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Mortality, wastage, and lifetime productivity of *Bos indicus* cows under extensive grazing in northern Australia
2. Continuous mating in the semi-arid tropics

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Summary. Mortality and wastage rates and lifetime productivity were studied over 4800 cow years from 1981 to 1990 with continuous mating and minimal management in the semi-arid tropics at Kidman Springs, Northern Territory. The proportional hazards model was used to estimate age-specific mortality and wastage rates, adjusted for cohort effects. Annual breeder mortality rate averaged 11.5%, with similar rates in the range 9.0–12.0% for 2–9-year olds, increasing to 15.5% for 10-year-olds, 17.9% for 11-year-olds, and >20% for older cows. A further 20.8% of the cows that calved failed to rear the calf to branding.

Wastage included mortalities and physical culls but minimal discretionary culls based on reproductive performance or maximum age. The wastage rate averaged 16.7%, ranged from 11.1 to 14.4% for 2–9-year-olds, increased to 21.1% for 10-year-olds and 34.3% for 11-year-olds, and exceeded 50% for older cows. The heifer replacement rate to maintain a stable herd size was 16.3%.

Typical lifetime productivity up to 10 years of age in this harsh north-western environment was 3.1 calves reared over a lifetime of 6.5 years in the breeding herd, at a rate of 44.5% calves per year. Timing of first pregnancy was identified as a useful predictor of lifetime productivity when overall productivity was low. Cows that were lactating as 2-year-olds reared 4.0 calves in their lifetime up to 10 years of age, cows pregnant at this age reared 3.2 calves, and nonpregnant cows reared only 2.6 calves.

Introduction

Breeding cow mortality rates in harsh environments of up to 15% in normal years and up to 30% in poor seasons (Holroyd and O'Rourke 1989) have a severe impact on the viability and profitability of beef enterprises in north-western Australia. There have been few reports quantifying mortality levels for different ages and reproductive classes in the herd and suggesting management changes to improve on these levels. Losses from confirmed pregnancy to branding exceed the acceptable and economically tolerable upper limit of 12% (Holroyd 1987) in the tropical tallgrass area near Darwin (McCosker and Eggington 1986), and would be expected to do so for other areas in north-western Australia.

Wastage rate represents the number of cows leaving the herd during the year through deaths and disposals. It determines the number of replacement heifers required to maintain a stable herd size. Producers in north-western Australia indicated that they retained 82% of their heifers as replacements, and 37% of producers retained all of their heifers (O'Rourke *et al.* 1992). Wastage rates and patterns for this environment still need to be analysed for herd dynamics and economic modelling (Azzam *et al.* 1990). Lifetime productivity, which integrates longevity, fertility, and growth to give the total value of each cow to the breeding enterprise, has been studied in southern Australia by Newman *et al.* (1990) and in several overseas herds (Sacco *et al.* 1989; Arthur *et al.* 1993; Morris *et al.* 1993) but not in north-western Australia.

This paper reports on a study of herd dynamics and lifetime productivity in the semi-arid tropics under continuous mating and with minimal management in north-western Australia. It follows the methodology used in a complementary study in the speargrass region in North Queensland (O'Rourke *et al.* 1995) to broaden the scope of the earlier results to a second environment in northern Australia. A third paper in this series will compare a range of culling strategies for their impact on the herd for these 2 environments.

Materials and methods

Location

The study was conducted from June 1981 to June 1990 at the Victoria River Research Station, Kidman Springs (16°7'S, 130°57'E), 220 km south-west of Katherine in the Victoria River district of the Northern Territory. The property is within the semi-arid tropics and has a hot, seasonally dry monsoonal climate.

