comparable to a liveweight range (300–324 kg) associated with over 75% conception in mixed-age maiden heifers during below-average seasonal conditions south of Alice Springs (Schatz 2011, pp.38,42).

At site B, the fall in average conception percentage of 1.5-year-old (maiden) heifers from 76 to 56% (Section 5.3.2.1) was associated with a year that had dry opening seasonal conditions (1994/95). These heifers had been weaned immediately before, during or immediately after the dry period. Although the low number of examined heifers prevented demonstration of a significant difference in conception, this has highlighted the prolonged negative influence of poor nutrition on heifer reproductive performance. By default this also supports reported observations on the importance of supplementation and paddocks (with better feed) to improve maiden heifer joining weights (Schatz 2011, p.69).

The averaged conception percentage of lactating 2-year-old heifers at site B (58%) (Section 5.3.2.1) was similar to the 12-months cumulative (pre-weaning) conception percentage of mixed-age, first-calved cows (58%) south of Alice Springs (Schatz 2011, pp.38,45), and was higher than the analysis of conception rate for (mixed age) first-calf heifers\(^1\) (52%) in the primary beef cattle project at site B (Coventry, Tye & Phillips 2001). However the low number of 2-year-old heifers in the present study for site B prevented demonstration of a significant difference. In Section 5.2.2 it was noted for the continuously–mated herd at site B that, compared to the lactating young-to-aged cows in ‘store’ to ‘forward store’ body condition, the lactating heifers had a lower, but non-significant, pregnancy percentage at muster (45%). For lactating first-calf heifers, in particular, the negative impact of growth and lactation on body condition underscores

\(^1\) The percentage of first-calf heifers that conceived again, within 12 months of their first calving.
the importance of weaning and good nutrition for the promotion of conception. This has been demonstrated on arid rangelands during trials in Arizona (Ray et al. 1993) and south of Alice Springs (Schatz 2011, p.39).

At site B, the percentage of 2-year-old heifers that entered a second lactation period twelve months after muster (47%) (Section 5.3.2.1) suggests 11% loss of conceptions after confirmed pregnancy in first-calf heifers. The combined lactation percentage of retained 2-year-old heifers at site B (95%), twelve months after muster, was higher than the ‘recalving’ percentages reported in Namibia for second-calving heifers (range: 70–93%) (Schoeman 1989), however the heifer performance at site B was inclusive of both first-calf and second-calf heifers, as well as interim culling decisions by the cattle manager.

7.2.2.6. Conclusions on Cows

Herd performance benchmarks

Averaging for 3- to 5-year periods of the present study provided benchmark ranges for branding (64–87%) and weaning (79–84%) percentages. The former confirmed a previously reported wide range in branding percentage for breeding herds on arid rangelands. A range in annual conception percentage (75–97%) was also noted for the different cow age-groups under average opening seasonal conditions.

Other benchmark ranges of performance were provided in the study: for the mean weight of weaner-age calves (165–288 kg); and for pre-, peri- and post-natal losses from confirmed pregnancy to branding (6.4–13.1%), based on extrapolated or derived data. In conjunction with qualification of management, rangeland and cow variables in the study, compound measures of reproductive efficiency provided credible benchmarks for extensive cattle management on arid rangelands, i.e. average weight of weaned calves per mated cow (147–271 kg); and average weight of weaned calves per 100 kg of mated cows (37–64 kg). The different time period and single genotype of cattle represented by
CHAPTER 7. DISCUSSION

Each primary beef cattle project provided no opportunity to consider breed differences in cow performance for the study, but by default, the range of seasonal conditions at each site enabled comparison of performance under the seasonally-adjusted stocking rates that are described in Appendix 5.

**Recording and managing breeding herd composition**

Key issues highlighted in the present study for extensive management of breeding herds on arid rangelands included: the use of body condition as a management guide; strategic culling to either adjust stocking rates or remove inefficient cows; plus review of the genetic pool during destocking or restocking of the herd. The complementary roles of (direct) recording and (default) extrapolation were also highlighted for determining (pre-, peri- and post-natal) reproductive losses, body mass (weight and condition) at conception, and sporadic cow mortality.

**Herd production efficiency**

Areas of low reproduction efficiency were highlighted for different cattle groups within the present study, i.e. 4.5% peri-/post-natal calf losses were associated with the heifer age-group; 6.9% pre-natal foetal losses and 1.4% calf losses between birth and branding were associated with the aged cow group; suspected dystocia was associated with heifers that had been in good seasonal conditions or had yearling conceptions; and reduced conception percentage of maiden heifers (56%) was associated with a dry period.

Areas of high reproduction efficiency were highlighted in the study, where average annual weaning percentage exceeded the minimum level for economic viability (70% weaning), and where higher lactation percentage was recorded in the mature cow group at muster (75%). The use of lactation percentage as an indicator of performance, nutritional need and reproductive loss was also demonstrated. Management and husbandry factors that were associated with good cow reproductive performance in the
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study included: regular culling (especially for excessive age and poor reproductive potential); weaning; vaccinations for botulism and vibriosis; strategic P and N supplementation; plus seasonally-adjusted stocking rates.

Most areas of low and high efficiency were associated with the success of conception in heifers and lactating young-to-aged cows. Discussion in the study about average weight-at-conception and average BCS-at-conception highlighted opportunities to promote conception with specific nutritional strategies. Discussion about the more vulnerable age-groups focused on pre-pubertal nutrition, segregation to manage related risks in heifers (dystocia and peri-natal death), and culling to manage the increased risks of reproductive loss and death in the aged cow group.

SECTION 7.3. REVIEW OF LABORATORY TEST RESULTS

7.3.1. Bacteriology

7.3.1.1. Culture for venereal pathogens

Campylobacter fetus subsp. venerealis

In the present study, there were no positive cultures for C. fetus subsp. venerealis from cattle at site B (Appendix 15), and with the exception of a year associated with drought (1994/95), the majority of herd bulls were vaccinated annually (range: 89–98%) against vibriosis (Appendix 3). These test and management details were comparable with that reported for contemporary beef cattle herds on the semi-arid rangelands of the Northern Territory (Barkly Tablelands). For the latter, most bulls were vaccinated annually against vibriosis, cultures for C. fetus subsp. venerealis were positive in less than 0.35% of tested bulls, but there was positive serology for C. fetus subsp. in cows from all surveyed herds (Norman et al. 2002). Similar to herd bulls at site B, these details appeared indeterminate with respect to the extent of vibriosis.
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*Tritrichomonas foetus* var.
The three positive cultures for *T. foetus* from two older bulls (8 and 8.5 years old) and one aged cow (> 10 years old) (Appendix 15) in one year confirmed the presence of trichomoniasis at site B. It is speculated that the aged cow was a concentrated source of infection that increased the possibility of culturing *T. foetus* from the herd bulls. Selective culling for excessive age, excessive body condition and lack of pregnancy resulted in removal of this cow from the herd.

It is unknown if vibriosis or trichomoniasis were in the breeding herds at sites A and C. Venereal disease testing of herd bulls was not a part of the primary beef cattle projects at those sites.

*Detection of herd infection*
The capacity of laboratory testing (by indirect bacterial cultures) to detect vibriosis and trichomoniasis in a herd is dependent on multiple factors, including: the number of animals sampled in the target population (Thrusfield 1995, p.182); the accuracy of the laboratory tests (sensitivity and specificity); the handling and transport of samples; and the sensitivity of the organisms to factors that reduce survival. *Campylobacter fetus* subsp. *venerealis* and *T. foetus* are particularly sensitive to sunlight, temperature extremes and overgrowth by other bacteria or fungi (OIE 2008b, 2008d), and thus are difficult to transport and culture (Entwistle 1984). The capacity to detect vibriosis and trichomoniasis is also dependent on the prevalence of disease, and this is influenced by herd management such as selective culling, vaccination, heifer segregation and bull control (de Witte, Jubb & Hedlefs 1998; Entwistle 1984; Fordyce 1992; Niethe 1986; Norman et al. 2002).

For the present study, analysis of the number of bulls tested, together with the test sensitivity and the test specificity, helped to qualify the possibility of infection at site B. An average of 94% (47/50) of mixed-age herd bulls were sampled and cultured for *C.*

(- 157 -)
fetus subsp. venerealis and T. foetus each year. Some bulls were not mustered and others could not be reasonably sampled in the yard on account of an injury. Selective culture and phenotyping is diagnostic of C. fetus subsp. venerealis, but the success of indirect bacterial culture with the type of transport enrichment media used for site B (Clarks TEM) (Appendix 12 b.) has been as low as 25% (Hum et al. 1994). Based on these indications of specificity (99%) and sensitivity (25%) for detection of C. fetus subsp. venerealis in bull preputial scrapings, the average annual number of sampled herd bulls at site B would have been sufficient to conclude with 96% confidence that, in the absence of a positive test, the prevalence of vibriosis in the population was no more than 23% (p = 0.04) (Cameron 1999). This poor capacity for detecting vibriosis is consistent with the wide 95% CI for the C. fetus subsp. venerealis culture results that were recorded for the older-to-aged bull category at site B in 1994/95 (0, 24%) (Appendix 15).

The success of culturing and detecting T. foetus is dependent on the temperature and time between collection and culture (Clavijo et al. 2011). Based on the average sensitivity (68%) and specificity (99%) for detecting T. foetus-infected bulls from a single culture (Cobo et al. 2007), the average annual number of sampled herd bulls at site B would have been sufficient to conclude with 97% confidence that, in the absence of a positive test, the prevalence of trichomoniasis in the population was no more than 6% (p = 0.02). However, given one or two positive tests, it would be concluded with 96% confidence that the population had a prevalence of trichomoniasis of no more than 14% (p = 0.04) (Cameron 1999). This low capacity for detecting the presence of trichomoniasis is consistent with the wide 95% CI for bulls in the older-to-aged category that cultured positive for T. foetus at site B in 1992/93 (0, 19%) (Appendix 15).

The presence of infection in two older bulls is consistent with an increased prevalence of vibriosis and trichomoniasis with advancing bull age (Entwistle 1984), and supports a
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recommendation for selective testing of older herd bulls or bulls culled to abattoirs
(Entwistle 1984; Norman et al. 2002).

Concerns were recorded twice during the five years of collections at site B, regarding
inappropriate handling and transport of samples, i.e. exposure to sunlight and transport
with chilled samples. These factors could have had a negative influence on the success
of laboratory testing (NT-DPI&F 2001a) and may have contributed to the lack of
positive cultures for venereal pathogens at site B.

7.3.1.2. Conclusions on bacteriology

Management implications
Bacteriological findings of the present study focused on two venereal pathogens that
have been previously recognised in the Alice Springs district (NT-DPI&F 1991b).
Analyses and discussion highlighted how effective use of available diagnostic tests and
best practice management can define and limit potential causes and effects of bovine
reproductive disease. In the study, there was emphasis on the roles of culling,
vaccination, bull control and herd records. As an example, vaccination against vibriosis
for all yarded bulls at musters during the year provided annual vaccination cover for up
to 98% of herd bulls at site B.

Recommendations
Given the difficulty in defining field cases of vibriosis and trichomoniasis, effort needs
to be made to not only maximise the sensitivity of indirect bacterial cultures, but also to
adopt complementary use of advanced diagnostic tests. This is consistent with
observations by Schmidt, Venter and Picard (2010) regarding the logistical dilemma of
transporting samples from extensive cattle herds in South Africa. Specific PCR assays
that have been recently developed to detect the deoxyribonucleic acid (DNA) of C. fetus
subsp. venerealis and T. foetus (Lew et al. 2006; McMillen et al. 2006; McMillen &
Lew 2006) may help address some logistical issues for disease sampling in extensive
cattle herds. If these PCR assays had been available for parallel testing in the primary beef cattle project at site B, there may have been more success in detecting *T. foetus* in individual bulls, and greater confidence in the culture results for *C. fetus* subsp. *venerealis*.

### 7.3.2. Serology

Some cattle diseases that can cause loss of herd production efficiency in northern Australia (Sackett et al. 2006, p.21) may be diagnosed with the assistance of serological tests. In the present study, testing for serological evidence of leptospires (three serovars: *L. sv* hardjo, *L. sv* pomona, *L. sv* tarassovi), BVDV and BHV1 was analysed to determine the association of risk factors with seroprevalence, and the association of positive titres with reproductive outcomes.

#### 7.3.2.1. Leptospires

*L. sv. hardjo*

Titres to *L. sv. hardjo* in Queensland have been associated with alkaline soils (Elder et al. 1986), rainfall and soils of a high water-holding capacity (Carroll & Campbell 1987). In the present study, positive MAT titres to *L. sv. hardjo* in herd bulls and cows suggested endemic herd infection, a finding which was consistent with surveys of extensive beef cattle herds in semi-arid areas of Australia (Black et al. 2001; Durham & Paine 1997; King 1991). Association of *L. sv. hardjo* with cattle reproduction was suggested by the presence of higher titres (MAT ≥ 1:800) in the more reproductively active cattle (young-to-mature bulls, heifers and young-to-aged cows). Positive titres (MAT ≥ 1:100) were also correlated with measures of reproductive performance, i.e. a tendency for a lower lactation percentage (p = 0.05) and a tendency for a higher pregnancy percentage (p = 0.09) in young-to-aged cows (Appendix 18). Correlations with lactation and pregnancy percentage may have reflected confounding rather than reproductive loss if cows developed immunity to *L. sv. hardjo* with only weak or non-
detectable MAT titres (< 1:100) (Radostits et al. 2007, p.1104), or if the absence of lactation was only the outcome of recent weaning in a sub-population of continuously-mated cows. The low number of cows in two examined age-categories limited comment on the reproductive failure that was noted in two seropositive heifers.

No significant relationship was noted between 2-months cumulative rainfall and the distribution of MAT titres to \textit{L. sv. hardjo} in cows or herd bulls in the study. However previous reports have indicated that the absence of rainfall has played an indirect role in the epidemiology of infection with \textit{L. sv. hardjo} in cattle of the Alice Springs district. During drought conditions, cattle placed in an opportunistic feedlot were found to have both a high prevalence of titres (over 90\%) to \textit{L. sv. hardjo} and ‘spotted kidney’ lesions at slaughter (NT-DPI&F 1989, p.38). Galahs and mice that had been attracted to the grain were culture-positive for leptospires. Wildlife is well recognised as a reservoir for leptospires (Bolin & Alt 1999; Faine et al. 1999, p.132) and the above report suggests that there would also be potential for transmission of leptospires between wildlife and cattle at water-points on beef cattle properties.

\textit{L. sv. pomona}

Titres to \textit{L. sv. pomona} in Queensland have been associated with low rainfall (Elder & Ward 1978), low relative humidity, clayey soil and the presence of feral pigs (Elder et al. 1986). Titres to \textit{L. sv. pomona} in the Northern Territory (28\% and 32\% crude seroprevalence) have been associated with areas of higher relative humidity and clayey waterholes (Andrews 1976); feral pigs are also known within these areas (Lapidge, Braysher & Sarre 2004-2012).

In the present study, serum testing indicated no active infection with \textit{L. sv. pomona} in the breeding herd. There were no MAT titres to \textit{L. sv. pomona} in either heifers or young-to-aged cows (Appendix 16), and repeat testing of the herd bulls for up to four years did not demonstrate a four-fold rise in MAT titres that would have confirmed an
active infection (Bolin & Alt 1999; Radostits et al. 2007, p.1104). Testing did indicate, however, that there were persistent titres to \textit{L. sv.} pomona in herd bulls, as a result of either past leptospiral infection or vaccination. \textit{Leptospira interrogans} serovar \textit{pomona} is an incidental (non-adapted) serovar in cattle and it can stimulate high MAT titres (up to 1:3000) (Radostits et al. 2007, p.1104), which then persist as low titres for years after recovery from infection (Bolin & Alt 1999). Some herd bulls at site B originated from studs in southern Queensland. Maintenance hosts for \textit{L. sv.} pomona (i.e. feral pigs) are common and widespread in this area (Lapidge, Braysher & Sarre 2004-2012). Titres to \textit{L. sv.} pomona that have been reported in surveys of unvaccinated beef cattle herds in central Queensland and western New South Wales (Black et al. 2001; King 1991) may have been influenced by exposure to feral pigs. More recently, high seroprevalence (70\%) of titres to \textit{L. sv.} pomona has been reported in a population of feral pigs in the north-east pastoral area of South Australia (Animal Health Australia 2003a) and positive titres to \textit{L. sv.} pomona have been reported in adult cattle (average: 5.9\% seroprevalence) in this pastoral area (PIRSA 2008). Titres to \textit{L. sv.} pomona in cattle also develop with bivalent leptospiral vaccination, which has been recommended for breeding bulls (Bertram 2003, p.43) and reported in surveys of other beef cattle herds in Queensland (Black et al. 2001).

\textit{L. sv.} tarassovi
In the present study, positive MAT titres to \textit{L. sv.} tarassovi in herd bulls and cows suggested endemic herd infection, which is consistent with serological surveys of beef cattle herds in arid and semi-arid areas of Australia (Black et al. 2001; Durham & Paine 1997). No correlation was demonstrated between MAT titres to \textit{L. sv.} tarassovi and aspects of calf production, but there were higher titres in significantly more cows (p < 0.05) within a higher (50+ mm) 2-months cumulative rainfall category (Appendix 17). This suggests increased exposure of cattle to \textit{L. sv.} tarassovi when effective carry-
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over rainfall produces surface water or more than a week of continued vegetation
growth (Perry 1962, p.121). This positive association is consistent with the reported
increase in titres to L. sv. tarassovi at the beginning of the ‘wet season’ in the Northern

In cattle, L. sv. tarassovi has been detected microscopically (Cousins, Robertson &
Hustas 1985), but not cultured (Black et al. 2001). Pigs are usually the preferred host,
but in the absence of both pigs and rainfall on arid rangelands, native animals may play
a role in the transmission of this serovar. More recently, low MAT titres (1:200) to
L. sv. tarassovi in cattle south of Alice Springs have been assumed to be cross-reactions
with concurrent high MAT titres (1:800 and 1:1600) to L. sv. topaz (NT-DoR 2009).

The latter serovar has been associated with macropods (Corney et al. 2008), but pending
confirmation of MAT cross-reactions or cross-infection of serovars from wildlife, the
present study simply supports the assumption that L. sv. tarassovi has been an incidental
(non-adapted) serovar in cattle and not a serious cause of production loss.

Management implications

Vaccination against leptospires is recommended where there is significant zoonotic risk
or economic loss from production disease (Bolin & Alt 1999; Radostits et al. 2007,
pp.1108-09). Similar to other surveyed arid or semi-arid areas (O'Rourke, Winks &
Kelly 1992), vaccination against leptospirosis has not been a part of standard cattle
management in the Alice Springs district (Oxley et al. c. 2006). However, given the
erratic seasons on arid rangelands, there is a potential for escalation of infections with
L. sv. hardjo and clinical disease following either an unusually large rainfall event
(annual rainfall above the 80th percentile) or prolonged absence of rainfall (annual
rainfall below the 30th percentile). Both events can be associated with an increase in
faecal and urine contamination by native and introduced animals around water-sources.
Although cattle production losses have been attributed to leptospirosis in the Alice Springs district (NT-DPI&F 1989, p.25; 1994d, p.93), no losses could be definitively attributed to leptospirosis in the present study. Pending definition of a measurable impact from leptospires in extensively-grazed cattle of the district, there is insufficient evidence to suggest that a targeted vaccination program to reduce leptospiral disease would realise a nett benefit. This is consistent with an assessed low economic impact of leptospirosis for beef cattle in northern Australia (Sackett et al. 2006, p.21).

7.3.2.2. Bovine Viral Diarrhoea Virus
In the present study, the seroprevalence of BVDV was similar in both age-categories for herd bulls (74% and 75%) and cows (80% and 81%). These seroprevalences were within the ranges reported for northern Australia (40–92%) (Littlejohns & Horner 1990; St. George et al. 1967) and semi-arid Australia (9–99%) (Brown 2002; Durham & Paine 1997). The high seroprevalence was consistent with the presence of persistently infected (PI) cattle in an endemically-infected herd (Littlejohns & Horner 1990). The endemic infection with BVDV at site B may have caused a low incidence of subclinical BVDV-related disease.

For the seropositive cattle, there were more low antibody levels (AGID = 1) in the older category of both genders (Appendix 19). High antibody levels (AGID = 3 or 4), which indicate exposure and seroconversion one to nine months prior to blood testing (McGowan et al. 2008), were recorded in both cow age-categories and the ‘young-to-mature bull’ category, but not in the ‘older-to-aged bull’ category. This suggested more recent exposure to BVDV in the more reproductively active cattle. A recent survey of cattle on a property in the Alice Springs district has shown an elevated seroprevalence in 2.5-year-old heifers (Schatz, Melville & Davis 2008). In the present study, all cattle in the ‘young-to-aged cow’ category that had high AGID antibody levels were in their second or third trimester of pregnancy. This may have reflected a conditional
relationship between exposure to BVDV, development of a pregnancy and development of high AGID antibody levels. Some cows with positive AGID antibody titres to BVDV became seronegative during a 3-year period. Fluctuation between an AGID seropositive and seronegative status has been previously reported for cows tested in an extensive beef cattle herd (Brown 2002). This may have parallels with the effective duration of antibody response to modified live BVDV vaccination (18 months) (Cortese 1999, p.ii) before the antibodies start to drop below a detectable level. It is, however, still possible for seronegative mature cows to have a level of protective immunity against BVDV (McGowan et al. 1993).

**Management implications**

Considerations for management of BVDV infection are consistent with the assessed medium economic impact of BVD/MD for beef cattle in northern Australia (Sackett et al. 2006, p.21). In general, infection with BVDV in a cattle herd can be managed either by eradication or by control activities (McGowan et al. 2008). Vaccination with inactivated or modified live BVDV can be a part of both. Inactivated BVDV vaccine has been available in Australia since 2003 (McGowan & Kirkland 2003). For a large or extensively-managed cattle herd, repeat vaccinations and ongoing biosecurity requirements (e.g. isolation fencing, sampling, testing and quarantine) (Radostits et al. 2007, p.1274) would be economically and logistically challenging (McGowan et al. 2008).

By default, control using active exposure to PI cattle to develop natural (protective) immunity is accepted for extensively-managed cattle herds. However this option is characterised by fluctuating herd immunity, which would be associated with some variable economic losses (Radostits et al. 2007, p.1254) and some of the BVDV-related production disease described by Hungerford (1990, pp.378-79). The cost of BVDV in an endemically-infected herd has been modelled (McGowan & Holmes 2008), but the
 nett cost to production has not been reported for eradication or control of BVDV under conditions of extensive management and marketing in Australia. The present study results have provided insight into some of the issues relevant to BVDV infection and extensive cattle management.

The positive titres for BVDV that were recorded for two cow age-categories in the study (80 and 81% seroprevalence) are comparable with the upper level of reported seroprevalence (range: 36–100%) for cows in eastern Australia (Kirkland et al. 2012, pp.13,16). Seroconversion after natural infection reflects the number of PI cattle, the age of cattle, the environment (Littlejohns & Horner 1990; McGowan et al. 2008), stocking density (Taylor & Rodwell 2001), concurrent management (Coventry 2006; McGowan et al. 2008) and period of contact (Cook, Littlejohns & Jessep 1990) between PI cattle and naïve cattle.

Yard-weaning is the best strategy for actively exposing naïve young cattle to PI cattle in extensively-managed breeding herds, provided that there is a guaranteed presence of PI cattle (McGowan et al. 2008), plus optimal feeding and handling to limit stress and immunosuppression during the transient period of infection with BVDV. Based on a conservative estimate of 1% PI cattle in an endemically-infected cattle herd (Littlejohns & Horner 1990; Radostits et al. 2007, p.1250) and suggested numbers for confidence that a disease-positive animal will be included (Cannon & Roe 1982, p.17), at least 460 weaned calves would need to be yarded to have 99% probability of including at least one PI calf. This is consistent with stochastic modelling (Smith et al. 2010b) that has demonstrated sustained endemic infection with BVDV in a group of 400 cattle.

Based on the lowest seroprevalence for an age-category (74%), 26% of maiden heifers and store steers at site B may still have been susceptible to infection with BVDV after paddock-based weaning. This suggests that additional close-yarding has the potential to increase the level of natural immunity against BVDV in young cattle, and thereby
decrease either reproductive failure in first-calving heifers or growth ‘set-backs’ in store steers that enter beef feedlots. As previously mentioned, serum antibodies developed to BVDV do not appear to persist in cows. This suggests that the yarding of cows with weaner-age calves prior to weaning may also help boost the level of protective immunity (Cook, Littlejohns & Jessep 1990) against BVDV in the breeding herd.

### 7.3.2.3. Bovine Herpes Virus Type 1

In the present study, the positive SN titres to BHV1 in herd bulls and cows at site B indicated endemic infection with BHV1 virus, and inferred subclinical incidence of some of the diseases previously reported in Australia (Clarke 1991, p.66; Parsonson 1964). The seroprevalence was higher in the ‘older-to-aged bull’ category (100%) compared to the ‘young-to-aged cow’ category (53%) (Appendix 19). These levels of seroprevalence were almost the same as those previously reported for beef cattle herds in northern Australia (96% of bulls, 52% of cows) (Radostits et al. 2007, p.1349) and similar to those of cattle sampled in semi-arid Australia (range: 30–78%) (Brown 2002; Durham & Paine 1997). The high seroprevalence in herd bulls at site B suggests either active or latent infection with BHV1 and reflects the frequency of sexual activity by working herd bulls in a continuously-mated breeding herd (Coventry 2005). The lower seroprevalence in cows may reflect a single mating challenge and then one conception per year (optimum), followed by an interim fall in humoral immunity to below detectable levels (OIE 2010), either in the absence of virus challenge or in the presence of stressors that suppress an immune response.

Although the low number of samples tested in the ‘heifer’ category at site B (n = 70) limited the capacity to detect significant reproductive effects with positive titres to BHV1, the seroprevalence in heifers (23%) was consistent with *ad hoc* disease investigations that have found seroconversion to BHV1 in young adult cattle in the Alice Springs district (NT-DBIRD 2003). The absence of positive titres to BHV1 in the
first trimester of heifer pregnancies at site B suggested a negative association between
initiation of heifer pregnancies and seroconversion in the study.

Management implications
Infection with BHV1 is endemic in extensively-managed cattle herds of northern
Australia (Radostits et al. 2007, p.1349; St. George et al. 1967) and a cause of genital
disease and infrequent ocular or respiratory disease (Clarke 1991, p.66; NT-DPI&F
1992b). However its cost to production has not been defined.
The impact of temporary reduction in libido following infection with BHV1 and
infectious balanoposthitis (IBP) in herd bulls is confounded by a multi-sire, continuous-
mating system in extensive herds. Cost-effectiveness of a BHV1 vaccine, as reported in
an overseas country for the control of IBP in bulls (Straub 1977), would be doubtful for
herd bulls in extensive herds that have an ongoing opportunity to develop and maintain
protective, cell-mediated and humoral (natural) immunity against clinical IBP.
However, the risk of reduced libido in young bulls as a result of clinical IBP is an
argument for mating young herd bulls only with maiden heifers.
Reproductive loss from infection with BHV1 and infectious pustular vulvovaginitis
(IPV) in cows has been associated with a highly virulent respiratory form of BHV1
virus in a feedlot (Allan, Dennett & Johnson 1975) and with AI using infected semen
(Parsonson & Snowdon 1975; White & Snowdon 1973). However, the management of
cattle in these reports was not routine for extensively-managed breeding herds.
Natural immunity against BHV1 virus can develop in calves with disappearance of
maternal antibodies by 6 months of age (Beveridge 1986, p.32; Radostits et al. 2007,
p.1351), but the opportunity to develop protective immunity would be limited for store
steers. The percentage that would develop antibodies to BHV1 may be as low as either
the heifer cohort in the present study (23%) or that reported for cattle entering
Australian feedlots (13%) (Office of the Gene Technology Regulator 2005). The need
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and opportunity for effective reduction of extended production losses from infection with BHV1 is yet to be identified for cattle on extensively-managed properties.

7.3.2.4. Conclusions on Serology

The present study has provided serological evidence of leptospires, BVDV and BHV1 and expanded the knowledge about the association of these pathogens with risk factors and reproductive outcomes in cattle of the Alice Springs district. More focused studies would enhance development or review of management recommendations with respect to these pathogens and related production issues for beef cattle on arid rangelands. It is noted that at the time of the primary beef cattle projects, serology for other reproductive pathogens, such as *Neospora caninum*, was either outside of the scope of the primary project or not of high enough priority to attract project funding.

*Leptospires*

Findings indicated that MAT titres need to be interpreted differently for each leptospiral serovar. More focused studies are needed if the epidemiology of endemic infection with *L. sv. hardjo* is to be defined, including the cost to production, the role of natural immunity and the cost-effectiveness of vaccination. The presence of serum titres to *L. sv. pomona* raised questions about the nature of persistent titres and the relationship of these to either vaccination or natural exposure with a maintenance host. No evidence was found of negative production impacts associated with MAT titres to *L. sv. tarassovi* in an extensively-grazed breeding herd.

*Bovine viral diarrhoea virus*

Limited seroconversion to BVDV in pre-pubertal cattle and loss of antibody titres in cows in an extensively-managed, endemically-infected breeding herd indicated potential to reduce associated BVDV-related production losses with targeted active exposure to PI cattle. More focused studies are needed if managed exposure to PI cattle is to be proven a practical and cost-effective strategy for these herds.

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*Bovine herpes virus type 1*

There was insufficient evidence to indicate that there would be practical benefit in control or treatment of BHV1 in an extensively-managed, endemically-infected breeding herd. More focused studies may provide information about the benefit and effectiveness of strategies for young cattle, either to manage exposure to BHV1, or to increase natural immunity against BHV1.

7.3.3. Biochemistry and Haematology

7.3.3.1. Optimal Biochemical and Haematological Values

‘Optimal values’ for serum and blood biochemistry and haematology were analysed in the present study, in order to provide regional reference ranges for beef cattle on arid rangelands (Section 2.2.1.2).

The significant differences between the mean or median of ‘optimal values’ for three representative cattle age-groups highlighted the need for critical interpretation of biochemical and haematological tests, as well as the need for consideration of biological variation ensuing from cattle factors (such as gender and age). Of the tests assessed for two cow age-groups in a compiled profile (Appendix 21), almost half (9/21) had outlying 10–90th percentile ranges, i.e. 10–90th percentile ranges of ‘optimal values’ that extended outside of the reference ranges of the testing laboratory, and outside most comparative ranges of selected key publications. For the eight pairs of outlying 10–90th percentile ranges considered regionally normal, their direction of variation away from the formal reference ranges and their suspected source of variation (biological or analytical) are indicated in Table 7-1. It is speculated that biological variation was an outcome of cattle adaptation to the arid rangelands at site B, and analytical variation was an outcome of blood collection, handling and storage (Boyd 1984) under the conditions of extensive management. The outlying 10–90th percentile ranges of biochemical and haematological values in Table 7-1 address an absence of regional
reference ranges for cattle on arid rangelands. Only the outlying 10–90th percentile ranges of serum P for the three age-groups were considered abnormal. The lower end of the latter ranges indicated a deficiency in dietary P.

Creating a regional reference range
Criteria have been recommended for sampling (Doumas 1997; Hutchison et al. 1991; Pfeiffer 1999) and data analyses (Boyd 1984; Griffiths et al. 2004) in order to create reference ranges. The alternative methods recommended for limited situations may include a minimum of 50 samples collected over a long time-period (Boyd 1984).

Table 7-1. Regional reference ranges for biochemistry and haematology of cows on arid rangelands at site B.

<table>
<thead>
<tr>
<th>Representative age-groups</th>
<th>Variation relative to other ranges</th>
<th>Suspected source of variation</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>TL&lt;sup&gt;(1)&lt;/sup&gt;</td>
<td>KP&lt;sup&gt;(2)&lt;/sup&gt;</td>
</tr>
<tr>
<td>heifer</td>
<td>mature cow</td>
<td></td>
</tr>
</tbody>
</table>

Ranges for Serum Biochemistry
- chloride (Cl) (mmol/L) 99–109 95–103 > TL in range + —
- gamma glutamyl transferase (GGT) (IU/L) 12–22 10–21 < TL in range + —
- creatine phosphokinase (CPK) (IU/L) 153–586 112–333 > TL > KP — +
- albumin (g/L) 35–44 32–43 > TL > KP + —
- globulin (g/L) 22–35 26–37 < TL < KP + —
- albumin-to-globulin ratio 1.0–1.9 1.0–1.6 > TL > KP + —

Ranges for Haematology
- haemoglobin (Hb) (g/L) 136–165 125–153 > TL > KP + —
- platelets (x10<sup>9</sup>/L) n/a 90–248 < TL < KP — +

n/a = not available; insufficient (< 50) samples assessed.

(1) reference range of the testing laboratory (TL), as per Appendix 21.
(2) comparative range of selected key publications (KP), as per Appendix 21.

The ranges in Table 7-1 were based on a customised default method, i.e. a minimum of 54 samples from a heifer group and a mature cow group under ‘optimal’ seasonal conditions. Seasonal conditions were defined as ‘optimal’ where the stage of greenness of the indicator grass (creek windmill grass) was ‘drying up’ at the time of blood
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sampling. By default it would have recently been ‘green’ and the cattle would have had
increased access to grass with a recognised high relative level of crude protein and
digestibility (Jeffery & McIntosh 2000, pp.2.8,3.4). Percentile ranges were used because
three sets of biochemical values were non-parametric (bilirubin, AST, CPK), and four
sets of biochemical and haematological values had non-parametric features (failure of
Levene’s test for homogeneity of variance at p < 0.001) (sodium (Na), Cl, albumin-to-
globulin ratio, red blood cell count).

7.3.3.2. Variation in Biochemical Values
Nutrition is a major driver of production efficiency for breeding herds on arid
rangelands (Section 2.1.5.1). Across northern Australia, nutritional deficiency has had a
high economic impact on extensively-grazed cattle (Sackett et al. 2006, p.21). In the
present study, biochemical tests on serum and blood samples were used to screen and
analyse herd nutrition with respect to risk factors and indicators of performance.

Serum phosphorus values and deficiency
The P-status (body stores) of cattle is best indicated by the testing of rib or coccygeal
to bone (McCosker & Winks 1994, p.58; Miller et al. 1998, pp.23-24). Circulating (blood
or serum) P is a specific but less sensitive indicator of P-status that is recognised as a
convenient or useful diagnostic tool (Jackson et al. 2012, p.5; McCosker & Winks 1994,
p.54; Miller et al. 1998, p.27; Ternouth 1990; Wadsworth et al. 1990). Clinical signs of
P-deficiency occur when blood P falls below a threshold of 1.2 mmol/L (~1.08 mmol/L
for jugular bleeding\(^1\)) (Radostits et al. 2007, p.1761). This threshold was similar to the
lower limit of the reference range used by the testing laboratory for the present study.
Recent recommendations for assessment of P-status of extensive cattle herds in northern
Australia have focused on selective testing of soil, faeces and blood. For the latter, it is
suggested that blood samples should be collected at the end of the ‘wet season’ from

\(^1\) Serum P results were multiplied by a factor of 0.9 as recommended by McCosker (1994, p.56).
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non-lactating, growing cattle (Jackson et al. 2012, p.5). For a commercial breeding herd on arid rangelands, consideration of these recommendations needs to take account of the lack of a recognised ‘wet season’, plus regular management practices such as weaning and removal of growing cattle (steers or heifers) from the breeding herd (Section 2.1.5.1), and provision of P and N supplementation (Section 2.1.3.1). Under average conditions, mobilisation of body P stores and intestinal (re)absorption of salivary and dietary P (Ternouth 1990) enable a cow to maintain blood P. Therefore if blood P levels fall below the normal range, this would indicate an inadequate P-status.

In the study, variation in serum P with below-normal serum values demonstrated dietary P-deficiency on arid rangelands, in association with aged cows, lactating cows and poor rangeland conditions. Because blood testing is considered to have poor sensitivity for the P-status of lactating cows (Jackson et al. 2012, p.38), this emphasises the diagnostic relevance of the present study findings. The 25th percentile serum P values in the young cow group suggested clinical P-deficiency during most years of the study for site B (collection via jugular vein: ≤ 1.1 mmol/L in 1991/92, 1993/94 and 1995/96) and site C (collection via coccygeal artery or vein: ≤ 0.96 mmol/L in 1999/2000 and 2001/02). For a tested group of lactating young cows at site B, below-normal serum P was associated with failure to conceive (p = 0.11), but the number of tested individuals was too small to demonstrate a significant difference.

The findings of low serum P in cattle in the present study are supported by a previous report of low blood P in cows during a drought year in the Alice Springs district (Barnes & Jephcott 1959). Overall, this is consistent with reports of seasonal P-deficiency on other arid rangelands of northern Australia (Bortolussi et al. 1999a,b; O'Rourke, Winks & Kelly 1992), Namibia (Grant et al. 1996) and USA (Holechek, Pieper & Herbel 2004, pp.359-61). This emphasises the need for targeted P-supplementation of breeding cattle on arid rangelands. As an example of the varying need of cattle for supplementation,
consumption of nutritional supplementation with P was noted to more than doubled for two water-points at site B (yards B.1 and B.3) in a year of declining rangeland conditions (1994). At yard B.3, the increased average consumption of supplement (6.7 g/ head/ day, increasing to 15.6 g/ head/ day) improved the average intake of phosphorus by 50% (up to 0.36 g P/ head/ day).

At site C, the exceptionally low serum P values in 2000 and 2001 may have been exacerbated by the presence of surface water, which diverted cattle from drinking the trough water that had been medicated with urea and P (Hill 2003, p.15).

The low correlation of liveweight with serum P for aged cows at site B (r = 0.35, p < 0.05) indicated a positive relationship between P-status and increased body mass of adult cows. However, for older bulls, a low negative correlation of liveweight with serum P (r = -0.52, p < 0.05) and an inverse relationship between liveweight and serum Ca highlighted the interaction between homeostasis of P and Ca (Latimer, Mahaffey & Prasse 2003), as well as the potential for serum biochemistry to be influenced by differences in gender or diet (Radostits et al. 2007, p.2047; Smith 1990, pp.399-400).

Serum vitamin A values and deficiency

In the present study, variation in serum vitamin A demonstrated below-normal serum values and deficiency in dietary sources of vitamin A on arid rangelands. This was associated with aged cows, low body condition, and dry seasonal conditions.

The vitamin A status (body stores) of cattle is most accurately measured with the testing of liver samples. For diagnostic and screening purposes, serum or plasma levels of vitamin A are more commonly tested (Radostits et al. 2007, p.1775), despite the fact that serum vitamin A does not reflect hepatic stores until the latter become critically depleted. Liver stores enable cattle to subsist on vitamin A-deficient diets for five to 18 months before clinical signs appear and serum vitamin A drops below normal levels. Serum vitamin A is considered optimal above 0.25 mg/L (Radostits et al. 2007, p.1775),
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which is just below the reference range of the testing laboratory used for the study. A sub-optimal level at the 25\textsuperscript{th} percentile serum vitamin A value (0.26 mg/L) in the young cow group during a year of drought (1994/95) at site B indicated deficiency in dietary sources of vitamin A for cows with neonatal calves during that period. This highlighted the potential for a primary vitamin A deficiency that is recognised during abnormal feed conditions, dry seasonal conditions or prolonged drought (Watkins & Knox 1950). Both low temperatures and absence of rain can limit the growth of grass and thus provide little or no carotene content in rangeland pastures (Repp & Watkins 1958a). These climatic and feed conditions are implicated in vitamin A deficiency on semi-arid and arid rangelands of Australia, as documented for young cattle in pastoral Western Australia (Nickels 2002), young cattle in south-west Queensland (Holroyd, Hill & Sullivan 2005) and peri-natal calves in north-west Queensland (Hill, Holroyd & Sullivan 2009).

The risk of vitamin A deficiency, which has been described for cows on arid rangelands of New Mexico (Watkins & Knox 1950), is more likely to be of clinical concern for young rather than adult cattle. Concern about the risk of vitamin A deficiency in adult cattle over a prolonged period would generally be superseded by the concurrent nutritional deficiencies in energy and protein (Holechek, Pieper & Herbel 2004, p.353). The risk of vitamin A deficiency in adult cattle can be mitigated by adequate hepatic (vitamin A) stores, as well as by consumption of any forbs and topfeed that remain green (Watkins & Knox 1950). The carotene content of dicots on the arid rangelands of Australia (mulga leaves) (Gartner & Anson 1966) and USA (prickly pear (Opuntia sp.), yucca (Yucca elata), palatable weeds) (Repp & Watkins 1958b; Watkins & Knox 1950) has been considered sufficient to meet the vitamin A requirement of browsing ruminants during periods of no grass growth. Cacti, such as Opuntia spp., are an important source of supplementary feed on arid rangelands of the USA (Holechek, Pieper & Herbel 2004,
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p.443) and northern Mexico (Huntsinger & Starrs 2006). The vitamin A nutrition of preruminant calves is, however, highly dependent on their dams’ hepatic store. Limited placental transfer occurs during late gestation and critical amounts are ingested in colostrum during the neonatal period (Debier & Larondelle 2005).

7.3.3.3. Conclusions on Biochemistry and Haematology

Regional reference ranges
Limited testing has been reported to establish a normal range of biochemical and haematological values for beef cattle on arid rangelands. Review of biochemical and haematological values under ‘optimal’ conditions in the present study provided regional reference ranges, based on two cow age-groups for eight laboratory tests (6 biochemical, 2 haematological). These ranges are more comprehensive and up-to-date than values previously reported for the Alice Springs district (Barnes & Jephcott 1959; White 1984), and they augment interpretation of blood tests as investigative tools for cattle herd health and performance under extensive-grazing conditions on arid rangelands.

Management of arid rangeland nutrition
In the present study, severe dietary P-deficiency was indicated in three out of five years on a beef cattle property in the Alice Springs district. This supports recommendations for P-supplementation of cattle in high risk areas on arid rangelands (e.g. with spinifex and mulga) (Jackson et al. 2012, pp.3-4,34; McCosker & Winks 1994, pp.75-78), especially for aged and lactating cows during poor seasonal conditions.

Deficiency in dietary sources of vitamin A was indicated in the study, in one out of five years on a property in the district. This suggests a need for follow-up investigations with targeted liver sampling (Hungerford 1990, p.1501; Radostits et al. 2007, pp.1775-76) of high risk cattle (older cows and reproductively active cattle) in order to better define the
suspected sub-optimal vitamin A nutrition or the need for vitamin A supplementation during prolonged droughts.

In general, cattle in breeding herds on arid rangelands need access to high quality feed during the unpredictable good-to-excellent seasonal conditions, in order to boost their body stores of P and vitamin A after periods of drought.

**Recommendation for future investigations**

In the present study, the biochemical testing to survey Cu nutrition (serum Cu values) (Radostits et al. 2007, pp.1715-17) was not analysed on account of the unsuitable sample type. Blood Cu is sequestered in ceruloplasmin during the clotting process (Laven, Lawrence & Livesey 2008) and this is a major cause of analytical variation in serum Cu levels. Plasma Cu (Paynter 1982) and liver sampling (Radostits et al. 2007, pp.1716-17) should be preferentially used to survey the level of Cu nutrition in cattle. Notwithstanding the inability to confidently interpret serum Cu values, the need to investigate the Cu-status of cattle in the Alice Springs district has been indicated by observations at site B, i.e. a fall in serum Cu associated with reproductively active cattle and dry seasonal conditions; and anecdotal darkening of cattle coats associated with the use of copper sulphate to prevent algal growth in the livestock water troughs. These observations have been supported by reports of Cu-deficient soil in the Alice Springs district (McEllister c. 1991; NT-DPI&F c. 2000, p.61) and references relating to a marginal Cu status in cattle on arid rangelands of Western Australia (Nickels 2002), South Australia (Animal Health Australia 2008), Namibia (Grant, Biggs & Meissner 1996) and south-west USA (Holechek, Pieper & Herbel 2004, p.360).

**7.3.4. Faecal Chemistry**

Nutritional deficiency is a threat to efficient and profitable production of extensively-grazed cattle herds in northern Australia. In the present study, the use of faecal
chemistry was reviewed for assessment of herd nutrition on arid rangelands, with respect to cattle risk factors and indicators of seasonal feed.

7.3.4.1. Variation in Faecal Chemistry Values

Faecal %P and %N values
In the study, low Faecal %P values at the 25th percentile (range: 0.12–0.19%) suggested that dietary P-deficiency on arid rangelands was associated with low rainfall, dry grass, absence of pasture germination and landsystems with known low soil P.

Low Faecal %N values at the 25th percentile (range: 1.05–1.23%) suggested that dietary N-deficiency on arid rangelands could be associated with moderate pasture germination (recruitment) and aspects of low rainfall or lactation that would respectively encourage selective grazing or restrictive grazing by cows.

Variations with non-selective and selective feeding
Faecal %P is accepted as a reasonable indicator of P in the diet of cattle in northern Australia (Jackson et al. 2009, p.137; Jackson et al. 2012, pp.5-6). Recommended assessment of P-status in extensive cattle herds of northern Australia has included testing of faecal samples from unsupplemented cattle in the middle of the ‘wet season’ (Jackson et al. 2012, p.5). Consideration of this for sites B and C indicated the need to take account of regular P and N supplementation, plus a lack of a recognised ‘wet season’. If the Faecal %P of supplemented cattle falls below a recognised level for deficiency, this would suggest a primary deficiency in the rangeland dietary P and inadequacy of the provided supplementation.

Low Faecal %P values at site C indicated dietary P-deficiency across all categories of assessed cumulative rainfall and cattle age-groups. This is consistent with the fact that site C was located mainly on Singleton and Titra landsystems (spinifex sand plains and mulga shrubland) (Appendix 1), which have acute deficiency in available soil P (< 4ppm) (McCosker & Winks 1994, p.43). Faecal %P values were positively and
significantly correlated with serum P (p < 0.05) at sites B and C. Although the correlation was poor to low, this indicated a capacity for Faecal %P to predict nutritional P-deficiency on landsystems in the Alice Springs district.

Faecal %N values were significantly lower (p < 0.01) in young, lactating cows compared to store steers at site C. This indicated dietary differences related to aspects of grazing behaviour during lactation. F-NIRS-predicted dietary CP has also been lower in cows (breeders) than in store cattle (steers and heifers) (Jackson et al. 2009, p.33). It has been noted that non-lactating cattle are more likely to walk further and thus have a greater selection of pastures (Jackson et al. 2009, p.35).

The lower Faecal %N and %DM associated with ‘moderate’ indicator grass recruitment at site B suggested selective grazing and browsing with diet switching. Escalating new grass growth would have encouraged cattle to start grazing immature pasture (forbs and grasses) that are usually highly digestible, low in dietary fibre and produce minimal dietary residue in the faeces. Grazing of immature, highly digestible plants is associated with increased levels of rumen digestible protein (Jeffery & McIntosh 2000, pp.2.8,3.4), which is poorly reflected in the Faecal %N. Unexpected low F-NIRS-predicted dietary CP has also been noted with pasture in the first two stages of growth after rainfall, when diet quality is often quite high but yield is low (Jackson et al. 2009, p.21).