The experimental area comprised 2 main soil types: a cracking clay and a calcareous red earth. The cracking clay soils are dominated by ribbon grass (*Chrysopogon fallax*) and Flinders grass (*Iseilema fragile*), with bluegrass (*Dichanthium* spp.), Mitchell grass (*Astrebla* spp.), and feathertop wire grass (*Aristida latifolia*) also present. The calcareous red earth was dominated by limestone grass (*Enneapogon* spp.), native couch (*Brachyachne convergens*), fairy grass (*Sporobulus australasicus*), and wire grass (*Aristida* spp.) (Foran *et al.* 1985). From 1981 to 1985 the herd grazed paddocks with predominantly cracking clay soils at stocking rates of 8–12 ha/cow (November–June) and paddocks dominated by calcareous red earth at rates of 5–8 ha/cow (June–November). From 1985 to 1987, cows grazed the same paddock for the full year at stocking rates of 7–10 ha/cow, but the animals were moved to a spelled paddock in June each year. The paddocks were spelled when not grazed by experimental animals and were not burnt. However, paddocks were set-stocked during the final 3 years at 14–16 ha/breeder.

Animals and measurements

A herd of 542 Droughtmaster x beef Shorthorn cows of 3/8 to 5/8 *Bos indicus* content was established in 1981 from several sources. The numbers of cows for each age group (2–10 years) were 61, 37, 94, 108, 59, 58, 53, 54, and 18. An extra 46 mature-aged cows were added in 1983 to compensate for losses from a severe botulism outbreak in 1982. The numbers of cows for the age groups 3–9 years were 5, 3, 23, 8, 4, 1, and 2. Two-year-old replacement heifers were added each year from 1982 to 1989 to maintain stable herd size; the numbers added were 78, 77, 61, 94, 77, 82, 80, and 80. No cow was transferred out of the herd, but nonpregnant cows aged ≥12 years were culled from 1985. At the end of the study in 1990, the number of cows remaining in each cohort (3–18 years) was 62, 52, 56, 46, 59, 32, 36, 35, 20, 10, 2, 4, 0, 1, 0, and 1.

Droughtmaster bulls remained with the breeding herd throughout the year, except for 3–4 weeks following the June muster. Calves weighing >100 kg were weaned from their dams at branding in June (all years), at the following muster in October (1985–89), or as yearlings in the following June (all years). Those selected as heifer replacements were returned to the herd as 2-year-olds between December and February. Heifer segregation from bulls before joining the herd was ineffective, particularly in the early years, and unweaned yearling heifers were also exposed to bulls. Consequently 13.3% of cows were rearing their first calf as 2-year-olds and a further 19.3% were ≥6 months pregnant by the June muster.

The breeding herd was mustered in June, October, and April each year, with the year considered to extend from June to June. Cows were individually identified so that their age could be determined from their branding cohort. Cow age was defined as the number of years since branding to the start of the current year in June. Actual age at the annual branding in June was in the range 0–12 months. Hence, a 2-year-old cow was 2–3 years old at the start of the year and 3–4 years old at the end.

At each muster, cows were weighed and examined for pregnancy by rectal palpation, and lactation status was determined. Cows were confirmed pregnant at the first muster when they were diagnosed as ≥3 months pregnant. Calving was defined by a completed, confirmed pregnancy. Failure to rear a calf to the first muster following calving and to branding were expressed as a percentage of cows that calved. Branding rate was assessed from lactation status in June as long as the cow had calved over the previous year. In this way, persistent lactation to support a yearling calf was distinguished from branding a new calf. These definitions were relevant for the study of fetal and calf losses. As a consequence of the long intervals between musters, losses could only be assigned loosely to prenatal, perinatal, and postnatal periods. A variable amount of prenatal loss would have occurred before confirmed pregnancy, and similarly for postnatal losses after rearing to first muster or to branding. Hence, these losses tend to be underestimates.

Dead cows were identified during regular paddock inspections, but death was usually defined retrospectively by absence at 5 consecutive musters of the expected and neighbouring paddocks. Time of death was assigned to the period immediately following the cow's final muster as dry season, late dry–early wet season, or late wet season. Culling was on physical defects, for injury, and on bad temperament. Infertility culling was used leniently, with cows culled only if they failed to rear a calf for 2 consecutive years and were still nonpregnant, and heifers if they failed to conceive by 3.5 years of age. All culling was at the June muster.