F-NIRS-predicted dietary CP, which is mirrored by the F-NIRS estimate of Faecal %N (Jackson et al. 2009, p.43), is not only influenced by rainfall, but also by the landsystem, dietary plant species (grass, ‘non-grass’) and dietary plant greenness (Jackson et al. 2009, pp.3–4). In the present study, it was found that association with Faecal %N was not consistent for landsystems at two sites, and was not significant for indicator grass greenness. The association of Faecal %N with serum urea and characteristics of the cattle was also limited. The indefinite nature of these associations probably reflected multiple factors, including the negative effects on digestion resulting
from high seasonal levels of dietary tannins and fibre on arid rangelands (Section 2.1.1.3). For example, leaves of the mulga tree are an important source of topfeed (Miller, Gutteridge & Shelton 1994), but contain 5 to 24% (dry weight) condensed tannins (Plumb et al. 1999) that bind dietary CP (Nunez-Hernandez et al. 1992) and interfere with digestion in the rumen and gastro-intestinal tract. As a result, dietary tannins can increase the threshold Faecal %N to 1.8% for CP deficiency in the rangeland diet of cattle (Hakkila et al. 1988).

Interpretation of Faecal %N in the present study also had to acknowledge the potential confounding effects of seasonal urea supplementation at both sites B and C. Urea supplementation can improve cattle nutrition, both by improving the nutritional value of a cattle diet (as demonstrated by increases in F-NIRS-predicted dietary CP and DMD (Jackson et al. 2009, p.136)), and by improving digestion of low quality rangeland feed (Jeffery & McIntosh 2000, p.5.25; Sprinkle 2001b). Changes in cattle feeding capacity and behaviour can be an outcome of the latter. As suggested in Section 2.1.3.1, the positive effect of urea supplement on rumen function and digesta-flow would be most marked in poor and dry seasonal conditions when feed quality is low (dry, low DMD, low dietary CP or high dietary tannins) and larger quantities of urea are consumed. In the study, cattle at sites B and C had access to urea and P supplement (Appendix 3), but consumption fluctuated. Entering into a year of drought (1994) at site B, consumption of supplement blocks containing urea more than doubled. At site C, consumption of trough water medicated with urea fell with the availability of surface water during good seasonal conditions (2000, 2001) (Hill 2003, p.15). The reduced consumption of urea may have coincided with low Faecal %N during periods when the rangeland pasture was commencing new growth (‘greening up’), germination was active (‘moderate recruitment’) and cattle would have, as previously mentioned, selectively grazed the immature pasture forbs and grasses.
Faecal %DM values and diagnostic potential
In general, the level of Faecal %DM reflects digesta transit-time and water resorption in the large intestine (Hecker & Grovum 1975; Radostits et al. 2007, p.307). Within a normal physiological range, increased Faecal %DM has been associated with lactation (Field 1970), and decreased Faecal %DM has been associated with high levels of rumen digestible protein (Kononoff, Heinrichs & Varga c. 2002). Outside a normal physiological range, increased Faecal %DM has been associated with restricted protein intake, and decreased Faecal %DM has been associated with high levels of rumen digestible protein, heat stress, hindgut fermentation, subclinical parasitism and gastrointestinal toxicoses (Kononoff, Heinrichs & Varga c. 2002). In the present study, Faecal %DM values were within the physiologically-normal range, except for some low Faecal %DM (loose faeces) associated with sampling from the aged cow group (11% faecal DM) and the sampling during moderate pasture germination (10% faecal DM). Within the normal range, significantly higher Faecal %DM values (p < 0.05) were associated with abundant pasture germination, low rainfall, steers and heifers.

The higher Faecal %DM records for the cattle with a lower body mass may have resulted from dehydration during yarding or during transit to livestock water-points from distant feeding locations. This premise of dehydration is supported by the significantly higher mean packed cell volume (43%, p < 0.00001) and mean serum Na (143 mmol/L, p = 0.00078) in heifers compared to mature cows under ‘optimal’ conditions (Appendix 21). Overall, access to urea supplement at both sites B and C would have promoted digesta-flow and helped maintain Faecal %DM within the physiologically-normal range. For this reason, comments in this study have been limited to the use of Faecal %DM for assessment of supplemented cattle. However caution should still be exercised in the interpretation of Faecal %DM and physical appearance (consistency) of cattle faecal pats. Although faecal consistency has been promoted as a
tool to assess dietary intake of grazing beef cows (Lyons, Machen & Stuth 2000), the presence of previously described factors has the potential to render Faecal %DM an unreliable indicator of dietary N and P for supplemented cattle on arid rangelands. In the present study, correlations between Faecal %DM and serum metabolites were either inconsistent (with serum P) or were not significant (with serum urea).

Collection of cattle faecal samples
Interpretation of the variation in faecal chemistry values of the present study highlighted the importance of collecting key records about the cattle and the grazed or browsed paddock area, similar to recommendations for F-NIRS (Jackson et al. 2009, p.4). Key cattle records include: age; gender; lactation status; risk of intestinal parasitism; and period in the paddock. Key paddock records include: landsystem; rainfall in the previous two months (minimum); pasture type; available topfeed; level of pasture germination (recruitment); stage of pasture growth (greenness); plus type and method of supplementation. F-NIRS-predicted dietary digestibility and dietary ‘non-grass’ would augment these paddock records. Faecal samples should be collected (freshly voided or per rectum) from individually-classified cattle and if the faecal samples are to be bulked for group analysis, the cattle group should be homogeneous.

7.3.4.2. Conclusions on Faecal Chemistry

Limitations and applications
Findings from the present study have indicated some limits in the use of faecal chemistry for cattle on arid rangelands. Faecal %DM and the consistency of cattle faecal pats should be used with caution to monitor dietary N of cattle supplemented with urea. Faecal %N is of equivocal benefit for assessing available dietary N for cattle supplemented with urea on arid rangelands. Within thresholds for different landsystems, assessment of Faecal %N may be useful in the periods when there is minimal
consumption of topfeed and little or nil immature pasture. This limitation may also apply to interpretation of dietary %N by Faecal NIRS.

Analysis of F-NIRS predictions is challenged by the presence of multiple C3 plants (topfeed, forbs or temperate grasses), which are classified as ‘non-grass’ in calibrations for north Australia. The diet of cattle on arid rangelands potentially contains a large number of these ‘non-grass’ plants. On mulga lands, the F-NIRS-predicted dietary proportion of ‘non-grass’ has been as high as 63% (Jackson et al. 2009, p.15). Where there is a large portion of ‘non-grass’ plants in the diet, more work is needed to interpret the availability of F-NIRS-predicted dietary CP (Jackson et al. 2009, p.16).

Interpretation would be assisted by local knowledge about the presence and consumption of different types of ‘non grass’ (palatable topfeed species and forbs) under wet versus dry seasonal conditions. However this is difficult with mixed land systems (Jackson et al. 2009, pp.54,59).

Faecal %P is useful for assessing the seasonal risk of dietary P-deficiency in cattle on arid rangelands. Recommendations for collection of faecal samples from cattle on arid rangelands should be considered for any of these faecal analyses.

7.3.5. Faecal Parasitology

Internal parasites have a medium economic impact on extensively-grazed cattle in northern Australia (Sackett et al. 2006, p.21). Their potential to impact negatively on herd production efficiency (Hungerford 1990, p.1397; Radostits et al. 2007, pp.1541-54) can be determined initially by screening with faecal parasitology. In the present study, the number and identity of nematode eggs, nematode larvae and coccidial oocysts in faecal samples were analysed with respect to cattle risk factors and indicators of environmental conditions on arid rangelands.
7.3.5.1. Intestinal Nematodes

Larval nematodes identified from cultured faecal samples in the present study (Appendix 24) were of the same genera as those previously reported in arid areas of northern Australia (Cooperia spp., Oesphagostomum sp., Haemonchus sp.) (Radunz 1992). Given the limits of diagnosis and known epidemiology of intestinal nematodes, the faecal egg counts indicated that clinical intestinal nematodiasis was a potential problem in weaned calves and herd bulls on arid rangelands.

Diagnosis and epidemiology of bovine intestinal nematodiasis

Larval cultures and intestinal worm counts are definitive for diagnosis (differentiation and quantification) of intestinal helminthosis (Radostits et al. 2007, pp.1544-50). Faecal egg counts have acceptable correlation with intestinal nematode burdens in young cattle (Radostits et al. 2007, p.1544). However these counts have poor diagnostic sensitivity where helminth infestations are suppressed on account of cattle immunity, anthelmintics, helminths with low fecundity or immature helminths (Radostits et al. 2007, p.1547) results in little, if any, faecal egg production. For this reason, the faecal egg counts of young cattle and the species of intestinal nematodes became a focal point for the present study.

The upper quartile of faecal egg counts for weaned calves was at least 50 epg in each year, and as expected for adult cattle (Radostits et al. 2007, p.1547), the upper quartile for cows was less (< 15 epg). The highest faecal egg counts were also recorded in weaned calves (maximum: 1,920 epg). Maximum faecal egg counts were lower in the mature-to-older bull and mature cow groups (720 epg and 140 epg respectively). Of the three nematode species identified in cattle on arid rangelands, Haemonchus sp. in particular has high fecundity (Hansen & Perry 1994). However, the free-living larvae of Cooperia spp. are more tolerant of desiccation and temperature extremes than are the free-living larvae of Haemonchus sp. (Reineke 1960). This is consistent with the study
CHAPTER 7. DISCUSSION

finding that 100% of identified larvae were *Cooperia* spp. in some cultured faecal samples (Appendix 24).

Reports from arid rangelands suggest that bovine intestinal helminthosis has been a minor concern. In the Alice Springs district, faecal egg counts in young cattle have been previously reported to be low (100 epg) or non-significant (Smeal 1995, pp.51,83). In arid or semi-arid areas of Queensland, faecal egg counts in weaner cattle have often been less than 60 epg (Clarke 1991, p.57; Winks 1968), and in arid south-west USA an average of 33 epg has been recorded in cattle (Becklund & Allen 1958; Miller 1993). Although typical conditions on arid rangelands (absence of rain, extreme temperatures, low stocking rates, grazing plus browsing) can limit transmission of intestinal helminths (Clarke 1991), high periods of larval survival, uptake and infestation have been reported in a semi-arid area (veld) of South Africa during summer and autumn (Reineke 1960). The latter conditions are assumed to be replicated for young cattle on the rangelands of Western Australia (Nickels 2002) and in the Alice Springs district, given wet years, high faecal egg counts in weaner cattle, or erratic periods of rainfall in excess of 50 mm (Radunz 1992). The cycle of uptake of infective nematode larvae can be increased in exceptionally wet years (Radunz 1992) or where drought-breaking rain (Radostits et al. 2007, p.1543; Reineke 1960) is associated with concentrated, close grazing and low quality or quantity in recent nutrition. In the present study, large rainfall events that followed dry seasonal conditions and poor seasonal conditions were associated with significantly higher faecal egg counts in weaned calves (p < 0.01) and indicated clinical intestinal nematodiasis at the 90\textsuperscript{th} percentile count (889 epg and 720 epg respectively). The maximum faecal egg count in the mature-to-older bulls (720 epg) in average-to-good seasonal conditions indicated clinical intestinal nematodiasis in up to 6\% of herd bulls.
CHAPTER 7. DISCUSSION

Infestation with infective nematode larvae is greater in cattle with low immunity against intestinal nematodes, i.e. cattle under the stress of poor nutrition, young cattle before 2 years of age and calves after the social and nutritional stress of weaning (Clarke 1991, p.57; Radunz 1992). When young cattle have poor immune competence, a low intestinal nematode burden may be pathogenic (Radunz 1992), but a low burden is less likely to adversely affect productivity if the young cattle have good nutrition (Clarke 1991, p.57). The occurrence of subclinical effects in young cattle in the Alice Springs district has been indicated by the improved appearance of store cattle for sale following opportunistic use of anthelmintics (as documented by Radunz (1992)), and by high faecal egg counts (> 500 epg) in more than 10% of some weaned-calf groups in the study.

7.3.5.2. Intestinal Coccidia

In the present study, identification of two species of intestinal coccidia (*Eimeria bovis, E. canadensis*) was consistent with reported multi-species infestation in extensive cattle herds of northern Australia (de Witte, Jubb & Hedlefs 1998; Parker et al. 1984). Given the limits of diagnosis and known epidemiology of coccidiosis in cattle of northern Australia, faecal oocyst counts in weaned calves did not indicate clinical coccidiosis, but did indicate a potential for disease on arid rangelands.

*Diagnosis and epidemiology of bovine coccidiosis*

The diagnostic value of faecal oocyst counts is limited by the absence of faecal oocysts in some cases of coccidiosis (Smith 1990, p.1535). There is a lag period, such as during the first month after weaning, before oocyst counts become associated with severe clinical diarrhoea in individual young cattle (Parker et al. 1984). In the main, base-level coccidial oocyst counts in young cattle indicate a low level of infestation that is considered acceptable for induction of a specific immunity (Radostits et al. 2007, p.1501). However, high oocyst counts should be avoided on account of the associated
high environmental contamination, clinical coccidiosis in cohorts, and damage to the intestinal mucosa of individual cattle (Smith 1990, p.1535). In the Northern Territory, clinical coccidiosis has been attributed to a low level of cattle immunity and a build up of oocyst contamination in the environment (de Witte, Jubb & Hedlefs 1998). The latter is associated with extended periods of yard-feeding, crowded conditions (Radostits et al. 2007, p.1500) and the environmental persistence of oocysts. A reduced level of cattle immunity against coccidia infestation is associated with handling stress, environmental temperature extremes (Parker et al. 1984) and poor post-weaning nutrition (Pinch & de Witte 1996).

In the present study, clinical coccidiosis in weaned calves was indicated by the maximum annual faecal oocyst counts in two out of the five years (15,050 opg and 11,000 opg). Weaned calves were the largest reservoir of oocysts and contaminated the environment with high levels in the faeces (> 5,000 opg). The level of faecal oocyst counts in the heifer group (up to 620 opg) was considered tolerable.

**7.3.5.3. Conclusions on Faecal Parasitology**

Findings from the present study augment reports on the epidemiology of bovine intestinal nematodiasis and coccidiosis in the Alice Springs district and highlight the potential for intestinal parasitic problems on arid rangelands. This supports recommendations for strategic management of both pasture and yard feeding of weaned calves, but adds little to regional knowledge about how the presence and treatment of intestinal parasitic disease relates to production, potential compensatory liveweight gain (Radunz 1992), and market opportunities (NT-DPI&F 1994b). This knowledge is needed in order to determine the nett benefit of anthelmintic and coccidiostat treatments.
CHAPTER 7. DISCUSSION

Recommendations for bovine intestinal nematodiasis

Although the risk of intestinal helminthosis in cattle is generally limited by conditions of extensive grazing in northern Australia (Clarke 1991, p.57; de Witte, Jubb & Hedlefs 1998; Niethe 1986, p.33; Radunz 1992), three intestinal nematodes with recognised differences in lifecycles (Cooperia spp., Oesphagostomum sp., Haemonchus sp.) have been identified in cattle in the Alice Springs district. For arid rangelands in general, credible risk of intestinal helminthosis in cattle may exist during irregular periods, either with good rain for an extended period (> 15 days) (van Wyk 1990), or with non-selective grazing under drought conditions (Reineke 1960). The latter conditions may occasionally arise on arid rangelands, when cattle move onto ‘green pick’ after a cold, dry winter (Clarke 1991, p.57). This is consistent with the findings in the present study for weaned calves when significant rain followed dry or poor seasonal conditions. The occurrence of poor seasonal conditions before significant rain is the norm for the Alice Springs district, so pending additional information on the nett benefit of specific strategies to manage grazing and nutrition of at-risk cattle, there would be benefit in the interim adoption of recommendations by Reineke (1960) for semi-arid areas, i.e. paddock rotations, improved nutrition, promotion of dung beetle activity and segregation of age-groups. Segregation of weaner cattle will improve the potential to manage their nutrition and remove them from the reservoir of intestinal nematodes in herd bulls. Findings from a trial in south-west Queensland have suggested that improvement in nutrition, rather than regular anthelmintic treatment, is more likely to produce a cost-effective improvement in productivity of young cattle (Clarke 1991, p.57). Although there is recognised need for strategic and integrated programs to control and manage bovine intestinal nematodiasis (Williams 1997), strategic use of anthelmintic treatments is considered unsuitable in areas of erratic rainfall (van Wyk 1990). Tactical use of anthelmintic treatments is theoretically more advisable, but only
for cattle at-risk of clinical intestinal nematodiasis (low immunity, high uptake of nematode larvae in the environment, or high faecal egg counts) and when treatments will achieve long-term health and production benefits. In Namibia, subsidisation of anthelmintic treatment, fodder and freight for livestock during drought has been criticised because there is a risk that these subsidies may encourage poor management practices (Sweet 1998). Elsewhere in south-west Africa it has been noted that with the exception of calves, intestinal helminths are not a big problem for extensive cattle enterprises, and extension messages are required to discourage inappropriate and unnecessary anthelmintic treatments (Sekokotla 2005, p.37).

Use of anthelmintics, such as subcutaneous injectable ivermectin and pour-on topical eprinomectin (B Broome (Elders Pastoral) 2011, pers. comm.), has been reported by 11% of surveyed cattle managers in the Alice Springs district (Leigo c. 2006). However there have been no district-based recommendations for integrated management of bovine intestinal nematodiasis that incorporates the use of anthelmintics. Past recommendations in the district have only been based on reported benefits from the use of anthelmintics under short-term and unusual situations, i.e. improved growth of cattle in an opportunistic feedlot (Bertram 1986), a noted improvement in coat appearance of store cattle at sale (Radunz 1992), and improved liveweight gain of weaner cattle in a paddock trial (Coventry 1998). In the absence of current district-based recommendations, the results of the present study and evidence-based knowledge would support the development of recommendations for the management of bovine nematodiasis. One important finding of this study was the frequently identified eggs and larvae of *Cooperia* spp.. Compared to other nematodes, the free-living larvae of *Cooperia* spp. are more resistant to the temperature extremes of arid rangelands (Reineke 1960), and anthelmintic resistance to benzimidazoles and macrocyclic lactones has been reported for *Cooperia* spp. (Besier 2008; Lyndal-Murphy, Ehrlich & Gemmell...
CHAPTER 7. DISCUSSION

2011). This latter issue is particularly relevant to the development of recommendations for the appropriate use of anthelmintics.

Other issues were highlighted by the present study and should be addressed in district-based recommendations. These include: the higher risk of clinical intestinal nematodiasis in young cattle; the potential for herd bulls to contaminate pasture with nematode eggs; the increased risk after rain events that are preceded by dry or poor periods; plus the protective role of good nutrition. These type of issues were considered in the strategies recommended by Reineke (1960). Demonstration of recommendations for integrated management of bovine intestinal nematodiasis in an extensive breeding herd could be achieved with longitudinal field studies in the Alice Springs district. This would allow sufficient time to assess the benefits of tactical anthelmintic treatments.

Recommendations for bovine intestinal coccidiosis

Although the findings of the present study suggest that the risk of clinical coccidiosis from the identified coccidia (*E. bovis, E. canadensis*) would be low for paddock-weaning of calves, the findings are consistent with reports about the potential for coccidiosis, four weeks after weaning (Parker et al. 1984) and in orphaned or early-weaned calves of the Alice Springs district (NT-DPI&F 1992b). In line with recommendations for prolonged yard-feeding of young cattle in the Northern Territory (Pinch & de Witte 1996), this suggests that high risk calves would benefit from strategic use of coccidiostats, along with reduction in faecal contamination of feed and promotion of supplementary feeding.

SECTION 7.4. SUMMARY

This study presents new information on reproductive performance, mortality, nutritional deficiency, infections and infestations of cattle on arid rangelands. The new information has provided points of reference for cattle research on issues such as aged cow and heifer reproductive performance, extrapolated annual mortality, phosphorus deficiency,
vitamin A deficiency, intestinal parasites and BVDV. New information has provided benchmarks of branding and weaning percentage, branded-calf production per herd bull and weaned-calf production per 100 kg of mated cows. New information has also confirmed and established regional reference ranges for biochemistry and haematology. A summary of this study also calls to attention specific data and analyses that were needed to optimise discussion: where cattle datasets were limited by physical and logistical challenges of the extensive environment; where objective measures of environmental variables were required; and where definition of herd health or disease was required. A default measure (lactation failure after confirmed early pregnancy) was used to determine conception losses; extrapolation and averaging of ‘non-pregnant’ or ‘pregnant’ measures of body mass were used to determine measures of body mass-at-conception; and the percentage of cattle that were persistently absent from five consecutive musters was used to help determine annual mortality. A default measure (‘drying up’ stage of greenness of an indicator grass at blood sampling) was used to define the conditions for ‘optimal’ cattle nutrition; and variable seasonal conditions were categorised by half-yearly blocks of cumulative rainfall. With regards to health and nutrition outcomes, population percentiles were used to identify normal data for regional references (biochemistry and haematology) and to screen for clinical disease (nutritional deficiency and infestations). Calculations of freedom from disease based on imperfect tests were used to determine the probability of detecting herd disease. Overall, the diverse results and discussion in the present study reflect the varied nature and timing of three primary beef cattle projects that were the source of data and laboratory results. The study results and discussion also reflect the additional analyses undertaken where aspects of breeding herd performance were not fully addressed in publications of the primary projects. By default this has helped to realise the significance of some previously unpublished data and laboratory results.
## APPENDICES

**Appendix 1. Paddock infrastructure, landsystems and rangeland pasture-types at sites.**

<table>
<thead>
<tr>
<th></th>
<th>site A</th>
<th>site B</th>
<th>site C</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Paddocks</strong></td>
<td>Kunoth (180 km²) (Low 1978a)</td>
<td>Westside (S … 500 km²)</td>
<td>Camel (W … 53 km²)</td>
</tr>
<tr>
<td></td>
<td>Kong (N … 40 km²)</td>
<td></td>
<td>Hill (E … 63 km²)</td>
</tr>
<tr>
<td><strong>Infrastructure</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Boundaries</td>
<td>barb-wire suspension fences, plus natural barrier (Chewings Range (S))</td>
<td>barb-wire suspension fences, plus natural barrier (Harts Range (S))</td>
<td>barb-wire suspension fences, plus plain-wire electric subdivision</td>
</tr>
<tr>
<td>Permanent/semi-permanent waters</td>
<td>3 bores, 3 dams</td>
<td>5 bores, 5 dams</td>
<td>4 bores, 1 dam</td>
</tr>
<tr>
<td><strong>Landsystem†</strong></td>
<td>Alcoota (mulga shrubland) ( + ) (Lendon &amp; Ross 1978)</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td></td>
<td>Boen (mulga shrubland) ( ++ ) ~ 40 km²</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td></td>
<td>Bond Springs (clayey, stoney slopes/hills) ( + )</td>
<td>(+++ ) 325 km²</td>
<td>—</td>
</tr>
<tr>
<td></td>
<td>Bushy Park (mulga shrubland) ( ++ ) ~ 30 km²</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td></td>
<td>Hamilton (open woodland, alluvial plains) ( ++ ) ~ 50 km²</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td></td>
<td>Harts (mountain ranges) ( + ) 27 km²</td>
<td>( + ) 75 km²</td>
<td>—</td>
</tr>
<tr>
<td></td>
<td>Kanandra (open woodland, alluvial plains)</td>
<td>( ++ ) 50 km² + part of 40 km²</td>
<td>—</td>
</tr>
<tr>
<td></td>
<td>Singleton (spinifex sand plains/dunes)</td>
<td>—</td>
<td>( ++ ) 39 km² + 22 km²</td>
</tr>
<tr>
<td></td>
<td>Titra (mulga shrubland)</td>
<td>—</td>
<td>( ++ ) 26 km² + 32 km²</td>
</tr>
<tr>
<td></td>
<td>Undippa (Mitchell grass)</td>
<td>—</td>
<td>( + ) part of 40 km²</td>
</tr>
</tbody>
</table>

† Relative area of landsystem per site: ( + ) = minor; ( ++ ) = notable; (+++ ) = major. Photographic examples of landsystems are provided on the following pages (source: (former) NT-DPI&F Rangeland Production Section, Alice Springs, NT).
Appendix 1.  (continued)

Example of Alcoota landsystem
(Yambah station, Alice Springs district, NT, March 1987).

Example of Bond Springs landsystem, with Harts landsystem behind
(Hamilton Downs station, Alice Springs district, NT, February 1987).

Example of Boen landsystem
(Amburla station, Alice Springs district, NT, April 1986).

Example of Bushy Park landsystem
(Utopia station, Alice Springs district, NT, September 1982).

(- 194 -)
Appendix 1. (continued)

Example of Hamilton landsystem
(Yambah station, Alice Springs district, NT, March 1987).

Example of Singleton landsystem
(Amburla station, Alice Springs district, NT, April 1986).

Example of Kanandra landsystem
(Owen Springs station, Alice Springs district, NT, March 1984).

Example of Titra landsystem
(Napperby station, Alice Springs district, NT, September 1972).
Appendix 2. Monthly rainfall totals for sites.

site A

source: CSIRO Rangeland Ecosystem Dynamics Study records (Low et al. 1979).

site B

source: Property homestead records (25 km from the centre of the site B).
Appendix 2. (continued)
site C

source: Property homestead records (20 km from the centre of the site C) and Bureau of Meteorology weather station - Yuendumu, NT (-22.26 S, 131.80 E; 100 km north from the centre of site C) (August, October, November and December 1997).
# APPENDICES

## Appendix 3. Cattle herd structure and management at sites.

<table>
<thead>
<tr>
<th></th>
<th>site A</th>
<th>site B</th>
<th>site C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Enterprise</td>
<td>Breeding and fattening of store cattle, plus holding of agistment cattle (Low 1978b).</td>
<td>Breeding and fattening of store cattle.</td>
<td>Breeding and fattening of store cattle.</td>
</tr>
<tr>
<td>Breed of cattle</td>
<td>Shorthorn cows</td>
<td>Poll Hereford cows</td>
<td>Shorthorn x Santa Gertrudis cows</td>
</tr>
<tr>
<td></td>
<td>Shorthorn bulls</td>
<td>Poll Hereford bulls</td>
<td>Brahman bulls</td>
</tr>
<tr>
<td>Cattle class</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cows:</td>
<td>- 1–10 years old;</td>
<td>- 1.5–12 years old;</td>
<td>- 2–10 years old;</td>
</tr>
<tr>
<td>- source</td>
<td>Low &amp; Wood c. 1980);</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>- recruited heifers sourced from retained weaner heifers (1972,</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Steers</td>
<td>Low numbers of store steers (6–18 months old, up to 23 head) retained</td>
<td>Low numbers of store steers (18–24 months old; over 200 head) during</td>
<td>Increasing numbers of store steers (12–18 months old, up to 214 head)</td>
</tr>
<tr>
<td>Calves and weaner cattle</td>
<td>No weaning in first year (1970), but thereafter, store steers moved to</td>
<td>Weaned calves trucked to another paddock, at an age determined by seasonal conditions.</td>
<td>Weaned calves trucked to another paddock.</td>
</tr>
<tr>
<td></td>
<td>another paddock (Low 1978b).</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
## Appendix 3. (continued)

<table>
<thead>
<tr>
<th>Herd bulls</th>
<th>site A</th>
<th>site B</th>
<th>site C</th>
</tr>
</thead>
<tbody>
<tr>
<td>- age</td>
<td>- recruited from ‘exceptional’ station-bred bulls (yearlings) and interstate ‘registered Shorthorn’ bulls (2–4 years old) (Low 1978b)(^1).</td>
<td>- 2–13 years old; - recruited from station stud and interstate Poll Hereford studs (Coventry, Taylor &amp; Pinch 2002a).</td>
<td>- 3–8 years old (NT-DPI&amp;F 1995c); - recruited from studs.</td>
</tr>
<tr>
<td>- source</td>
<td>- recruited from ‘exceptional’ station-bred bulls (yearlings) and interstate ‘registered Shorthorn’ bulls (2–4 years old) (Low 1978b)(^1).</td>
<td>- recruited from station stud and interstate Poll Hereford studs (Coventry, Taylor &amp; Pinch 2002a).</td>
<td>- recruited from studs.</td>
</tr>
</tbody>
</table>

### Herd management

| Mating system | Continuous | Continuous | Continuous |

| Drought management strategies | - destocking of excess cattle during drought (sale of older cows; agistment of cows with calves) (Low 1978b; Low, Hodder & Abel 1978). | - destocking (sale) of older cows; - early weaning; - water reticulated to new (ungrazed) areas to extend grazing. | - destocking of excess cattle (sale of older cows and cull cows) if no effective, summer rain by February. |

| Supplementation | A urea-molasses-salt supplement fed as a loose-mix in troughs or as lick blocks during drought periods (Low 1978b). | Year-round P and urea supplementation with commercial lick blocks at livestock waters. | Year-round P and urea supplementation supplied by nutrient supplement in water medication (Hill 2003). |

| Control of (feral dog) predation | Nil recorded; however, dingo predation (was) noted when natural food (became) scarce (Low 1978b). | Combined area (1080 poison) baiting program as required, plus extra vigilance for at-risk calves during musters and yard work. | Combined area (1080 poison) baiting program as required; however, no (feral dog) tracks were seen during good seasons. |

---

\(^1\) Muster of bulls may be incomplete (Low 1978b).
## Appendix 3. (continued)

<table>
<thead>
<tr>
<th></th>
<th>site A</th>
<th>site B</th>
<th>site C</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Cattle handling</strong></td>
<td>- biannual/triannual musters; - trapping on water, plus mustering with horses and motor bikes; mustering efficiency was poorer (90%) during good seasonal conditions (1973–1975) (WA Low 2003, pers. comm.); - branding, castrating, weaning, turning off fat steers and cull cows, plus disease testing (BTEC) (Low 1978b; Low &amp; Wood c. 1980).</td>
<td>- biannual musters; - trapping on water, plus mustering with vehicle, horse and helicopter; mustering efficiency was poorest (&lt; 90%) during rain (early 1992); - branding, castration, weaning plus turning off steers and cull cattle.</td>
<td>- biannual/triannual musters; - trapping on water, plus mustering with vehicle, motor bike and helicopter (when surface water persisted); mustering efficiency was poor (80%) during good seasonal conditions (2000, 2001) (Hill 2003, p.15); - branding, castrating, weaning, speying and turning off cull cattle.</td>
</tr>
<tr>
<td><strong>Yard musters</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- frequency</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- method and efficiency</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- routine activity</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Culling</strong></td>
<td>- cows, for excessive age (at 8–10 years old) or poor reproductive performance (non-productive) (Low 1978b); - herd bulls, for excessive age or behavioural problems (WA Low 2006, pers. comm.).</td>
<td>- cows, if with visible physical faults, undesirable temperament, or poor reproductive performance; - herd bulls, if with physical problems, including geriatric degeneration.</td>
<td>- cows, if non-lactating and non-pregnant; - herd bull culling not recorded.</td>
</tr>
<tr>
<td><strong>Treatment and prophylactic procedures</strong></td>
<td>- no prophylactic procedures were recorded; disease and parasites were not (considered) a serious problem (Low 1978b).</td>
<td>- vaccination against botulism and vibriosis; - external parasiticide treatment (Tiguvon®) under poor seasonal conditions.</td>
<td>- vaccination against botulism for steers from properties with known botulism deaths; - no prophylactic procedures recorded.</td>
</tr>
<tr>
<td>- routine</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- seasonal</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
APPENDICES

Appendix 4. Number of cows, herd bulls and calves related to annual calf production at sites.

### site A

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Muster reference</td>
<td>01</td>
<td>02</td>
<td>03</td>
<td>04</td>
<td>05</td>
</tr>
<tr>
<td>Mated cows¹</td>
<td>293</td>
<td>276</td>
<td>258</td>
<td>311</td>
<td>331</td>
</tr>
<tr>
<td>Herd bulls²</td>
<td>26</td>
<td>22</td>
<td>18</td>
<td>20</td>
<td>16³</td>
</tr>
<tr>
<td>Branded calves⁴</td>
<td>149</td>
<td>109</td>
<td>145</td>
<td>238</td>
<td>299</td>
</tr>
<tr>
<td>Unweaned calves⁵</td>
<td>64</td>
<td>32</td>
<td>40</td>
<td>nil</td>
<td>56</td>
</tr>
</tbody>
</table>

¹ Number of mustered cows (Low 1978b) that were mated to produce the branded calves in the current financial year, and the unweaned calves (6–12 months old) in the consecutive calendar year; mustering percentage not taken into consideration. The source of data on the number of mated cows is summarised in Table 3-5.

² Number of herd bulls to mate cows, based on number weighed from paddock (Low & Wood c. 1980) and ‘returned to paddock following musters’ (Low 1978b).

³ Low number of reported bulls when the efficiency of bull mustering was reduced by obstinate bull behaviour and surface waters during a good season (1974/75) (WA Low 2006, pers. comm.).

⁴ Numbers of branded calves, with consideration of reported ‘calves branded as determined from Station records’ and ‘yearlings calved’ (Low 1978b).

⁵ Numbers of unweaned calves (6–12 months old) sequentially weighed (Low & Wood 1979).

⁶ Number of cows (all ages) mated to produce the branded calves in the current financial year, and the weaned calves in the consecutive calendar year. The source of data on the number of mated cows is summarised in Table 3-5.

⁷ Number of herd bulls to mate cows.

### site B

<table>
<thead>
<tr>
<th></th>
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<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Muster reference</td>
<td>01</td>
<td>02</td>
<td>03</td>
<td>04</td>
<td>05</td>
</tr>
<tr>
<td>Mated cows⁶</td>
<td>1,141</td>
<td>1,031</td>
<td>1,088</td>
<td>1,009</td>
<td>1,153</td>
</tr>
<tr>
<td>Herd bulls⁷</td>
<td>53</td>
<td>60</td>
<td>63</td>
<td>55</td>
<td>47</td>
</tr>
<tr>
<td>Branded calves</td>
<td>538</td>
<td>701</td>
<td>333</td>
<td>565</td>
<td>413</td>
</tr>
<tr>
<td>Weaned calves</td>
<td>884</td>
<td>420</td>
<td>584</td>
<td>477</td>
<td>520</td>
</tr>
</tbody>
</table>

¹ Number of mustered cows (Low 1978b) that were mated to produce the branded calves in the current financial year, and the unweaned calves (6–12 months old) in the consecutive calendar year; mustering percentage not taken into consideration. The source of data on the number of mated cows is summarised in Table 3-5.

² Number of herd bulls to mate cows, based on number weighed from paddock (Low & Wood c. 1980) and ‘returned to paddock following musters’ (Low 1978b).

³ Low number of reported bulls when the efficiency of bull mustering was reduced by obstinate bull behaviour and surface waters during a good season (1974/75) (WA Low 2006, pers. comm.).

⁴ Numbers of branded calves, with consideration of reported ‘calves branded as determined from Station records’ and ‘yearlings calved’ (Low 1978b).

⁵ Numbers of unweaned calves (6–12 months old) sequentially weighed (Low & Wood 1979).

⁶ Number of cows (all ages) mated to produce the branded calves in the current financial year, and the weaned calves in the consecutive calendar year. The source of data on the number of mated cows is summarised in Table 3-5.

⁷ Number of herd bulls to mate cows.
Appendix 4.  *(continued)*

site C

<table>
<thead>
<tr>
<th></th>
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</tr>
</thead>
<tbody>
<tr>
<td>Muster reference</td>
<td>01</td>
<td>02</td>
<td>03</td>
<td>04</td>
</tr>
<tr>
<td>Mated cows$^1$</td>
<td>159</td>
<td>142</td>
<td>124</td>
<td></td>
</tr>
<tr>
<td>Herd bulls$^2$</td>
<td>13</td>
<td>10</td>
<td>10</td>
<td></td>
</tr>
<tr>
<td>Branded calves</td>
<td>n/a</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Weaned calves</td>
<td>nil</td>
<td>66</td>
<td>23</td>
<td>49</td>
</tr>
</tbody>
</table>

$^1$ Number of cows (all ages) mated to produce the weaned calves in the consecutive calendar year. The source of data on the number of mated cows is summarised in Table 3-5.

$^2$ Number of herd bulls to mate cows.
APPENDICES

Appendix 5. Range of cattle numbers and stocking densities at sites.

<table>
<thead>
<tr>
<th>Location</th>
<th>site A</th>
<th>site B</th>
<th>site C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Area stocked</td>
<td>180 km$^2$</td>
<td>500 km$^2$</td>
<td>53 km$^2$</td>
</tr>
<tr>
<td>Carrying capacity$^1$</td>
<td>0.5–8 head/km$^2$</td>
<td>0.5–8 head/km$^2$</td>
<td>0.5–4 head/km$^2$</td>
</tr>
</tbody>
</table>

**Minimum stocking**

<table>
<thead>
<tr>
<th></th>
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</thead>
<tbody>
<tr>
<td>Head$^a$</td>
<td>av. wt (kg)$^b$</td>
<td>AE</td>
<td>head</td>
</tr>
<tr>
<td>Weaner-age calves</td>
<td>68</td>
<td>148$^6$</td>
<td>22</td>
</tr>
<tr>
<td>Cows</td>
<td>168</td>
<td>329</td>
<td>173</td>
</tr>
<tr>
<td>Steers</td>
<td>0</td>
<td>62$^7$</td>
<td>500$^7$</td>
</tr>
<tr>
<td>Herd bulls</td>
<td>10</td>
<td>477</td>
<td>11</td>
</tr>
<tr>
<td>Total</td>
<td>246</td>
<td>206</td>
<td>1,268</td>
</tr>
</tbody>
</table>

Calculated (minimum) annual stocking density$^{11}$ of area

| | 1.15 AE/km$^2$ | 3.02 AE/km$^2$ | 3.84 AE/km$^2$ |

$^1$ General recommendations have been made for the predominant pasture-types (Perry 1962, p.248).

$^2$ The original beef cattle project at site B commenced on 540 km$^2$, and after drought (late 1994) continued on only 500 km$^2$ (Westside (S)).

$^3$ The original beef cattle project at site C commenced on 63 km$^2$ (Hill paddock), and continued on 53 km$^2$ (Camel paddock) at the end of 1999.

$^4$ Cattle returned to the paddock after muster (Low 1978b); numbers do not take account of mustering efficiency (≥95%) (WA Low 2003, pers. comm.).

$^5$ Reported average weight of young-to-aged cows and herd bulls (Low & Wood c. 1980).

$^6$ No data recorded; average weaner weight estimated as 45% of the average cow weight.

$^7$ Number of steers mustered from site B.

$^8$ No data recorded; average steer weight estimated from comparable (age, area) steer weights.

$^9$ Number of steers released into site C.

$^{10}$ No data recorded; average bull weight estimated.

$^{11}$ Stocking density is measured in animal (cattle) equivalents (AE) per square kilometre. One AE describes the annual feed requirement to maintain one 450-kg dry cow or steer, so the feed requirements of other cattle classes are compared with this (QDPIF 2005). For the table, cows are assumed to be lactating or pregnant, and thus requiring an extra 0.3 AE.
Appendix 5. (continued)

<table>
<thead>
<tr>
<th>Location</th>
<th>site A</th>
<th>site B</th>
<th>site C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Area stocked</td>
<td>180 km²</td>
<td>500 km²</td>
<td>53 km²</td>
</tr>
<tr>
<td>Carrying capacity</td>
<td>0.5–8 head/km²</td>
<td>0.5–8 head/km²</td>
<td>0.5–4 head/km²</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Maximum stocking</th>
</tr>
</thead>
<tbody>
<tr>
<td>Year</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>Weaner-age calves</td>
</tr>
<tr>
<td>Cows</td>
</tr>
<tr>
<td>Steers</td>
</tr>
<tr>
<td>Herd bulls</td>
</tr>
<tr>
<td>Total</td>
</tr>
</tbody>
</table>

Calculated (maximum) annual stocking density¹¹ of area

| | 4.29 AE/km² | 4.01 AE/km² | 8.60 AE/km² |

¹ General recommendations have been made for the predominant pasture-types (Perry 1962, p.248).
² Cattle returned to the paddock after muster (Low 1978b); numbers do not take account of mustering efficiency (≥95%) (WA Low 2003, pers. comm.).
³ Reported average weight of young-to-aged cows, herd bulls and steers (Low & Wood c. 1980).
⁴ No data recorded; average weaner weight estimated as 45% of the average cow weight.
⁵ Number of steers mustered from site A.
⁶ No data recorded; average steer weight estimated from comparable (age, area) steer weights.
⁷ No data recorded; average bull weight estimated.
⁸ Number of steers released into site C.
⁹ Average recorded density of cattle on preferred pasture-types was as high as 40 head/km² for short periods (Low 1978b).
¹⁰ Stocking density is measured in animal (cattle) equivalents (AE) per square kilometre.
Appendix 6. Gantt charts: number of cows in paddock at sites.

site A

Cows that are removed, retained or absent from muster at site A have not been directly reported\(^1,2,3,4\).

\(^1\) Net number of removed cows was based on the reduced number returned to paddock after pregnancy testing at the previous muster (Low & Wood c. 1980), plus the number sent to agistment during drought (November 1971) (Low 1978b), plus the heifers not retained after introduction in December 1974 (Low 1978b).

\(^2\) Net number of new cows was based on the extra number returned to paddock after pregnancy testing at the previous muster (Low 1978b; Low & Wood c. 1980).

\(^3\) Number of new heifers was based on the number mustered and pregnancy tested that exceeded the number mustered and weighed (Low & Wood c. 1980), plus the number of heifers retained after introduction in December 1974 (Low 1978b).

\(^4\) Number of cows absent from muster was not included. The estimated 95% mustering efficiency (WA Low 2003, pers. comm.) was possibly reduced to 90% in 1974/75.
Appendix 6. (continued)

site B

Number of Cows - site B

site C

Number of Cows - site C
APPENDICES

Appendix 7. Number of mustered cows, including those removed (by culling or mortality) and those recruited for sites.

<table>
<thead>
<tr>
<th></th>
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<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Muster reference</td>
<td>01</td>
<td>02</td>
<td>03</td>
<td>04</td>
<td>05</td>
<td>06</td>
</tr>
<tr>
<td>Number of cows per muster</td>
<td>196</td>
<td>285</td>
<td>266</td>
<td>103</td>
<td>183</td>
<td>230</td>
<td>208</td>
</tr>
<tr>
<td>Number of cows removed</td>
<td>n/a</td>
<td>n/a</td>
<td>n/a</td>
<td>n/a</td>
<td>n/a</td>
<td>n/a</td>
<td>n/a</td>
</tr>
<tr>
<td>young-to-aged cow (&gt; 2.5 years old)</td>
<td>(0)</td>
<td>(9)</td>
<td>(26)</td>
<td>(99)</td>
<td>(15)</td>
<td>(0)</td>
<td>(0)</td>
</tr>
<tr>
<td>heifer (&lt; 2.5 years old)</td>
<td>(n/a)</td>
<td>(n/a)</td>
<td>(n/a)</td>
<td>(n/a)</td>
<td>(n/a)</td>
<td>(n/a)</td>
<td>(n/a)</td>
</tr>
<tr>
<td>Number of cows recorded dead in paddock</td>
<td>(n/a)</td>
<td>(n/a)</td>
<td>(n/a)</td>
<td>(n/a)</td>
<td>(n/a)</td>
<td>(n/a)</td>
<td>(n/a)</td>
</tr>
<tr>
<td>Number of mustered cows, absent from next 5 musters</td>
<td>(n/a)</td>
<td>(n/a)</td>
<td>(n/a)</td>
<td>(n/a)</td>
<td>(n/a)</td>
<td>(n/a)</td>
<td>(n/a)</td>
</tr>
<tr>
<td>New breeders</td>
<td>97</td>
<td>n/a</td>
<td>n/a</td>
<td>n/a</td>
<td>n/a</td>
<td>n/a</td>
<td>n/a</td>
</tr>
<tr>
<td>young-to-aged cow (&gt; 2.5 years old)</td>
<td>(97)</td>
<td>(0)</td>
<td>(0)</td>
<td>(0)</td>
<td>(0)</td>
<td>(3)</td>
<td>(50)</td>
</tr>
<tr>
<td>heifer (&lt; 2.5 years old)</td>
<td>(0)</td>
<td>(0)</td>
<td>(26)</td>
<td>(0)</td>
<td>(41)</td>
<td>(35)</td>
<td>(15)</td>
</tr>
<tr>
<td>Recruited cows</td>
<td>n/a</td>
<td>n/a</td>
<td>n/a</td>
<td>n/a</td>
<td>n/a</td>
<td>n/a</td>
<td>n/a</td>
</tr>
</tbody>
</table>

1. Except for a partial muster to removed cows for drought agistment at the end of 1971, the number of mustered cows was the number reported for pregnancy testing (Low, Müller & Dudzinski 1980).
2. The total number of removed cows was not reported—extrapolated nett numbers have been given, based on the numbers weighed, pregnancy tested (Low & Wood c. 1980) and returned to the paddock (Low 1978; Low, Müller & Dudzinski 1980).
3. The total number of dead cows seen in the paddock was not reported.
4. The total number of cows absent from consecutive musters was not reported.
5. Up to 100 head of cows or heifers were introduced (Low, Müller & Dudzinski 1980) at both musters 01 and 10 (WA Low 2006, pers. comm.).
## Appendix 7. (continued)

### site B

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Muster reference</strong></td>
<td>01</td>
<td>02</td>
<td>03</td>
<td>04</td>
<td>05</td>
</tr>
<tr>
<td><strong>Number of cows at muster</strong></td>
<td>1,056</td>
<td>968</td>
<td>885</td>
<td>1,033</td>
<td>830</td>
</tr>
<tr>
<td><strong>Number of cows removed</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>young-to-aged cow (&gt; 2.5 years old)</td>
<td>1</td>
<td>130</td>
<td>21</td>
<td>361</td>
<td>14</td>
</tr>
<tr>
<td>heifer (&lt; 2.5 years old)</td>
<td>(1)</td>
<td>(121)</td>
<td>(21)</td>
<td>(361)</td>
<td>(12)</td>
</tr>
<tr>
<td>(0)</td>
<td>(9)</td>
<td>(0)</td>
<td>(0)</td>
<td>(2)</td>
<td>(3)</td>
</tr>
<tr>
<td><strong>Number of cows recorded dead in paddock</strong></td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td><strong>Number of mustered cows, absent from next 5 musters</strong></td>
<td>16</td>
<td>15</td>
<td>10</td>
<td>18</td>
<td>n/a</td>
</tr>
<tr>
<td><strong>Number of mustered cows, returned to paddock</strong></td>
<td>1,055</td>
<td>838</td>
<td>864</td>
<td>672</td>
<td>816</td>
</tr>
<tr>
<td><strong>New-tagged cows per muster</strong></td>
<td>174</td>
<td>20</td>
<td>31</td>
<td>171</td>
<td>124</td>
</tr>
<tr>
<td>young-to-aged cow (&gt; 2.5 years old)</td>
<td>(0)</td>
<td>(0)</td>
<td>(28)</td>
<td>(93)</td>
<td>(79)</td>
</tr>
<tr>
<td>heifer (&lt; 2.5 years old)</td>
<td>(174)</td>
<td>(20)</td>
<td>(3)</td>
<td>(78)</td>
<td>(45)</td>
</tr>
<tr>
<td><strong>Recruited cows (extrapolated)</strong></td>
<td>194</td>
<td>181</td>
<td>307</td>
<td>74</td>
<td>237</td>
</tr>
</tbody>
</table>

1. ‘Dead cows’ included those either found dead (18 head) or euthanased for medical reasons (5 head).
2. Of the cows absent from the next 5 musters, one was of unknown age and two that reappeared at the end of the primary beef cattle project were identified.
3. The number of recruited cows has been extrapolated from the number of new-tagged cows, minus the estimated number of lost identification (numbered ear-tags) (loss accumulating at an estimated 2 to 0.5% per year). Over 5 years the extrapolated number of recruited cows (993 head) approximated the sum of: paddocked heifers in the first financial year (191 head); heifers that were believed to have missed the weaning musters over the last four financial years (119 head); plus cows introduced with calves-at-foot. There was a total of 641 cows introduced in 1992/93 (180 head), 1993/94 (130 head), 1994/95 (92 head) and 1995/96 (239 head).
Appendix 7.  (continued)

site C

<table>
<thead>
<tr>
<th>Financial year</th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Muster reference</td>
<td>01</td>
<td>02</td>
<td>03</td>
<td>04</td>
<td>05</td>
<td>06</td>
<td>07</td>
<td>08</td>
</tr>
<tr>
<td>Number of cows per muster</td>
<td>159</td>
<td>152</td>
<td>147</td>
<td>289</td>
<td>99</td>
<td>114</td>
<td>108</td>
<td>87</td>
</tr>
<tr>
<td>Number of cows removed</td>
<td>(0)</td>
<td>0</td>
<td>0</td>
<td>147</td>
<td>0</td>
<td>0</td>
<td>2</td>
<td>0</td>
</tr>
<tr>
<td>young-to-aged cow (&gt; 2.5 years old)</td>
<td>(0)</td>
<td>(0)</td>
<td>(0)</td>
<td>(147)</td>
<td>(0)</td>
<td>(0)</td>
<td>(2)</td>
<td>(0)</td>
</tr>
<tr>
<td>heifer (&lt; 2.5 years old)</td>
<td>(0)</td>
<td>(0)</td>
<td>(0)</td>
<td>(0)</td>
<td>(0)</td>
<td>(0)</td>
<td>(0)</td>
<td>(0)</td>
</tr>
<tr>
<td>Number of cows recorded dead in paddock</td>
<td>0</td>
<td>2+ (?)</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Number of mustered cows, absent from next 5 musters</td>
<td>4</td>
<td>4</td>
<td>4</td>
<td>n/a</td>
<td>n/a</td>
<td>n/a</td>
<td>n/a</td>
<td>n/a</td>
</tr>
<tr>
<td>Number of mustered cows, returned to paddock</td>
<td>159</td>
<td>152</td>
<td>147</td>
<td>142</td>
<td>99</td>
<td>114</td>
<td>106</td>
<td>87</td>
</tr>
<tr>
<td>New-tagged cows</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>142</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>young-to-aged cow (&gt; 2.5 years old)</td>
<td>(0)</td>
<td>(0)</td>
<td>(0)</td>
<td>(142)</td>
<td>(0)</td>
<td>(1)</td>
<td>(0)</td>
<td>(1)</td>
</tr>
<tr>
<td>heifer (&lt; 2.5 years old)</td>
<td>(0)</td>
<td>(0)</td>
<td>(0)</td>
<td>(0)</td>
<td>(0)</td>
<td>(0)</td>
<td>(0)</td>
<td>(0)</td>
</tr>
<tr>
<td>Recruited cows</td>
<td>0</td>
<td>144</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

1 More than two head of dead cattle were reported in the paddock with the mixed-age cows in 1998 or 1999 (Hill 2003, p.9), but the year of death and identity of the cattle was not confirmed. If the identity had been known, this may have reduced the ‘number of mustered cows, absent from next 5 musters’.

2 As required by the design of the primary beef cattle project, the mixed-age cow group was replaced by a first-calving heifer group in 1999/2000. Two young cows in this recruited group were yarded for ear-tagging in subsequent years.
### Appendix 8. Type and delegation of primary beef cattle project activity at sites.

<table>
<thead>
<tr>
<th>Location</th>
<th>site A</th>
<th>site B</th>
<th>site C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Project activity</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Individual cattle identification</td>
<td>Individual ear-tags (Low &amp; Wood c. 1980) and age (year) brands (WA Low 2006, pers. comm.).</td>
<td>Double-tagging with plastic numbered ear-tags. Bulls were also identified by ear-tattoos, fire-brands and freeze-brands to accommodate increased risk of ear-tag loss.</td>
<td>Single-tagging with plastic numbered, coloured ear-tags, with extra reference ear-tags in latter years.</td>
</tr>
<tr>
<td>Activity at musters</td>
<td>Information was collected (Low &amp; Wood c. 1980) at 13 musters during a 5½-year period (Low, Dudzinski &amp; Müller 1981), including a partial muster during drought (agistment cattle, late 1971).</td>
<td>Information and samples were collected at ten musters during a 5-year period, including a muster limited by rain (early 1992), and default mustering (trapping only) during drought (small cattle mobs, late 1994).</td>
<td>Information and samples were collected at eight musters during a 4-year period, including musters limited by surface water (2000, 2001).</td>
</tr>
<tr>
<td>Activity at surveys</td>
<td>- 108 aerial surveys (Low, Müller &amp; Dudzinski 1980) and 50 field observations (24-hour watch for up to four days) (Low, Hodder &amp; Abel 1978) at fortnightly intervals; - 13 monthly faecal collections (Low et al. 1973); - information and sample collection (for contemporary studies).</td>
<td>- 17 field and yard surveys, greater than six weeks before or after musters; - information and sample collection.</td>
<td>nil</td>
</tr>
</tbody>
</table>
**APPENDICES**

**Appendix 8. (continued)**

<table>
<thead>
<tr>
<th>Location</th>
<th>site A</th>
<th>site B</th>
<th>site C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Delegation for data and sample collection</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Data recording</td>
<td>CSIRO Officer</td>
<td>Property Staff</td>
<td>NTG Animal Production Officer</td>
</tr>
<tr>
<td>Numbers of branded calves</td>
<td>Cattle Manager (Low 1978b)</td>
<td>Cattle Manager</td>
<td>Cattle Manager</td>
</tr>
<tr>
<td>Numbers of weaned calves</td>
<td>Cattle Manager (Low 1978b)</td>
<td>Cattle Manager</td>
<td>Property Staff</td>
</tr>
<tr>
<td>Cattle gender and identification</td>
<td>CSIRO Officer</td>
<td>Property Staff</td>
<td>Property Staff</td>
</tr>
<tr>
<td>Cattle age</td>
<td>CSIRO Officer</td>
<td>Property Staff</td>
<td>Property Staff</td>
</tr>
<tr>
<td>Decisions for cattle culling</td>
<td>Cattle Manager</td>
<td>Cattle Manager</td>
<td>NTG Advisory Officer</td>
</tr>
<tr>
<td>Cattle liveweight</td>
<td>CSIRO Officer</td>
<td>Property Staff</td>
<td>NTG Animal Production Officer</td>
</tr>
<tr>
<td>Cattle frame score</td>
<td>nil</td>
<td>Property Staff</td>
<td>nil</td>
</tr>
<tr>
<td>Cattle body condition score</td>
<td>Cattle Manager, CSIRO Officer</td>
<td>NTG Animal Health Officer</td>
<td>NTG Animal Production Officer</td>
</tr>
<tr>
<td>Cow pregnancy status</td>
<td>CSIRO Officer</td>
<td>NTG Animal Health Officer</td>
<td>NTG Advisory Officer</td>
</tr>
<tr>
<td>Cow lactation status</td>
<td>CSIRO Officer</td>
<td>Property Staff</td>
<td>NTG Advisory Officer</td>
</tr>
<tr>
<td>Bull prepuce inspection</td>
<td>nil</td>
<td>NTG Animal Health Officer</td>
<td>nil</td>
</tr>
<tr>
<td>Bull seminal vesicle palpation</td>
<td>nil</td>
<td>NTG Animal Health Officer</td>
<td>nil</td>
</tr>
<tr>
<td>Pasture assessment</td>
<td>CSIRO Officer</td>
<td>NTG Animal Health Officer</td>
<td>nil</td>
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<tr>
<td>Rainfall</td>
<td>CSIRO Officer</td>
<td>Cattle Manager</td>
<td>Cattle Manager</td>
</tr>
<tr>
<td>Temperature</td>
<td>Australian Bureau of Meteorology (plus CSIRO Officer)</td>
<td>Australian Bureau of Meteorology (plus Jindalee Defence Base)</td>
<td>Australian Bureau of Meteorology</td>
</tr>
<tr>
<td>Cattle management details</td>
<td>Cattle Manager, CSIRO Officer</td>
<td>Property Staff</td>
<td>Property Staff, NTG Advisory Officer</td>
</tr>
<tr>
<td>Faecal sample collection</td>
<td>CSIRO Officer</td>
<td>NTG Animal Health Officer</td>
<td>NTG Advisory Officer</td>
</tr>
<tr>
<td>Blood sample collection</td>
<td>nil</td>
<td>NTG Animal Health Officer</td>
<td>NTG Animal Production Officer</td>
</tr>
<tr>
<td>Preputial scraping collection</td>
<td>nil</td>
<td>NTG Animal Health Officer</td>
<td>nil</td>
</tr>
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### Appendix 9. Muster dates at sites.

#### site A

<table>
<thead>
<tr>
<th>Date</th>
<th>Muster number</th>
<th>Yard</th>
<th>Paddock area</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jul-70</td>
<td>01</td>
<td>A.1</td>
<td>(whole)</td>
<td></td>
</tr>
<tr>
<td>Feb-71</td>
<td>02</td>
<td>A.1</td>
<td>(whole)</td>
<td></td>
</tr>
<tr>
<td>Aug-71</td>
<td>03</td>
<td>A.1</td>
<td>(whole)</td>
<td></td>
</tr>
<tr>
<td>Nov-71</td>
<td>04</td>
<td>A.1</td>
<td>(part)</td>
<td>destock¹</td>
</tr>
<tr>
<td>Jan-72</td>
<td>05</td>
<td>A.1</td>
<td>(whole)</td>
<td></td>
</tr>
<tr>
<td>May-72</td>
<td>06</td>
<td>A.1</td>
<td>(whole)</td>
<td></td>
</tr>
<tr>
<td>Oct-72</td>
<td>07</td>
<td>A.1</td>
<td>(whole)</td>
<td></td>
</tr>
<tr>
<td>Jul-73</td>
<td>08</td>
<td>A.1</td>
<td>(whole)</td>
<td></td>
</tr>
<tr>
<td>Nov-73</td>
<td>09</td>
<td>A.1</td>
<td>(whole)</td>
<td></td>
</tr>
<tr>
<td>May-74</td>
<td>10</td>
<td>A.1</td>
<td>(whole)</td>
<td></td>
</tr>
<tr>
<td>May-74</td>
<td>11</td>
<td>A.1</td>
<td>(whole)</td>
<td>no muster data</td>
</tr>
<tr>
<td>Dec-74</td>
<td>12</td>
<td>A.1</td>
<td>(whole)</td>
<td></td>
</tr>
<tr>
<td>Jun-75</td>
<td>13</td>
<td>A.1</td>
<td>(whole)</td>
<td></td>
</tr>
<tr>
<td>Dec-75</td>
<td>14</td>
<td>A.1</td>
<td>(whole)</td>
<td></td>
</tr>
</tbody>
</table>

¹ Partial muster (agistment cattle) during drought (Low 1978b).

#### site B

<table>
<thead>
<tr>
<th>Date</th>
<th>Muster number</th>
<th>Yard</th>
<th>Paddock area</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>4-Sep-91</td>
<td>01</td>
<td>B.1</td>
<td>(S)-range</td>
<td></td>
</tr>
<tr>
<td>11-Sep-91</td>
<td>01</td>
<td>B.2</td>
<td>(S)-central</td>
<td></td>
</tr>
<tr>
<td>3-Nov-91</td>
<td>01</td>
<td>B.3</td>
<td>(S)-west</td>
<td></td>
</tr>
<tr>
<td>9-Nov-91</td>
<td>01</td>
<td>B.4</td>
<td>(N)</td>
<td></td>
</tr>
<tr>
<td>15-May-92</td>
<td>02</td>
<td>B.1</td>
<td>(S)-range</td>
<td></td>
</tr>
<tr>
<td>1-Jun-92</td>
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<td>2-Jun-92</td>
<td>02</td>
<td>B.3</td>
<td>(S)-west</td>
<td></td>
</tr>
<tr>
<td>15-Apr-92</td>
<td>02</td>
<td>B.4</td>
<td>(N)</td>
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</tr>
<tr>
<td>4-Sep-92</td>
<td>03</td>
<td>B.1</td>
<td>(S)-range</td>
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</tr>
<tr>
<td>17-Sep-92</td>
<td>03</td>
<td>B.2</td>
<td>(S)-central</td>
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<tr>
<td>18-Sep-92</td>
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<td>(S)-west</td>
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</tr>
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<td>14-Sep-92</td>
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<td>B.4</td>
<td>(N)</td>
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</tr>
<tr>
<td>22-Mar-93</td>
<td>04</td>
<td>B.1</td>
<td>(S)-range</td>
<td></td>
</tr>
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<td>2-Apr-93</td>
<td>04</td>
<td>B.2</td>
<td>(S)-central</td>
<td></td>
</tr>
<tr>
<td>14-Apr-93</td>
<td>04</td>
<td>B.3</td>
<td>(S)-west</td>
<td></td>
</tr>
<tr>
<td>20-Apr-93</td>
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<td>(N)</td>
<td></td>
</tr>
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<td>05</td>
<td>B.1</td>
<td>(S)-range</td>
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</tr>
<tr>
<td>10-Sep-93</td>
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<td>(S)-central</td>
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</tr>
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<td>10-Sep-93</td>
<td>05</td>
<td>B.3</td>
<td>(S)-west</td>
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</tr>
<tr>
<td>25-Oct-93</td>
<td>05</td>
<td>B.4</td>
<td>(N)</td>
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</table>
**APPENDICES**

**Appendix 9. (continued)**

### site B

<table>
<thead>
<tr>
<th>Date</th>
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<th>Yard</th>
<th>Paddock area</th>
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</tr>
</thead>
<tbody>
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<td></td>
</tr>
<tr>
<td>15-Apr-94</td>
<td>06</td>
<td>B.2</td>
<td>(S)-central</td>
<td></td>
</tr>
<tr>
<td>14-Apr-94</td>
<td>06</td>
<td>B.3</td>
<td>(S)-west</td>
<td></td>
</tr>
<tr>
<td>17-Apr-94</td>
<td>06</td>
<td>B.4</td>
<td>(N)</td>
<td>destock(^1)</td>
</tr>
<tr>
<td></td>
<td>07</td>
<td></td>
<td></td>
<td><strong>no muster(^2)</strong></td>
</tr>
<tr>
<td>27-Apr-95</td>
<td>08</td>
<td>B.1</td>
<td>(S)-range</td>
<td></td>
</tr>
<tr>
<td>4-May-95</td>
<td>08</td>
<td>B.2</td>
<td>(S)-central</td>
<td></td>
</tr>
<tr>
<td>4-May-95</td>
<td>08</td>
<td>B.3</td>
<td>(S)-west</td>
<td></td>
</tr>
<tr>
<td>25-Aug-95</td>
<td>09</td>
<td>B.1</td>
<td>(S)-range</td>
<td></td>
</tr>
<tr>
<td>1-Sep-95</td>
<td>09</td>
<td>B.2</td>
<td>(S)-central</td>
<td></td>
</tr>
<tr>
<td>31-Aug-95</td>
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<td>B.3</td>
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<tr>
<td>29-Mar-96</td>
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<td>B.1</td>
<td>(S)-range</td>
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</tr>
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<td>10-Apr-96</td>
<td>10</td>
<td>B.2</td>
<td>(S)-central</td>
<td></td>
</tr>
<tr>
<td>9-Apr-96</td>
<td>10</td>
<td>B.3</td>
<td>(S)-west</td>
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</table>

### site C\(^3\)

<table>
<thead>
<tr>
<th>Date</th>
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<tbody>
<tr>
<td>14-Dec-98</td>
<td>01</td>
<td>C.1</td>
<td>(E)</td>
<td></td>
</tr>
<tr>
<td>14-Apr-99</td>
<td>02</td>
<td>C.1</td>
<td>(E)</td>
<td></td>
</tr>
<tr>
<td>17-Aug-99</td>
<td>03</td>
<td>C.1</td>
<td>(E)</td>
<td></td>
</tr>
<tr>
<td>26-Oct-99</td>
<td>04</td>
<td>C.1</td>
<td>(E)</td>
<td>destock</td>
</tr>
<tr>
<td>31-May-00</td>
<td>05</td>
<td>C.1</td>
<td>(E)</td>
<td>destock(^4)</td>
</tr>
<tr>
<td>28-Oct-99</td>
<td>04</td>
<td>C.1</td>
<td>(W)</td>
<td>recruited cattle</td>
</tr>
<tr>
<td>30-May-00</td>
<td>05</td>
<td>C.1</td>
<td>(W)</td>
<td></td>
</tr>
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<td>14-Nov-00</td>
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<td>C.1</td>
<td>(W)</td>
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<td>28-May-01</td>
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<td>C.1</td>
<td>(W)</td>
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<td>07-Nov-01</td>
<td>08</td>
<td>C.1</td>
<td>(W)</td>
<td></td>
</tr>
</tbody>
</table>

---

\(^1\) No cattle data were collected from Yard B.4 and associated paddock area for the remainder of the primary beef cattle project.

\(^2\) Surveys (17-Aug-94, 20-Oct-94), plus weaning figures from yard-trapped cows, provided default muster data during drought in late 1994 at site B.

\(^3\) Musters were co-ordinated with unsupplemented cattle in an adjacent (alternate) paddock area of site C.

\(^4\) Muster in May 2000 of residual cattle from 1998/99 breeder groups at site C.
### Appendix 10. Categories of cattle and environmental variables in study.

<table>
<thead>
<tr>
<th>Categorical Terms</th>
<th>Measure</th>
<th>Reference</th>
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<tr>
<td>Financial years</td>
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</tr>
<tr>
<td>site A</td>
<td>Opening seasonal conditions for study</td>
<td>Table 3-2</td>
</tr>
<tr>
<td>1970/71 to 1974/75</td>
<td></td>
<td></td>
</tr>
<tr>
<td>site B</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1991/92 to 1995/96</td>
<td></td>
<td></td>
</tr>
<tr>
<td>site C</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1997/98 to 2000/01</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Categorical terms</td>
<td>Measure</td>
<td>Reference</td>
</tr>
<tr>
<td>site A</td>
<td>Opening seasonal conditions for study</td>
<td>Table 3-2</td>
</tr>
<tr>
<td>1970/71 to 1974/75</td>
<td>combined years</td>
<td></td>
</tr>
<tr>
<td>site B</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1991/92 to 1995/96</td>
<td></td>
<td></td>
</tr>
<tr>
<td>site C</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1997/98 to 2000/01</td>
<td>combined years</td>
<td></td>
</tr>
<tr>
<td>6-months cumulative rainfall</td>
<td>2-months cumulative rainfall</td>
<td>Appendix 2</td>
</tr>
<tr>
<td>poor</td>
<td>&lt; 50 mm – poorly effective rainfall</td>
<td>50–99mm</td>
</tr>
<tr>
<td>short</td>
<td>50+ mm – potentially effective rainfall</td>
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</tr>
<tr>
<td>medium</td>
<td>(Perry 1962, p.121)</td>
<td>100–199mm</td>
</tr>
<tr>
<td>long</td>
<td></td>
<td>200–299mm</td>
</tr>
<tr>
<td>prolonged</td>
<td></td>
<td>&gt; 300mm</td>
</tr>
<tr>
<td>Indicator grass greenness stage</td>
<td>Indicator grass recruitment level</td>
<td>Section 3.3.1</td>
</tr>
<tr>
<td>dry</td>
<td>nil</td>
<td></td>
</tr>
<tr>
<td>drying off</td>
<td>scarce</td>
<td></td>
</tr>
<tr>
<td>greening up</td>
<td>moderate</td>
<td></td>
</tr>
<tr>
<td>flush green</td>
<td>abundant</td>
<td></td>
</tr>
<tr>
<td>Lactation status</td>
<td></td>
<td>Appendix 12 a.</td>
</tr>
<tr>
<td>non-lactating</td>
<td></td>
<td></td>
</tr>
<tr>
<td>lactating</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pregnancy status</td>
<td></td>
<td>Appendix 12 a.</td>
</tr>
<tr>
<td>non-pregnant</td>
<td>Pregnancy trimesters</td>
<td>Gestation</td>
</tr>
<tr>
<td>pregnant</td>
<td>trimester 1</td>
<td>1.5–3.5 months</td>
</tr>
<tr>
<td></td>
<td>trimester 2</td>
<td>3.5–6.5 months</td>
</tr>
<tr>
<td></td>
<td>trimester 3</td>
<td>6.5–9.5 months</td>
</tr>
</tbody>
</table>
## APPENDICES

### Appendix 10. (continued)

<table>
<thead>
<tr>
<th>Categorical Terms</th>
<th>Measure</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Body condition score (BCS)</strong></td>
<td>Body condition</td>
<td>Appendix 12 a.</td>
</tr>
<tr>
<td>site B^1</td>
<td>site C</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>1</td>
<td>poor</td>
</tr>
<tr>
<td>2</td>
<td>2</td>
<td>store</td>
</tr>
<tr>
<td>3</td>
<td>3</td>
<td>forward store</td>
</tr>
<tr>
<td>4</td>
<td>4</td>
<td>fat</td>
</tr>
<tr>
<td>5</td>
<td>5, 6</td>
<td>combined BCS</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Cattle class</th>
<th>Age</th>
<th>Appendix 12 a.</th>
</tr>
</thead>
<tbody>
<tr>
<td>General age cohorts</td>
<td>(ordinal numbers)</td>
<td>2 –10 years old</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Cattle class</th>
<th>Age-group</th>
<th>Age-category</th>
<th>Appendix 12 a.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cow</td>
<td>yearling heifer</td>
<td>12–18 months old</td>
<td></td>
</tr>
<tr>
<td>Cow</td>
<td>heifer</td>
<td>1.5–2.5 years old</td>
<td></td>
</tr>
<tr>
<td>Cow</td>
<td>young cow</td>
<td>3 –5 years old</td>
<td></td>
</tr>
<tr>
<td>Cow</td>
<td>mature cow</td>
<td>young-to-aged cow</td>
<td></td>
</tr>
<tr>
<td>Cow</td>
<td>aged cow</td>
<td>5.5–7.5 years old</td>
<td></td>
</tr>
<tr>
<td>Herd Bull</td>
<td>young bull</td>
<td>young-to-mature bull</td>
<td></td>
</tr>
<tr>
<td>Herd Bull</td>
<td>mature bull</td>
<td>2 –3.5 years old</td>
<td></td>
</tr>
<tr>
<td>Herd Bull</td>
<td>older bull</td>
<td>4 –6 years old</td>
<td></td>
</tr>
<tr>
<td>Herd Bull</td>
<td>aged bull</td>
<td>older-to-aged bull</td>
<td></td>
</tr>
<tr>
<td>Young Cattle</td>
<td>weaner-age calves</td>
<td>mixed weaned-calf</td>
<td></td>
</tr>
<tr>
<td>Young Cattle</td>
<td>steers</td>
<td>store steer</td>
<td></td>
</tr>
</tbody>
</table>

^1 Half increments of BCS are reported where required.
## APPENDICES

**Appendix 11. Comparing mean faecal counts of sub-groups for stratification of representative groups at site B.**

<table>
<thead>
<tr>
<th>Representative group</th>
<th>sub-group</th>
<th>measure of faecal count</th>
<th>difference in means</th>
<th>p-value</th>
<th>faecal counts back-transformed from log_{10}</th>
</tr>
</thead>
<tbody>
<tr>
<td>mixed weaned-calf (&lt; 12 months old)</td>
<td>female, weaned calves</td>
<td>log_{10} (faecal egg count)</td>
<td>significant</td>
<td>p &lt; 0.05</td>
<td>46.2 epg, n = 132</td>
</tr>
<tr>
<td></td>
<td>male, weaned calves</td>
<td></td>
<td></td>
<td></td>
<td>83.6 epg, n = 126</td>
</tr>
<tr>
<td>mixed weaned-calf (&lt; 12 months old)</td>
<td>female, weaned calves</td>
<td>log_{10} (faecal oocyst count)</td>
<td>not significant</td>
<td>p &gt; 0.1</td>
<td>2.5 opg, n = 118</td>
</tr>
<tr>
<td></td>
<td>male, weaned calves</td>
<td></td>
<td></td>
<td></td>
<td>2.8 opg, n = 112</td>
</tr>
<tr>
<td>mature cow (5.5–7.5 years old)</td>
<td>nil</td>
<td>n/a</td>
<td>n/a</td>
<td>n/a</td>
<td>n/a</td>
</tr>
<tr>
<td>mature-toOLDER bull (4–8.5 years old)</td>
<td>mature bull group</td>
<td>log_{10} (faecal egg count)</td>
<td>not significant</td>
<td>p &gt; 0.1</td>
<td>3.8 epg, n = 12</td>
</tr>
<tr>
<td></td>
<td>older bull group</td>
<td></td>
<td></td>
<td></td>
<td>2.0 epg, n = 12</td>
</tr>
<tr>
<td>mature-toOLDER bull (4–8.5 years old)</td>
<td>mature bull group</td>
<td>log_{10} (faecal oocyst count)</td>
<td>not significant</td>
<td>p &gt; 0.1</td>
<td>0.9 opg, n = 12</td>
</tr>
<tr>
<td></td>
<td>older bull group</td>
<td></td>
<td></td>
<td></td>
<td>0.3 opg, n = 12</td>
</tr>
</tbody>
</table>

n/a = not applicable.
APPENDICES

Appendix 12, parts a. and b.  Cattle data and samples at sites.

### Appendix 12 a.  Cattle data collected

<table>
<thead>
<tr>
<th>Data</th>
<th>Method</th>
<th>site A</th>
<th>site B</th>
<th>site C</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Individual identification</strong></td>
<td>Individual (unique) cattle ear-tag numbers recorded.</td>
<td>1,052 cows&lt;sup&gt;1&lt;/sup&gt; 36+ bulls&lt;sup&gt;2&lt;/sup&gt; 467 steers&lt;sup&gt;3&lt;/sup&gt;</td>
<td>2,014 cows 108 bulls&lt;sup&gt;4&lt;/sup&gt;</td>
<td>303 cows 23 bulls</td>
</tr>
<tr>
<td><strong>Age</strong></td>
<td>Age determined:</td>
<td>cows</td>
<td>cows</td>
<td>cows</td>
</tr>
<tr>
<td></td>
<td>- by incisor pairs (Dodt &amp; O'Rourke 1988; St. Clair 1975) and wear;</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td></td>
<td>- by age cohort (Hill 2003, p.5) or year-brand (WA Low 2006, pers. comm.);</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td></td>
<td>- by ear-tattoo numbers related to records at purchase.</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td><strong>Liveweight</strong></td>
<td>Individual liveweights recorded:</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td></td>
<td>- on electronic scales (Ruddweigh®);</td>
<td>cows, bulls, steers, weaner cattle&lt;sup&gt;7&lt;/sup&gt;&lt;sup&gt;8&lt;/sup&gt;</td>
<td>—</td>
<td>cows, bulls, steers, weaner cattle&lt;sup&gt;9&lt;/sup&gt;</td>
</tr>
<tr>
<td></td>
<td>- on portable scales (Avery®)&lt;sup&gt;5&lt;/sup&gt; and permanent platform scales (Donald®)&lt;sup&gt;6&lt;/sup&gt;.</td>
<td>cows, steers</td>
<td>—</td>
<td>—</td>
</tr>
</tbody>
</table>

<sup>1</sup> Based on records of cows that conceived more than once (987 head), once (59 head) or did not conceive (6 head) in the primary beef cattle project (Low & Wood c. 1980).
<sup>2</sup> Based on bulls mustered February 1971 (26 head), extra bulls put into the paddock December 1974 (10 head) (Low 1978b; Low & Wood c. 1980); retained 'exceptional' bull calves not identified.
<sup>3</sup> Based on 467 store steers weighed out of the paddock (Low & Wood c. 1980).
<sup>4</sup> Ear-tattoos, fire-brands and freeze-brands were also used to help identify bulls.
<sup>5</sup> Cattle at muster (Yard A.1) were weighed after an overnight food and water curfew (Low & Wood c. 1980).
<sup>6</sup> Cattle at survey (Yard A.2) were weighed without curfew on Donald® platform, model 2200 (Low & Hodder 1976).
<sup>7</sup> Cattle were weighed within a week of being trapped or mustered; no water curfew was imposed; cattle were held in a holding paddock or fed hay in the yard as required.
<sup>8</sup> Ruddweigh® Data Collecta Model KD1, 2500KM 1E TANDEM Serial 10968.
<sup>9</sup> Cattle were weighed within 24 hours of being mustered; no water curfew was imposed.
### APPENDICES

#### Appendix 12 a.  (continued)

<table>
<thead>
<tr>
<th>Data</th>
<th>Method</th>
<th>site A</th>
<th>site B</th>
<th>site C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Frame size</td>
<td>Frame score recorded as an indication of growth potential (McKiernan 2005).</td>
<td>—</td>
<td>cows, bulls</td>
<td>—</td>
</tr>
<tr>
<td>Body condition</td>
<td>Body condition recorded to indicate relative level of past nutrition:</td>
<td>—</td>
<td>cows, bulls</td>
<td>—</td>
</tr>
<tr>
<td></td>
<td>- on a score of 1–5 (Graham 2006), and half increments reported as required;</td>
<td>—</td>
<td>—</td>
<td>cows</td>
</tr>
<tr>
<td></td>
<td>- on a score of 1–6 (McKiernan &amp; Sundstrom 2006);</td>
<td></td>
<td>—</td>
<td></td>
</tr>
<tr>
<td></td>
<td>- as condition class (fat, forward store, store, backward store and poor), based on fat distribution and body fleshing (Low &amp; Wood c. 1980).</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pregnancy</td>
<td>Rectal palpation of the reproductive tract:</td>
<td>—</td>
<td>cows</td>
<td>—</td>
</tr>
<tr>
<td></td>
<td>- to determine age (months) of the conceptus (Honey 1998, pp.31-35);</td>
<td>—</td>
<td>—</td>
<td></td>
</tr>
<tr>
<td></td>
<td>- to determine trimester of pregnancy;</td>
<td>—</td>
<td>—</td>
<td>cows</td>
</tr>
<tr>
<td></td>
<td>- to determine trimester of pregnancy and age of foetus (Low &amp; Wood c. 1980).</td>
<td>cows</td>
<td>—</td>
<td></td>
</tr>
<tr>
<td>Lactation</td>
<td>Determine presence of lactation:</td>
<td>—</td>
<td>cows</td>
<td>—</td>
</tr>
<tr>
<td></td>
<td>- by observation of udder filling and wet teats;</td>
<td>—</td>
<td>—</td>
<td>cows</td>
</tr>
<tr>
<td></td>
<td>- by observation of udder filling, wet teats and liquid stripped from the teat;</td>
<td>—</td>
<td>—</td>
<td>cows</td>
</tr>
<tr>
<td></td>
<td>- by palpation of udder and teats (Low &amp; Wood c. 1980).</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Aspects of bull breeding soundness</td>
<td>Findings recorded:</td>
<td>—</td>
<td>bulls</td>
<td>—</td>
</tr>
<tr>
<td></td>
<td>- for inspection (+ palpation) of key criteria (prepuce, penis, seminal vesicles, testicles and external physical aspects (eyes, limbs)) (McGowan et al. 1995, pp.16-21);</td>
<td>—</td>
<td>—</td>
<td></td>
</tr>
<tr>
<td></td>
<td>- for measurements of testicular circumference (McGowan et al. 1995, p.24).</td>
<td>—</td>
<td>—</td>
<td></td>
</tr>
<tr>
<td>Collation</td>
<td>Data were collated where possible with individual cattle identification on an electronic database (Microsoft 1992-2003)</td>
<td>—</td>
<td>cows, bulls</td>
<td>cows, steers</td>
</tr>
</tbody>
</table>
## APPENDICES

### Appendix 12 b. Cattle samples collected

<table>
<thead>
<tr>
<th>Sample</th>
<th>Method</th>
<th>site A</th>
<th>site B</th>
<th>site C</th>
<th>cattle sampled</th>
</tr>
</thead>
<tbody>
<tr>
<td>Blood collection</td>
<td>Blood samples were collected from individually-identified cows (stratified, opportunistic collection) via the neck (jugular vein)(^1), into labelled, 10-ml vacuum tubes (one EDTA tube, one lithium heparin tube, three plain tubes(^2)).</td>
<td>nil</td>
<td>27–50 per muster; 12–25 per survey</td>
<td>nil</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>A blood sample was collected from individually-identified cows (stratified, opportunistic collection) via the tail (coccygeal artery or vein) into a labelled, 10-ml vacuum tube (one plain tube).</td>
<td>n/a(^3)</td>
<td>nil</td>
<td>8–25 per muster</td>
<td></td>
</tr>
<tr>
<td></td>
<td>A blood sample was collected from individually-identified bulls (opportunistic collection) via the tail (coccygeal artery) into a labelled, 10-ml vacuum tube (one plain tube).</td>
<td>n/a</td>
<td>25–53 per muster</td>
<td>nil</td>
<td></td>
</tr>
<tr>
<td></td>
<td>A blood sample was collected from uniformly-described steers (opportunistic collection) via the tail (coccygeal artery) into a labelled, 10-ml vacuum tube (one plain tube).</td>
<td>n/a</td>
<td>nil</td>
<td>5–12 per muster</td>
<td></td>
</tr>
<tr>
<td>Blood transport and processing</td>
<td>Blood samples in EDTA and lithium heparin tubes were stored for transport in a chilled esky(^4).</td>
<td>—</td>
<td>cows</td>
<td>—</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Blood samples in plain tubes were wrapped in aluminium foil to exclude light and then stored in a chilled esky, pending removal of serum.</td>
<td>—</td>
<td>cows</td>
<td>—</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Blood samples in plain tubes were stood at ambient temperature to clot and then stored in a chilled esky or portable refrigerator, pending removal of serum on the same day as collection.</td>
<td>—</td>
<td>bulls</td>
<td>cows, steers</td>
<td></td>
</tr>
</tbody>
</table>

---

\(^1\) A halter, rope and pulley helped extend the neck, plus maximise operator safety and efficiency while filling the vacuum tubes.

\(^2\) Vacuum tubes were filled in the set order to minimise contamination of serum in the plain tubes.

\(^3\) Blood collected for the BTEC property program was not a part of the primary beef cattle project.

\(^4\) Blood collected in the EDTA tube was gently inverted to distribute the anticoagulant and minimise WBC disintegration. If this blood could not be delivered to a diagnostic laboratory within 12 hours of collection, blood smears were made at the site and fixed in methanol prior to storage.
### Appendix 12 b. (continued)

<table>
<thead>
<tr>
<th>Sample</th>
<th>Method</th>
<th>site A</th>
<th>site B</th>
<th>site C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Blood transport and processing continued</td>
<td>Blood samples in plain tubes were centrifuged at 3,000–5,000 rpm and serum samples were transferred into labelled, plastic screw-top vials(^1).</td>
<td>—</td>
<td>cows, bulls</td>
<td>cows, steers</td>
</tr>
<tr>
<td></td>
<td>Chilled samples were either delivered to Arid Zone Research Institute–Animal Health Laboratory, Alice Springs, NT (AZRI-AHL), or packed (as per IATA Packing Instruction 650) (NT-DPI&amp;F 2001a) for air-freight to Berrimah Veterinary Laboratories, Darwin, NT (BVL) and Agriculture Western Australia–Animal Health Laboratories, South Perth, WA (AgWA-AHL)(^2).</td>
<td>—</td>
<td>cows, bulls</td>
<td>cows, steers</td>
</tr>
<tr>
<td>Blood testing</td>
<td>Serum samples were tested at the BVL (1992–2001) (NT-DPI&amp;F 2001a) for enzymes and metabolites (creatinine, urea, bilirubin, ALT, AST, ALP, GGT, CPK) using a multiple biochemical analyser (Roche Diagnostica Cobas Mira®).</td>
<td>—</td>
<td>cows, bulls</td>
<td>cows, steers</td>
</tr>
<tr>
<td></td>
<td>Serum samples were tested at the BVL (1992–2001) (NT-DPI&amp;F 2001a) for indicators of nutrition and homeostasis (protein, albumin, albumin-to-globulin ratio, Na, K, Cl, Ca, P, Mg, total serum Fe, Cu, Zn) using a multiple biochemical analyser (Roche Diagnostica Cobas Mira®).</td>
<td>—</td>
<td>cows, bulls</td>
<td>cows, steers</td>
</tr>
<tr>
<td></td>
<td>Blood samples in lithium heparin were tested at the BVL (1992–1995) (NT-DPI&amp;F 2001a) for glutathione peroxidise activity using a multiple biochemical analyser (Roche Diagnostica Cobas Mira®), as per Australian Standard Diagnostic Techniques (Paynter, Halpin &amp; Caple 1993).</td>
<td>—</td>
<td>cows</td>
<td>—</td>
</tr>
</tbody>
</table>

---

\(^1\) Serum from each cow-blood sample was transferred into paired vials; one vial of serum was wrapped in aluminium foil prior to storage and transport.

\(^2\) Aluminium foil-wrapped vials of serum were stock-piled under deep freeze and forwarded to AgWA-AHL for referral testing at the end of the primary beef cattle project.
APPENDICES

Appendix 12 b.  (continued)

<table>
<thead>
<tr>
<th>Sample</th>
<th>Method</th>
<th>site A</th>
<th>site B</th>
<th>site C</th>
</tr>
</thead>
</table>
| Blood testing continued | Serum samples were referred to AgWA-AHL (1996) for vitamin A and vitamin E testing, by the method of McMurray and Blanchflower (1979) on a Waters HPLC system, using a Waters Radial-Pak® Cartridge 8 C185 micron and Waters Maxima® Program:  
- Waters UV Detector® (at 325nm wavelength) was used for the vitamin A testing;  
- Hitachi Fluorescence Detector® was used for the vitamin E testing. | —     | cows  | —     |
|         | Serum samples were tested at the BVL (1992–2004) (NT-DPI&F 2001a) for antibodies to pathogens:  
- BVD agar gel immunodiffusion (AGID) test for antibodies to BVDV, as per Australian Standard Diagnostic Techniques (Kirkland & MacKintosh 1993);  
- IBR serum neutralisation (SN) test for antibodies to bovine herpes virus type 1, as per Australian Standard Diagnostic Techniques (Young 1993);  
- micro-agglutination test (MAT) for antibodies to leptospiral serovars (L. sv. hardjo, L. sv. pomona, L. sv. tarassovi), as per Australian Standard Diagnostic Techniques (Chappel 1993). | —     | cows, bulls | —     |
|         | Blood samples in EDTA were analysed at the BVL (1992–1996) (NT-DPI&F 2001a) for haematological parameters (WBC, RBC, Hb, HCT, MCV, MCH, MCHC, Platelets) using an automatic cell counter (bench-top MINOS COBAS ST VET® haematology analyser (ABX); veterinary threshold selection unit on setting 3 for bovine blood). | —     | cows  | —     |
|         | Blood smears were assessed microscopically (1991, 1995) using manual white cell differential counts and morphological assessment for neutrophils, lymphocytes, monocytes, eosinophils, basophils and platelets, as per standard methods of Benjamin (1978). | —     | cows  | —     |
### Appendix 12 b. (continued)

<table>
<thead>
<tr>
<th>Sample</th>
<th>Method</th>
<th>site A</th>
<th>site B</th>
<th>site C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Faeces collection</td>
<td>Faeces were collected from individually-identified cows (stratified, opportunistic collection) via sampling of unvoided (rectal) or freshly-voided dung to fill two labelled, 20-ml screw-top containers.</td>
<td>nil</td>
<td>14–30 per muster; 10–25 per survey</td>
<td>nil</td>
</tr>
<tr>
<td>Faeces were collected from individually-identified cows (stratified, opportunistic collection) via sampling of unvoided (rectal) dung to fill a labelled, 20-ml screw-top container.</td>
<td>nil</td>
<td>nil</td>
<td>10–25 per muster</td>
<td></td>
</tr>
<tr>
<td>Faeces were collected from individually-identified bulls (opportunistic collection) via sampling of unvoided (rectal) dung to fill a labelled, 20-ml screw-top container.</td>
<td>nil</td>
<td>7–19 per muster</td>
<td>nil</td>
<td></td>
</tr>
<tr>
<td>Faeces were collected from uniformly-described steers (opportunistic collection) via sampling of unvoided (rectal) dung to fill a labelled, 20-ml screw-top container.</td>
<td>nil</td>
<td>5–20 per muster</td>
<td>4–13 per muster</td>
<td></td>
</tr>
<tr>
<td>Faeces were collected from balanced numbers of weaner heifers and steers (opportunistic collection) via sampling of unvoided (rectal) dung to fill a labelled, 20-ml screw-top container.</td>
<td>nil</td>
<td>20–37 per muster</td>
<td>nil</td>
<td></td>
</tr>
<tr>
<td>Faeces were collected from cattle that had been feeding in, or residing in mulga land (opportunistic collection) (Low et al. 1973) via sampling of freshly-voided dung, which was placed into labelled plastic bags (WA Low 2006, pers. comm.).</td>
<td>8 per month</td>
<td>nil</td>
<td>nil</td>
<td></td>
</tr>
<tr>
<td>Faeces transport and testing</td>
<td>Faecal samples were stored for transport in a portable refrigerator or chilled esky (WA Low 2006, pers. comm.).</td>
<td>unspecified</td>
<td>cows, bulls, steers, weaner cattle</td>
<td>cows, steers</td>
</tr>
<tr>
<td>Chilled faecal samples were delivered to Arid Zone Research Institute–Animal Nutrition Laboratory, Alice Springs, NT (AZRI-ANL).</td>
<td>—</td>
<td>cows, steers</td>
<td>cows, steers</td>
<td></td>
</tr>
<tr>
<td>Chilled faecal samples were delivered to AZRI-AHL, or packed (as per IATA Packing Instruction 650) (NT-DPI&amp;F 2001a) for air-freight to BVL.</td>
<td>—</td>
<td>cows, bulls, weaner cattle</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

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APPENDICES

<table>
<thead>
<tr>
<th>Sample</th>
<th>Method</th>
<th>site A</th>
<th>site B</th>
<th>site C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Faeces transport and testing continued</td>
<td>Chilled faecal samples were delivered to Arid Zone Research Institute–CSIRO Laboratory, Alice Springs, NT (AZRI-CSIRO).</td>
<td>unspecified</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td></td>
<td>Faecal samples were tested at the AZRI-ANL (1991–2001) for chemical and physical properties: - for Faecal %N, <em>as per</em> the modified Micro-Kjedahl Method (McKenzie &amp; Wallace 1954); - for Faecal %P, <em>as per</em> American Association of Analytical Chemists (Horwitz, Chichilo &amp; Reynolds 1970); - for Faecal %DM, <em>as per</em> standard laboratory method.</td>
<td>—</td>
<td>cows, steers</td>
<td>cows, steers</td>
</tr>
<tr>
<td></td>
<td>Faecal samples were examined at the AZRI-AHL (1991) or the BVL (1992–1996) (NT-DPI&amp;F 2001a) for intestinal parasites (nematode egg counts, oocyst counts, larval cultures), <em>as per</em> standard methods of Ministry of Agriculture Fisheries and Food (1986).</td>
<td>—</td>
<td>cows, steers</td>
<td>cows, steers</td>
</tr>
<tr>
<td></td>
<td>Faecal samples were bulked and tested at the BVL (1992–1996) (NT-DPI&amp;F 2001a) for botulinum toxin, <em>as per</em> methods described by Streeten (1989).</td>
<td>—</td>
<td>cows, bulls</td>
<td>—</td>
</tr>
<tr>
<td></td>
<td>Faecal samples were examined at AZRI-CSIRO for identification of large plant fragments using a dissecting microscope (WA Low 2006, pers. comm.) and stained slides (Williams 1969, cited by Low et al. 1973) for smaller fragments.</td>
<td>unspecified</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>Preputial scraping – collection</td>
<td>Samples were collected from the prepuce of individually-identified bulls (preputial scrapings) (opportunistic collection), <em>as per</em> recommended field methods (NT-DPI&amp;F 2001a).</td>
<td>nil</td>
<td>25–48 per muster</td>
<td>nil</td>
</tr>
</tbody>
</table>

1 Results of faecal examination for primary beef cattle project were not included in the present study.
### Appendix 12 b. (continued)

<table>
<thead>
<tr>
<th>Sample</th>
<th>Method</th>
<th>site A</th>
<th>site B</th>
<th>site C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Preputial scraping – transport and processing</td>
<td>Sub-samples of collected preputial scrapings were inoculated into labelled transport media (Clarks Transport Enrichment Medium (Australian TEM); (Modified Plastridge) Selective Medium for <em>Tritrichomonas foetus</em>) that were warmed to ambient temperature and stored away from light. This was consistent with recommended field methods (NT-DPI&amp;F 2001a)(^1). The inoculated transport media were packed in an insulated esky (<em>as per IATA Packing Instruction 650</em>) (NT-DPI&amp;F 2001a) for air-freight to the BVL.</td>
<td>—</td>
<td>bulls</td>
<td>—</td>
</tr>
<tr>
<td>Preputial scraping – testing</td>
<td>Inoculated transport media were cultured at the BVL (1991–1996) (NT-DPI&amp;F 2001a) for <em>Campylobacter fetus</em> subsp. <em>venerealis</em> and <em>T. foetus</em>, as per Australian Standard collected Diagnostic Techniques (Hum &amp; McInnes 1993; Vaughan 1993).</td>
<td>—</td>
<td>bulls</td>
<td>—</td>
</tr>
</tbody>
</table>

---

\(^1\) Amelioration of ambient temperature extremes was also attempted by use of water bottles, a portable reverse-cycle refrigerating/heating box in the field, and a laboratory oven set at 37° Celcius in the NTG-Alice Springs office.
Appendix 13. Pregnancy percentage at muster, within categories of body condition for lactating and non-lactating cows, per cow age-group at sites B and C.

<table>
<thead>
<tr>
<th>Age-group [ages]</th>
<th>site B</th>
<th>Pregnancy % (95% CI)</th>
</tr>
</thead>
<tbody>
<tr>
<td>[1.5–2.5 years old]</td>
<td>heifer 380 n.s.</td>
<td>lactating</td>
</tr>
<tr>
<td>[ 3–5 years old ]</td>
<td>young cow 2396 n.s.</td>
<td>45 (38, 51)(^b)</td>
</tr>
<tr>
<td>[5.5–7.5 years old]</td>
<td>mature cow 1698 n.s.</td>
<td>50 (46, 52)(^{a,b})</td>
</tr>
<tr>
<td>[ ≥ 8 years old ]</td>
<td>aged cow 1319 n.s.</td>
<td>56 (52, 59)(^a)</td>
</tr>
<tr>
<td>[1.5–2.5 years old]</td>
<td>non-lactating heifer 346 n.s.</td>
<td>81 (71, 90)(^c)</td>
</tr>
<tr>
<td>[ 3–5 years old ]</td>
<td>young cow 979 **</td>
<td>86 (82, 90)(^c)</td>
</tr>
<tr>
<td>[5.5–7.5 years old]</td>
<td>mature cow 569 n.s.</td>
<td>89 (83, 94)(^c)</td>
</tr>
<tr>
<td>[ ≥ 8 years old ]</td>
<td>aged cow 521 n.s.</td>
<td>94 (89, 97)(^c)</td>
</tr>
</tbody>
</table>

Body condition [BCS scale: 1–5]
- store [1.5–2]
- forward store [2.5–3]
- fat [3.5–4]

Percentages with different superscripts within columns are significantly different (p < 0.05). Percentages with different superscripts within rows are no significantly different (p < 0.05).
### APPENDICES

<table>
<thead>
<tr>
<th>site C</th>
<th>Pregnancy % (95% CI)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Body condition [BCS scale: 1–6]</td>
</tr>
<tr>
<td>Age-group† [ages]</td>
<td>number of records</td>
</tr>
<tr>
<td>young cow [3–5 years old]</td>
<td>419</td>
</tr>
<tr>
<td>non-lactating young cow [3–5 years old]</td>
<td>383</td>
</tr>
</tbody>
</table>

n.s. = no significantly different percentages within row; ** = some significantly different percentages within row (p < 0.05). Percentages with different superscripts within columns are significantly different (p < 0.05). 
† Data not available for other age-groups under a comparable 4-year period.
Appendix 14. Percentage of confirmed pregnancies with lactation failure, per stage of reproductive loss and cow age-group at site B.

<table>
<thead>
<tr>
<th>Age-group</th>
<th>Number of confirmed pregnancies*</th>
<th>Pre-natal (1st trimester of pregnancy)</th>
<th>Pre-natal (2nd or 3rd trimester of pregnancy)</th>
<th>Peri-/post-natal</th>
<th>All stages (95% CI)</th>
</tr>
</thead>
<tbody>
<tr>
<td>heifer [1.5–2.5 years old]</td>
<td>44</td>
<td>0.0</td>
<td>0.0</td>
<td>4.5</td>
<td>4.5 (0.6, 15.5)</td>
</tr>
<tr>
<td>young cow [3–5 years old]</td>
<td>221</td>
<td>2.3</td>
<td>1.4</td>
<td>1.8</td>
<td>5.4 (2.8, 9.3)</td>
</tr>
<tr>
<td>mature cow [5.5–7.5 years old]</td>
<td>131</td>
<td>3.1</td>
<td>0.8</td>
<td>2.3</td>
<td>6.1 (2.7, 11.7)</td>
</tr>
<tr>
<td>aged cow [≥8 years old]</td>
<td>87</td>
<td>6.9</td>
<td>0.0</td>
<td>3.4</td>
<td>10.3 (4.8, 18.7)</td>
</tr>
<tr>
<td>Lactation failure - all age-groups</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total number</td>
<td>15</td>
<td>4</td>
<td>12</td>
<td>31</td>
<td></td>
</tr>
<tr>
<td>Total percentage (of confirmed pregnancies)</td>
<td>3.1</td>
<td>0.8</td>
<td>2.5</td>
<td>6.4 (4.4, 9.0)</td>
<td></td>
</tr>
</tbody>
</table>


n.s. = no significant difference between age-group categories.
Appendix 15. Percentage of herd bulls with a positive culture of preputial scrapings for *Campylobacter fetus* subsp. *venerealis* and *Tritrichomonas foetus*, per bull age-category and year at site B.

<table>
<thead>
<tr>
<th>Financial year</th>
<th><em>Campylobacter fetus</em> subsp. <em>venerealis</em></th>
<th><em>Tritrichomonas foetus</em></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Herd bulls with positive culture % (95% CI)</td>
<td>Herd bulls with positive culture % (95% CI)</td>
</tr>
<tr>
<td></td>
<td>young-to-mature bull (≤ 6 years old)</td>
<td>older-to-aged bull (&gt; 6 years old)</td>
</tr>
<tr>
<td>culture positive</td>
<td><em>n</em></td>
<td>n.s.</td>
</tr>
<tr>
<td>1991/92</td>
<td>15</td>
<td>0</td>
</tr>
<tr>
<td>1992/93</td>
<td>20</td>
<td>0</td>
</tr>
<tr>
<td>1993/94</td>
<td>35</td>
<td>0</td>
</tr>
<tr>
<td>1994/95</td>
<td>21</td>
<td>0</td>
</tr>
<tr>
<td>1995/96</td>
<td>31</td>
<td>0</td>
</tr>
</tbody>
</table>

Significance of difference between financial year categories: n.s. = no significant difference.

1 It was noted that a culled aged cow, which was sent to abattoirs in early 1993, had ovarian indications of repeat cycling, as well as a pyometra that cultured positive for *T. foetus.*

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### APPENDICES

Appendix 16. Percentage of herd bulls and cows with MAT titres to *L. sv. hardjo*, *L. sv. pomona* and *L. sv. tarassovi*, per age-categories of bulls and cows at site B.

<table>
<thead>
<tr>
<th>MAT titre to <em>L. sv. hardjo</em></th>
<th>Herd Bulls % (95% CI)</th>
<th>Cows % (95% CI)</th>
</tr>
</thead>
<tbody>
<tr>
<td>(n = 42)</td>
<td>(n = 57)</td>
<td>(n = 97)</td>
</tr>
<tr>
<td>0–1:50</td>
<td>67 (50, 80)</td>
<td>72 (58, 83)</td>
</tr>
<tr>
<td>1:100–1:200</td>
<td>21 (10, 37)</td>
<td>23 (13, 36)</td>
</tr>
<tr>
<td>&gt; 1:400</td>
<td>12 ( 4, 26)</td>
<td>5 ( 1, 15)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>MAT titre to <em>L. sv. pomona</em></th>
<th>(n = 42)</th>
<th>(n = 57)</th>
<th>(n = 76)</th>
<th>(n = 254)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0–1:50</td>
<td>83 (69, 93)</td>
<td>81 (68, 90)</td>
<td>100 (95, 100)</td>
<td>100 (99, 100)</td>
</tr>
<tr>
<td>1:100–1:200</td>
<td>5 ( 1, 16)</td>
<td>11 ( 4, 22)</td>
<td>0 ( 0, 5)</td>
<td>0 ( 0, 1)</td>
</tr>
<tr>
<td>&gt; 1:400</td>
<td>12 ( 4, 26)</td>
<td>9 ( 3, 19)</td>
<td>0 ( 0, 5)</td>
<td>0 ( 0, 1)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>MAT titre to <em>L. sv. tarassovi</em></th>
<th>(n = 42)</th>
<th>(n = 57)</th>
<th>(n = 98)</th>
<th>(n = 264)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0–1:50</td>
<td>86 (71, 95)</td>
<td>81 (68, 90)</td>
<td>65 (55, 75)</td>
<td>53 (47, 59)</td>
</tr>
<tr>
<td>1:100–1:200</td>
<td>12 ( 4, 26)</td>
<td>16 ( 7, 28)</td>
<td>18 (11, 27)</td>
<td>33 (27, 39)</td>
</tr>
<tr>
<td>&gt; 1:400</td>
<td>2 ( 0, 13)</td>
<td>4 ( 0, 12)</td>
<td>16 (10, 25)</td>
<td>14 (10, 19)</td>
</tr>
</tbody>
</table>
Appendix 17. Percentage of herd bulls and cows with MAT titres to *L. sv. hardjo*, *L. sv. pomona* and *L. sv. tarassovi*, per 2-months cumulative rainfall at site B.

<table>
<thead>
<tr>
<th>MAT titre to <em>L. sv. hardjo</em></th>
<th>Herd Bulls % (95% CI)</th>
<th>Cows % (95% CI)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>&lt; 50 mm rainfall</td>
<td>50+ mm rainfall</td>
</tr>
<tr>
<td></td>
<td>(n = 64)</td>
<td>(n = 72)</td>
</tr>
<tr>
<td>0–1:50</td>
<td>58 (45, 70)</td>
<td>74 (62, 83)</td>
</tr>
<tr>
<td>1:100–1:200</td>
<td>33 (22, 46)</td>
<td>19 (11, 30)</td>
</tr>
<tr>
<td>≥ 1:400</td>
<td>9 ( 4, 19)</td>
<td>7 ( 2, 15)</td>
</tr>
<tr>
<td>MAT titre to <em>L. sv. pomona</em></td>
<td>(n = 73)</td>
<td></td>
</tr>
<tr>
<td>0–1:50</td>
<td>71 (59, 81)</td>
<td>78 (68, 87)</td>
</tr>
<tr>
<td>1:100–1:200</td>
<td>11 ( 5, 20)</td>
<td>13 ( 7, 22)</td>
</tr>
<tr>
<td>≥ 1:400</td>
<td>18 (10, 29)</td>
<td>8 ( 3, 17)</td>
</tr>
<tr>
<td>MAT titre to <em>L. sv. tarassovi</em></td>
<td>(n = 64)</td>
<td></td>
</tr>
<tr>
<td>0–1:50</td>
<td>81 (70, 90)</td>
<td>75 (63, 84)</td>
</tr>
<tr>
<td>1:100–1:200</td>
<td>16 ( 8, 27)</td>
<td>21 (12, 32)</td>
</tr>
<tr>
<td>≥ 1:400</td>
<td>3 ( 0, 11)</td>
<td>4 ( 1, 12)</td>
</tr>
</tbody>
</table>
**APPENDICES**

**Appendix 18. Lactation and pregnancy percentages with positive titres to *L. sv. hardjo* and *L. sv. tarassovi*: odds ratios and chi² values, per cow age-category at site B.**

<table>
<thead>
<tr>
<th>Seropositive* vs. seronegative</th>
<th>Number</th>
<th>%</th>
<th>Odds ratio (95% CI)</th>
<th>heifer (&lt; 2.5 years old)</th>
<th>young-to-aged cow (&gt; 2.5 years old)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>heifer (lactating)</td>
<td>young-to-aged cow (lactating)</td>
</tr>
<tr>
<td>+ ve¹</td>
<td>29</td>
<td>48</td>
<td>1.0</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>- ve</td>
<td>73</td>
<td>49</td>
<td>1.0</td>
<td>(0.4, 2.5)</td>
<td>168</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>64</td>
<td>76</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1.7</td>
<td>(1.0, 3.0)</td>
</tr>
<tr>
<td>+ ve²</td>
<td>27</td>
<td>56</td>
<td>1.0</td>
<td>—</td>
<td>57</td>
</tr>
<tr>
<td>- ve</td>
<td>66</td>
<td>55</td>
<td>1.0</td>
<td>(0.4, 2.4)</td>
<td>95</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>53</td>
<td>0.6</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>(0.3, 1.1)</td>
<td></td>
</tr>
<tr>
<td>L. sv. tarassovi</td>
<td></td>
<td></td>
<td></td>
<td>heifer (lactating)</td>
<td>young-to-aged cow (lactating)</td>
</tr>
<tr>
<td>+ ve²</td>
<td>35</td>
<td>49</td>
<td>1.0</td>
<td>—</td>
<td>106</td>
</tr>
<tr>
<td>- ve</td>
<td>68</td>
<td>49</td>
<td>1.0</td>
<td>(0.4, 2.3)</td>
<td>151</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>69</td>
<td>0.7</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>(0.4, 1.3)</td>
<td></td>
</tr>
<tr>
<td>+ ve²</td>
<td>33</td>
<td>52</td>
<td>1.0</td>
<td>—</td>
<td>78</td>
</tr>
<tr>
<td>- ve</td>
<td>61</td>
<td>57</td>
<td>1.3</td>
<td>(0.5, 3.0)</td>
<td>74</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>61</td>
<td>1.3</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>(0.7, 2.4)</td>
<td></td>
</tr>
</tbody>
</table>

* Seropositive: MAT titre to *L. sv. hardjo* ≥ 1:100; MAT titre to *L. sv. tarassovi* ≥ 1:100.

Chi-square tests for independence to analyse differences associated with positive titres:

1 'heifer': $\chi^2 = 0.01$ for 1 df; $p = 0.924$.  
2 'young-to-aged cow': $\chi^2 = 3.82$ for 1 df; $p = 0.051$.  
3 'heifer': $\chi^2 = 0.01$ for 1 df; $p = 0.929$.  
4 'young-to-aged cow': $\chi^2 = 2.88$ for 1 df; $p = 0.090$.  
3 'heifer': $\chi^2 = 0.00$ for 1 df; $p = 0.997$.  
4 'young-to-aged cow': $\chi^2 = 1.33$ for 1 df; $p = 0.248$.  
4 'heifer': $\chi^2 = 0.30$ for 1 df; $p = 0.585$.  
3 'young-to-aged cow': $\chi^2 = 0.50$ for 1 df; $p = 0.478$.  

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Appendix 19. Percentage of herd bulls and cows with AGID level of antibody to BVDV and SN titres to BHV1, per age-categories of bulls and cows at site B.

<table>
<thead>
<tr>
<th>AGID antibody level (BVDV)</th>
<th>Herd Bulls % (95% CI)</th>
<th>Cows % (95% CI)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>young-to-mature bull (≤ 6 years old)</td>
<td>older-to-aged bull (&gt; 6 years old)</td>
</tr>
<tr>
<td>0 or 0.5</td>
<td>26 (16, 40)</td>
<td>25 (15, 37)</td>
</tr>
<tr>
<td>1</td>
<td>32 (20, 45)</td>
<td>50 (37, 63)</td>
</tr>
<tr>
<td>2</td>
<td>40 (28, 54)</td>
<td>25 (15, 37)</td>
</tr>
<tr>
<td>3</td>
<td>2 (0, 9)</td>
<td>0 (0, 6)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>SN titre (BHV1)</th>
<th>(n = 28)</th>
<th>(n = 32)</th>
<th>(n = 64)</th>
<th>(n = 59)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>4 (0, 18)</td>
<td>0 (0, 11)</td>
<td>77 (64, 86)</td>
<td>47 (34, 61)</td>
</tr>
<tr>
<td>1:3–1:48</td>
<td>29 (13, 49)</td>
<td>13 (4, 29)</td>
<td>14 (7, 25)</td>
<td>17 (8, 29)</td>
</tr>
<tr>
<td>1:64–1:2048</td>
<td>68 (48, 84)</td>
<td>88 (71, 96)</td>
<td>9 (4, 19)</td>
<td>36 (24, 49)</td>
</tr>
</tbody>
</table>
### APPENDICES

**Appendix 20. Lactation and pregnancy percentages with positive titres to BVDV and BHV1: odds ratios and chi² values, per cow age-category at site B.**

<table>
<thead>
<tr>
<th>Seropositive* vs. seronegative</th>
<th>BVDV</th>
<th></th>
<th></th>
<th>BHV1</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>heifer (&lt; 2.5 years old)</td>
<td>young-to-aged cow (&gt; 2.5 years old)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Number</strong></td>
<td><strong>%</strong></td>
<td><strong>Odds ratio (95% CI)</strong></td>
<td><strong>Number</strong></td>
<td><strong>%</strong></td>
<td><strong>Odds ratio (95% CI)</strong></td>
<td></td>
</tr>
<tr>
<td>lactating</td>
<td></td>
<td></td>
<td>lactating</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>+ ve&lt;sup&gt;1&lt;/sup&gt;</td>
<td>77</td>
<td>45</td>
<td>1.0 —</td>
<td>222</td>
<td>64</td>
<td>1.0 —</td>
</tr>
<tr>
<td>- ve</td>
<td>19</td>
<td>47</td>
<td>1.1 (0.4, 3.0)</td>
<td>60</td>
<td>73</td>
<td>1.5 (0.8, 2.9)</td>
</tr>
<tr>
<td>pregnant</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>+ ve&lt;sup&gt;2&lt;/sup&gt;</td>
<td>69</td>
<td>54</td>
<td>1.0 —</td>
<td>107</td>
<td>54</td>
<td>1.0 —</td>
</tr>
<tr>
<td>- ve</td>
<td>17</td>
<td>65</td>
<td>1.6 (0.5, 4.8)</td>
<td>32</td>
<td>63</td>
<td>1.4 (0.6, 3.2)</td>
</tr>
<tr>
<td>lactating</td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>+ ve&lt;sup&gt;3&lt;/sup&gt;</td>
<td>17</td>
<td>53</td>
<td>1.0 —</td>
<td>42</td>
<td>67</td>
<td>1.0 —</td>
</tr>
<tr>
<td>- ve</td>
<td>53</td>
<td>38</td>
<td>0.5 (0.2, 1.6)</td>
<td>33</td>
<td>70</td>
<td>1.2 (0.4, 3.1)</td>
</tr>
<tr>
<td>pregnant</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>+ ve&lt;sup&gt;4&lt;/sup&gt;</td>
<td>16</td>
<td>44</td>
<td>1.0 —</td>
<td>31</td>
<td>48</td>
<td>1.0 —</td>
</tr>
<tr>
<td>- ve</td>
<td>45</td>
<td>62</td>
<td>2.1 (0.7, 6.7)</td>
<td>23</td>
<td>48</td>
<td>1.0 (0.3, 2.9)</td>
</tr>
</tbody>
</table>

* Seropositive: AGID level of antibody to BVDV ≥ 1; positive SN titre to BHV1.

Chi-square tests for independence to analyse differences associated with positive titres:

1 ‘heifer’: $\chi^2 = 0.02$ for 1 df; $p = 0.881$.  
‘young-to-aged cow’: $\chi^2 = 1.68$ for 1 df; $p = 0.195$.  
2 ‘heifer’: $\chi^2 = 0.68$ for 1 df; $p = 0.410$.  
‘young-to-aged cow’: $\chi^2 = 0.69$ for 1 df; $p = 0.407$.  
3 ‘heifer’: $\chi^2 = 1.23$ for 1 df; $p = 0.268$.  
‘young-to-aged cow’: $\chi^2 = 0.08$ for 1 df; $p = 0.780$.  
4 ‘heifer’: $\chi^2 = 1.65$ for 1 df; $p = 0.199$.  
‘young-to-aged cow’: $\chi^2 = 0.00$ for 1 df; $p = 0.967$.  

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APPENDICES

Appendix 21. Biochemistry and haematology under ‘optimal’ seasonal conditions: means and medians for cow and herd bull groups at site B.

<table>
<thead>
<tr>
<th>SERUM AND BLOOD BIOCHEMISTRY</th>
<th>heifer (1.5–2.5 years old)</th>
<th>mature cow (5.5–7.5 years old)</th>
<th>mature bull (4–6 years old)</th>
<th>Difference between groups</th>
<th>Testing Laboratory – Reference Range</th>
<th>Key Publications – Comparative Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>sodium (Na) (mmol/L) (n)</td>
<td>(57)</td>
<td>(74)</td>
<td>(28)</td>
<td></td>
<td>132–152</td>
<td>132–152^p</td>
</tr>
<tr>
<td>mean (95% CI)</td>
<td>143^a (141.144)</td>
<td>140^p (138.141)</td>
<td>144^a (140.147)</td>
<td>p = 0.00078</td>
<td></td>
<td></td>
</tr>
<tr>
<td>median (10–90^th percentile)</td>
<td>142 (136,150)</td>
<td>140 (134,145)</td>
<td>143 (136,157)^*</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>chloride (Cl) (mmol/L) (n)</td>
<td>(57)</td>
<td>(74)</td>
<td>(28)</td>
<td></td>
<td>95–100</td>
<td>95–110^p</td>
</tr>
<tr>
<td>mean (95% CI)</td>
<td>103^a (102,105)</td>
<td>100^p (99,101)</td>
<td>107^a (103,110)</td>
<td>p &lt; 0.0001</td>
<td></td>
<td></td>
</tr>
<tr>
<td>median (10–90^th percentile)</td>
<td>103 (99,109)^*</td>
<td>100 (95,103)^*</td>
<td>105 (98,116)^*</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>creatinine (µmol/L) (n)</td>
<td>(57)</td>
<td>(74)</td>
<td>(27)</td>
<td></td>
<td>88–239</td>
<td>67–175^p</td>
</tr>
<tr>
<td>mean (95% CI)</td>
<td>148^a (140,155)</td>
<td>144^a (138,151)</td>
<td>191^b (180,202)</td>
<td>p &lt; 0.0001</td>
<td></td>
<td></td>
</tr>
<tr>
<td>median (10–90^th percentile)</td>
<td>144 (118,181)</td>
<td>145 (110,180)</td>
<td>190 (155,232)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>urea (mmol/L) (n)</td>
<td>(57)</td>
<td>(74)</td>
<td>(27)</td>
<td></td>
<td>2.1–9.6</td>
<td>2.0–7.5^p</td>
</tr>
<tr>
<td>mean (95% CI)</td>
<td>5.3^a (5.0,5.7)</td>
<td>4.0^b (3.6,4.3)</td>
<td>5.0^a,b (4.0,5.9)</td>
<td>p = 0.00001</td>
<td></td>
<td></td>
</tr>
<tr>
<td>median (10–90^th percentile)</td>
<td>5.5 (3.0,7.1)</td>
<td>3.9 (2.5,5.3)</td>
<td>4.7 (2.9,7.5)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>bilirubin-total (µmol/L) (n)</td>
<td>(54)</td>
<td>(73)</td>
<td>(25)</td>
<td></td>
<td>0–32</td>
<td>0.2–9^p</td>
</tr>
<tr>
<td>mean (95% CI)</td>
<td>n/a</td>
<td>n/a</td>
<td>n/a</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>median (10–90^th percentile)</td>
<td>4^a (2.8)</td>
<td>5^b (2.12)</td>
<td>2^b (0.3)</td>
<td>p &lt; 0.0001</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

1 Cow and herd bull group means or medians with different superscripts within rows are significantly different (p < 0.05).
2 Comparison with reference range of Testing Laboratory. Percentiles of cow and herd bull group medians are superscripted where: the 10^th percentile is lower than the reference range (^); the 90^th percentile is lower than the reference range (*); the 90^th percentile is higher than the reference range (^); the 10^th percentile is higher than the reference range (*); or both the 10^th and 90^th percentiles are outside of the reference range (^).
3 Two selected Key Publications: p (Radostits et al. 2007); and β (Boyd 1984).
4 n/a = not available; mean not analysed for non-parametric data that violated Levene’s test for homogeneity of variance (p < 0.001).
APPENDICES

Appendix 21. (continued)

<table>
<thead>
<tr>
<th></th>
<th>heifer (1.5–2.5 years old)</th>
<th>mature cow (5.5–7.5 years old)</th>
<th>mature bull (4–6 years old)</th>
<th>Difference between groups</th>
<th>Testing Laboratory – Reference Range</th>
<th>Key Publications – Comparative Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>mean (95% CI)</td>
<td>n/a</td>
<td>n/a</td>
<td>n/a</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>median (10–90th percentile)</td>
<td>80 (60,148)*</td>
<td>75 (61,98)</td>
<td>81 (35,137)*</td>
<td>p = 0.38</td>
<td></td>
<td></td>
</tr>
<tr>
<td>alkaline phosphatase (ALP) (IU/L) (n)</td>
<td>(54)</td>
<td>(73)</td>
<td>(25)</td>
<td></td>
<td>41–94</td>
<td>0–500p</td>
</tr>
<tr>
<td>mean (95% CI)</td>
<td>111a (81,141)</td>
<td>55b (39,72)</td>
<td>65ab (31,98)</td>
<td>p = 0.00179</td>
<td></td>
<td></td>
</tr>
<tr>
<td>median (10–90th percentile)</td>
<td>83 (45,142)*</td>
<td>40 (26,80)*</td>
<td>45 (22,107)*</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>gamma glutamyl transferase (GGT) (IU/L) (n)</td>
<td>(54)</td>
<td>(73)</td>
<td>(25)</td>
<td></td>
<td>13–32</td>
<td>6–17p</td>
</tr>
<tr>
<td>mean (95% CI)</td>
<td>16 (14,18)</td>
<td>15 (14,16)</td>
<td>17 (16,19)</td>
<td>p = 0.26359</td>
<td></td>
<td></td>
</tr>
<tr>
<td>median (10–90th percentile)</td>
<td>14 (12,22)*</td>
<td>15 (10,21)*</td>
<td>17 (13,21)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>creatine phosphokinase (CPK) (IU/L) (n)</td>
<td>(54)</td>
<td>(73)</td>
<td>(25)</td>
<td></td>
<td>66–220</td>
<td>35–280p</td>
</tr>
<tr>
<td>mean (95% CI)</td>
<td>n/a</td>
<td>n/a</td>
<td>n/a</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>median (10–90th percentile)</td>
<td>225a (153,586)*</td>
<td>191b (112,333)*</td>
<td>131b (43,880)*</td>
<td>p = 0.001</td>
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<td></td>
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<tr>
<td>protein (g/L) (n)</td>
<td>(54)</td>
<td>(73)</td>
<td>(25)</td>
<td></td>
<td>57–81</td>
<td>57–81p</td>
</tr>
<tr>
<td>mean (95% CI)</td>
<td>67a (66,69)</td>
<td>70b (68,71)</td>
<td>71b (69,73)</td>
<td>p = 0.00119</td>
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<td></td>
</tr>
<tr>
<td>median (10–90th percentile)</td>
<td>67 (62,73)</td>
<td>69 (64,75)</td>
<td>71 (64,78)</td>
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</tr>
</tbody>
</table>
### APPENDICES

#### Appendix 21. (continued)

<table>
<thead>
<tr>
<th></th>
<th>heifer (1.5–2.5 years old)</th>
<th>mature cow (5.5–7.5 years old)</th>
<th>mature bull (4–6 years old)</th>
<th>Difference between groups</th>
<th>Testing Laboratory – Reference Range</th>
<th>Key Publications – Comparative Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>albumin (g/L) (n)</td>
<td>(57)</td>
<td>(74)</td>
<td>(28)</td>
<td></td>
<td>21–36</td>
<td>21–36p</td>
</tr>
<tr>
<td>mean (95% CI)</td>
<td>39a (38,40)</td>
<td>38b (37,39)</td>
<td>35b (34,37)</td>
<td>p = 0.00026</td>
<td>21–36</td>
<td>21–36p</td>
</tr>
<tr>
<td>median (10–90th percentile)</td>
<td>38 (35,44)</td>
<td>37 (32,43)</td>
<td>35 (31,41)</td>
<td></td>
<td>28–50</td>
<td>29–49p</td>
</tr>
<tr>
<td>albumin-to-globulin ratio (n)</td>
<td>(54)</td>
<td>(73)</td>
<td>(25)</td>
<td></td>
<td>0.6–1.3</td>
<td>0.6–1.3b</td>
</tr>
<tr>
<td>mean (95% CI)</td>
<td>1.4a (1.3,1.5)</td>
<td>1.2b (1.2,1.3)</td>
<td>1.0c (0.9,1.1)</td>
<td>p &lt; 0.00001</td>
<td>2–2.63</td>
<td>2.43–3.10p</td>
</tr>
<tr>
<td>median (10–90th percentile)</td>
<td>1.4 (1.0,1.9)</td>
<td>1.1 (1.0,1.6)</td>
<td>1.0 (0.7,1.4)</td>
<td></td>
<td>2.38 (2.20,2.49)</td>
<td>2.22 (2.00,2.38)</td>
</tr>
<tr>
<td>calcium (Ca) (mmol/L) (n)</td>
<td>(54)</td>
<td>(73)</td>
<td>(25)</td>
<td></td>
<td>1.29–2.26</td>
<td>1.08–2.76p</td>
</tr>
<tr>
<td>mean (95% CI)</td>
<td>2.37a (2.33,2.40)</td>
<td>2.19b (2.16,2.23)</td>
<td>2.30a (2.23,2.38)</td>
<td>p &lt; 0.00001</td>
<td>1.71a (1.62,1.80)</td>
<td>1.18b (1.11,1.25)</td>
</tr>
<tr>
<td>median (10–90th percentile)</td>
<td>2.38 (2.20,2.49)</td>
<td>2.22 (2.00,2.38)</td>
<td>2.36 (2.05,2.53)</td>
<td></td>
<td>1.69 (1.28,2.17)</td>
<td>1.16 (0.82,1.52)</td>
</tr>
<tr>
<td>phosphorus (P) (mmol/L) (n)</td>
<td>(54)</td>
<td>(73)</td>
<td>(25)</td>
<td></td>
<td>1.29–2.26</td>
<td>0.49–1.44</td>
</tr>
<tr>
<td>mean (95% CI)</td>
<td>1.71a (1.62,1.80)</td>
<td>1.18b (1.11,1.25)</td>
<td>1.95c (1.80,2.09)</td>
<td>p &lt; 0.0001</td>
<td>1.05 (1.00,1.11)</td>
<td>1.03 (0.98,1.08)</td>
</tr>
<tr>
<td>median (10–90th percentile)</td>
<td>1.69 (1.28,2.17)</td>
<td>1.16 (0.82,1.52)</td>
<td>2.00 (1.50,2.43)</td>
<td></td>
<td>1.00 (0.83,1.34)</td>
<td>1.02 (0.72,1.26)</td>
</tr>
<tr>
<td>magnesium (Mg) (mmol/L) (n)</td>
<td>(57)</td>
<td>(74)</td>
<td>(27)</td>
<td></td>
<td>0.49–1.44</td>
<td>0.74–1.10p</td>
</tr>
<tr>
<td>mean (95% CI)</td>
<td>0.95 (0.93,1.07)</td>
<td>0.97 (0.93,1.10)</td>
<td>0.97 (0.93,1.10)</td>
<td>p = 0.47793</td>
<td>0.49–1.44</td>
<td>0.74–1.10p</td>
</tr>
<tr>
<td>median (10–90th percentile)</td>
<td>1.00 (0.83,1.34)</td>
<td>1.02 (0.72,1.26)</td>
<td>0.97 (0.82,1.20)</td>
<td></td>
<td>1.00 (0.83,1.34)</td>
<td>1.02 (0.72,1.26)</td>
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</table>
### APPENDICES

**Appendix 21. (continued)**

<table>
<thead>
<tr>
<th>HAEMATOLOGY²</th>
<th>heifer (1.5–2.5 years old)</th>
<th>mature cow (5.5–7.5 years old)</th>
<th>mature bull (4–6 years old)¹</th>
<th>Difference between groups</th>
<th>Testing Laboratory – Reference Range</th>
<th>Key Publications – Comparative Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>haemoglobin (Hb) (g/L) (n)</td>
<td>(54)</td>
<td>(73)</td>
<td>(n/a)</td>
<td>80–150</td>
<td>80–150⁹</td>
<td></td>
</tr>
<tr>
<td>mean (95% CI)</td>
<td>150ᵃ (147,154)</td>
<td>139ᵇ (137,142)</td>
<td></td>
<td></td>
<td>p &lt; 0.00001</td>
<td></td>
</tr>
<tr>
<td>median (10–90ᵗʰ percentile)</td>
<td>152 (136,165)ᵃ</td>
<td>140 (125,153)ᵇ</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>packed cell volume (PCV) (percentage) (n)</td>
<td>(54)</td>
<td>(73)</td>
<td>(n/a)</td>
<td>0.24–0.46</td>
<td>0.24–0.46⁹</td>
<td></td>
</tr>
<tr>
<td>mean (95% CI)</td>
<td>0.43ᵃ (0.42,0.44)</td>
<td>0.40ᵇ (0.39,0.40)</td>
<td></td>
<td></td>
<td>p &lt; 0.00001</td>
<td></td>
</tr>
<tr>
<td>median (10–90ᵗʰ percentile)</td>
<td>0.43 (0.39,0.47)ᵃ</td>
<td>0.40 (0.36,0.44)ᵇ</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>total red cell count (RBCc) (x10¹²/L) (n)</td>
<td>(30)</td>
<td>(70)</td>
<td>(n/a)</td>
<td>5–10</td>
<td>5–10⁹</td>
<td></td>
</tr>
<tr>
<td>mean (95% CI)</td>
<td>8.5ᵃ (8.1,8.8)</td>
<td>7.3ᵇ (7.1,7.4)</td>
<td></td>
<td></td>
<td>p &lt; 0.00001</td>
<td></td>
</tr>
<tr>
<td>median (10–90ᵗʰ percentile)</td>
<td>8.7 (7.2,9.5)ᵃ</td>
<td>7.4 (6.4,7.9)ᵇ</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>total white cell count (WBCc) (x10⁹/L) (n)</td>
<td>(29)</td>
<td>(70)</td>
<td>(n/a)</td>
<td>4–12</td>
<td>4–12⁹</td>
<td></td>
</tr>
<tr>
<td>mean (95% CI)</td>
<td>8.2ᵃ (7.5,8.9)</td>
<td>6.7ᵇ (6.4,7.1)</td>
<td></td>
<td></td>
<td>p = 0.00007</td>
<td></td>
</tr>
<tr>
<td>median (10–90ᵗʰ percentile)</td>
<td>8.3 (6.1,10.5)ᵃ</td>
<td>6.6 (4.9,9.0)ᵇ</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>platelets (x10⁹/L) (n)</td>
<td>(30)</td>
<td>(55)</td>
<td>(n/a)</td>
<td>100–800</td>
<td>100–800⁹</td>
<td></td>
</tr>
<tr>
<td>mean (95% CI)</td>
<td>197ᵃ (170,224)</td>
<td>152ᵇ (135,168)</td>
<td></td>
<td></td>
<td>p = 0.00284</td>
<td></td>
</tr>
<tr>
<td>median (10–90ᵗʰ percentile)</td>
<td>196 (91,306)ᵃ</td>
<td>138 (90,248)ᵇ</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

¹ n/a = not available; no haematological tests were reported for bulls.
² See footnotes at front of Appendix 21 for details on comparative reference ranges, significance of difference between means or medians, and comparisons with 10–90ᵗʰ percentiles.
Appendix 22. Biochemical indicators of nutrition, per categories of financial years: 25\textsuperscript{th} percentile and median value of lowest ranked year, compared with reference range for cow and herd bull groups at sites B and C.

<table>
<thead>
<tr>
<th>Serum and Blood Biochemistry (reference range ( ^{\text{TL}} ))</th>
<th>site B</th>
<th>site C</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>young cow (3–5 years old)</td>
<td>mature bull (4–6 years old)</td>
</tr>
<tr>
<td>urea (2.1–9.6 mmol/L)</td>
<td>1995/96 ( ^{(3)} )*** (2.4, 3.8)</td>
<td>1994/95 ( ^{(4)} )*** (3.1, 4.1)</td>
</tr>
<tr>
<td>calcium (Ca) (2–2.63 mmol/L)</td>
<td>1992/93 ( ^{(5)} ) n.s. (2.06, 2.22)</td>
<td>1993/94 ( ^{(4)} )*** (2.14, 2.25)</td>
</tr>
<tr>
<td>phosphorus (P) (1.29–2.26 mmol/L)</td>
<td>1991/92 ( ^{(3)} )*** (0.90#, 1.00#)</td>
<td>1992/93 ( ^{(3)} ) n.s. (1.60, 1.80)</td>
</tr>
<tr>
<td>glutathione peroxidise (GSH-Px) (60–130+ U/g Hb)</td>
<td>1994/95 ( ^{(4)} )*** (70, 78)</td>
<td>n/a</td>
</tr>
<tr>
<td>vitamin A (0.3–0.6 mg/L)</td>
<td>1994/95 ( ^{(5)} )*** (0.26#, 0.30#)</td>
<td>n/a</td>
</tr>
<tr>
<td>vitamin E (1.9–8.6 mg/L)</td>
<td>1991/92 ( ^{(5)} )*** (6.03, 6.36)</td>
<td>n/a</td>
</tr>
</tbody>
</table>

\( ^{\text{TL}} \) = not available: limited biochemical tests at sites B and C.

Number of years analysed: \( ^{(3)} \) = based on 3 years of data; \( ^{(4)} \) = based on 4 years of data; \( ^{(5)} \) = based on 5 years of data.

Significance of difference between categories of financial years: n.s. = no significant difference; ** = \( p < 0.05 \); *** = \( p < 0.01 \).

Comparison with reference range of the testing laboratory (\( ^{\text{TL}} \)): \( ^{\#} \) = below normal reference range.
Appendix 23. Faecal chemistry values, per categories of 2-months cumulative rainfall: median and quartile range for cow and steer groups at sites B and C.

<table>
<thead>
<tr>
<th>2-months cumulative rainfall</th>
<th>site B</th>
<th>site C</th>
</tr>
</thead>
<tbody>
<tr>
<td>young cow (3–5 years old)</td>
<td>store steer (&lt; 2.5 years old)</td>
<td>young cow (3–5 years old)</td>
</tr>
<tr>
<td>n ≥ 24</td>
<td>n ≥ 19</td>
<td>n ≥ 19</td>
</tr>
<tr>
<td>median% (quartile range%)</td>
<td>median% (quartile range%)</td>
<td>median% (quartile range%)</td>
</tr>
</tbody>
</table>

**Faecal %P** reference: 0.2% faecal P (threshold value for maintenance)

<table>
<thead>
<tr>
<th>2-months cumulative rainfall</th>
<th>site B</th>
<th>site C</th>
</tr>
</thead>
<tbody>
<tr>
<td>0–24mm</td>
<td><strong>0.16</strong> (0.15–0.20)</td>
<td>n.s.</td>
</tr>
<tr>
<td>25–49mm</td>
<td>0.29 (0.25–0.33)</td>
<td>n/a (n/a)</td>
</tr>
<tr>
<td>50–99mm</td>
<td><strong>0.28</strong> (0.23–0.32)</td>
<td>n/a (n/a)</td>
</tr>
<tr>
<td>200+mm</td>
<td>n/a (n/a)</td>
<td>n/a (n/a)</td>
</tr>
</tbody>
</table>

**Faecal %N** reference: 1.3% faecal N (threshold value for maintenance)

<table>
<thead>
<tr>
<th>2-months cumulative rainfall</th>
<th>site B</th>
<th>site C</th>
</tr>
</thead>
<tbody>
<tr>
<td>0–24mm</td>
<td><strong>1.46</strong> (1.27–1.78)</td>
<td><strong>1.66</strong> (1.47–2.03)</td>
</tr>
<tr>
<td>25–49mm</td>
<td>1.55 (1.44–1.83)</td>
<td>n/a (n/a)</td>
</tr>
<tr>
<td>50–99mm</td>
<td><strong>1.61</strong> (1.50–1.82)</td>
<td><strong>1.45</strong> (1.35–1.73)</td>
</tr>
<tr>
<td>200+mm</td>
<td>n/a (n/a)</td>
<td>n/a (n/a)</td>
</tr>
</tbody>
</table>

n/a = not available: less than five samples.

Significance of difference between cumulative rainfall categories with faecal chemistry values: n.s. = no significant difference; * = p < 0.1; ** = p < 0.05; *** = p < 0.01.

Ranking of cumulative rainfall categories with faecal chemistry values: (l) = lowest; (h) = highest; (≈) = equivalent.

Comparison of quartile range: # = extends below a reference threshold value for maintenance (McCosker & Winks 1994, p.56).
### Appendix 23. (continued)

<table>
<thead>
<tr>
<th>2-months cumulative rainfall</th>
<th>site B</th>
<th>site C</th>
</tr>
</thead>
<tbody>
<tr>
<td>young cow (3–5 years old)</td>
<td>store steer (&lt; 2.5 years old)</td>
<td>young cow (3–5 years old)</td>
</tr>
<tr>
<td>median% (quartile range%)</td>
<td>median% (quartile range%)</td>
<td>median% (quartile range%)</td>
</tr>
<tr>
<td>n &gt; 24</td>
<td>n &gt; 19</td>
<td>n &gt; 13</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Faecal %DM reference: 12–24% faecal DM (range of physiologically-normal values)</th>
</tr>
</thead>
<tbody>
<tr>
<td>***</td>
</tr>
<tr>
<td>0–24mm</td>
</tr>
<tr>
<td>25–49mm</td>
</tr>
<tr>
<td>50–99mm</td>
</tr>
<tr>
<td>200+mm</td>
</tr>
</tbody>
</table>

n/a = not available; less than five samples.

Significance of difference between cumulative rainfall categories with faecal chemistry values: n.s. = no significant difference; * = p < 0.1; ** = p < 0.05; *** = p < 0.01.

Ranking of cumulative rainfall categories with faecal chemistry values: (l) = lowest; (h) = highest; (≈) = equivalent.

Comparison of quartile range: ## = extends outside a reference range for the physiologically-normal values (Harper et al. 1997; Weiss & St-Pierre 2006).
## Appendix 24. Genera of intestinal nematode eggs and larvae in faecal samples at site B.

<table>
<thead>
<tr>
<th>Cattle class</th>
<th>acc: nematode eggs*</th>
<th>acc: nematode larvae†</th>
<th>Cooperia spp.-type</th>
<th>Oesphagostomum sp./Haemonchus sp.-type</th>
<th>Percentage of larvae cultured per faecal sample</th>
</tr>
</thead>
<tbody>
<tr>
<td>female weaned-calf</td>
<td>7</td>
<td>4</td>
<td>0–150</td>
<td>0–120</td>
<td>0–100%</td>
</tr>
<tr>
<td>male weaned-calf</td>
<td>4</td>
<td>11</td>
<td>0–120</td>
<td>0–480</td>
<td>0–100%</td>
</tr>
<tr>
<td>cow</td>
<td>4</td>
<td>3</td>
<td>0–90</td>
<td>0–120</td>
<td>0–100%</td>
</tr>
<tr>
<td>herd bull</td>
<td>0</td>
<td>2</td>
<td>n/a</td>
<td>n/a</td>
<td>0–100%</td>
</tr>
</tbody>
</table>

n/a = not available: limited samples assessed for site B.

* collected within six months of the first muster.
† collected within 18 months of the last muster.
Appendix 25. Faecal egg and oocyst counts, per categories of financial years: key data distribution ranges for cow, herd bull and weaned-calf groups at site B.

<table>
<thead>
<tr>
<th>Financial year</th>
<th>Quartile range</th>
<th>10–90th percentile</th>
<th>Quartile range</th>
<th>10–90th percentile</th>
<th>Quartile range</th>
<th>10–90th percentile</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Faecal egg count (epg)</strong></td>
<td>reference: 500 epg (threshold for clinical intestinal nematodiasis)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1991/92</td>
<td>(l)0–50</td>
<td>0–120</td>
<td>(l)0–0</td>
<td>0–0</td>
<td>0–10</td>
<td>n.s.</td>
</tr>
<tr>
<td>1992/93</td>
<td>100–440</td>
<td>0–720&lt;sup&gt;#&lt;/sup&gt;</td>
<td>(h)0–0</td>
<td>0–10</td>
<td>(h)0–50</td>
<td>0–80&lt;sup&gt;ab&lt;/sup&gt;</td>
</tr>
<tr>
<td>1993/94</td>
<td>40–240</td>
<td>0–456&lt;sup&gt;ew&lt;/sup&gt;</td>
<td>0–0</td>
<td>0–20</td>
<td>(h)0–0</td>
<td>0–28</td>
</tr>
<tr>
<td>1994/95</td>
<td>(h)140–420</td>
<td>69–889&lt;sup&gt;#&lt;/sup&gt;</td>
<td>0–0</td>
<td>0–0</td>
<td>0–0</td>
<td>0–0</td>
</tr>
<tr>
<td>1995/96</td>
<td>40–200</td>
<td>0–300</td>
<td>0–0</td>
<td>0–0</td>
<td>0–0</td>
<td>0–0</td>
</tr>
<tr>
<td><strong>Faecal oocyst count (opg)</strong></td>
<td>reference: 5,000 opg (threshold for clinical coccidiosis)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1991/92</td>
<td>0–0</td>
<td>0–14</td>
<td>(l)0–0</td>
<td>0–0</td>
<td>0–0</td>
<td>0–0</td>
</tr>
<tr>
<td>1992/93</td>
<td>0–40</td>
<td>0–120&lt;sup&gt;ow&lt;/sup&gt;</td>
<td>(l)0–0</td>
<td>0–0</td>
<td>(l)0–0</td>
<td>0–0</td>
</tr>
<tr>
<td>1993/94</td>
<td>(h)0–0</td>
<td>0–0</td>
<td>(l)0–0</td>
<td>0–0</td>
<td>(l)0–0</td>
<td>0–0</td>
</tr>
<tr>
<td>1994/95</td>
<td>(h)0–120</td>
<td>0–980</td>
<td>(l)0–0</td>
<td>0–0</td>
<td>(l)0–0</td>
<td>0–0</td>
</tr>
<tr>
<td>1995/96</td>
<td>(h)0–60</td>
<td>0–240</td>
<td>(l)0–0</td>
<td>0–0</td>
<td>(l)0–0</td>
<td>0–0</td>
</tr>
</tbody>
</table>

Significance of difference between financial year categories with transformed faecal counts: n.s. = no significant difference; *** = p < 0.01.
Ranking of financial year categories with transformed faecal counts: (l) = lowest; (h) = highest; (≈) = equivalent.
Range of faecal counts: # = above a reference threshold for clinical intestinal nematodiasis (Radunz 1992); ## = above a reference threshold for clinical coccidiosis (Radostits et al. 2007, p.1503).
Maximum faecal egg count for cattle group: ec = 140 epg; eb = 720; ew = 1,920 epg.
Maximum faecal oocyst count for cattle group: oc = 20 opg; ob = 100 opg; ow = 15,050 opg.
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NT-DOR—see NORTHERN TERRITORY DEPARTMENT OF RESOURCES
NT-DPI&F—see NORTHERN TERRITORY DEPARTMENT OF PRIMARY INDUSTRY AND FISHERIES
NT-DPP—see NORTHERN TERRITORY DEPARTMENT OF PRIMARY PRODUCTION
NT-NRETAS—see NORTHERN TERRITORY DEPARTMENT OF NATURAL RESOURCES, ENVIRONMENT, THE ARTS AND SPORT
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