The data used for lifetime productivity was from 690 cows that joined the herd as 2-year-olds in 9 cohorts from 1981 to 1989. Rearing status was determined at the June muster by lactation following confirmed pregnancy (indicating that a calf was reared to branding, coded as 1) or nonlactation (indicating failure to rear, coded as 0) for each year in the herd from 2-year-old to a maximum of 10-year-old. The number of records for each cow indicated its productive time in the herd, with the record being truncated by death or culling on physical abnormalities. When the study was terminated in 1990, the 1979 and 1980 cohorts had completed their maximum herd life up to 10 years, the 1981 cohort was up to 9 years, and successively up to the 1987 cohort, which had records only up to 3 years of age. Dead or culled cows did not rear a calf during their final year in the herd. As calves were not identified with their dams, output in terms of weaner weight could not be assigned to individual cows. Hence, the primary lifetime data for each cow were number of years in the herd and number of calves reared to branding, with standardisation to potential years in the herd to assist with interpretation (O'Rourke *et al.* 1995). Additional data sets were established for maximum age of 8 years by editing out data beyond the specified maximum age.

Progeny liveweights were measured in June each year, so that branding weights were available for 1981–87 cohorts, yearling weights for 1980–87 cohorts, and 2-year-old weights for all 9 cohorts. The 2-year-old weights were confounded because of variable pregnancy and lactation status (see above).

Statistical methods

The proportional hazards model for grouped data (Bartlett 1978) was used to estimate age and year effects for mortality and wastage rates, as described by O'Rourke *et al.* (1995). The least squares method for unequal subclass numbers (Harvey 1960; 1982) was used to analyse branding rate and lifetime productivity data. Reproductive status at 2 years of age was coded into 5 classes: lactating, for cows that had already calved; 6–9 months pregnant, to account for unscheduled conceptions; 5 months pregnant, as the ideal conception time; 1–4 months pregnant, as normal conception times; and not pregnant, for late conception or infertile cows. Animal-to-animal variation within cells was used to estimate experimental error. Pairwise testing of means for each main effect used the protected least significant difference procedure.

Results

Seasonal conditions

Rainfall was highly seasonal, with >80% of the average annual total of 672 mm falling from December to March and only 1% from May to September. Seasonal rainfall during the study is given in Table 1. Out-of-season rain during the dry season occurred only twice during 10 years, in July 1986 and May 1990. Wet season rainfall was effective in all years except 1988, but the date of onset and duration of effective rainfall were highly variable. Annual rainfall varied from 353 mm in 1987–88 to 912 mm in 1983–84. The rainfall in 1987–88 was marginally effective at best and produced very little pasture growth over the season.

Table 1. Seasonal and annual rainfall (mm) from July 1980 to June 1990 and long-term (1968–91) mean

	Dry season (July–Nov.)	Wet season (Dec.–Mar.)	Transition (Apr.–June)	Total
1980–81	49	667	0	716
1981–82	142	654	0	796
1982–83	78	435	39	552
1983–84	103	774	35	912
1984–85	71	463	270	804
1985–86	60	432	14	506
1986–87	42	545	0	587
1987–88	52	294	7	353
1988–89	144	450	43	637
1989–90	95	371	55	521
Long-term mean	87	555	30	672

Age and year effects for mortality, wastage, and branding rates

Age and year effects were significant ($P<0.01$) for mortality, wastage, and branding rates. The residual was also significant ($P<0.01$) but was of a lower order of magnitude than the main effects in all cases. Clearly, factors other than age and year affect these parameters in this environment, but age and year had highly important effects. The rates were similar at each age on the simple and adjusted scales, indicating the stability of estimates from this large data set which was reasonably balanced across years and cohorts.

The number of records (cows at risk) was highest at age 2 years, reduced gradually from ages 3 to 12, and was quite low after age 13 years. This pattern reflects cumulative wastage but also a relatively stable situation for a fixed number of years (Table 2). Mortality rates were similar at 9.0–12.0% for ages 2–9 years, suggesting that death was primarily a random event up to age 9 years. The rate then increased markedly from 10.3 to 37.9% between ages 9 and 13 years. The apparent drop at higher ages reflects instability from low numbers of cows and the tendency to cull older cows which might become survival risks during the following year. Wastage rates showed a tendency towards a U-shaped distribution, with slightly elevated rates at ages 2 and 3 years (13.1%), lowest rates at ages 4–6 (11.6%), an increase at ages 7–9 (14.0%), substantial increases at ages 10 (21.1%) and 11 (34.3%), and a plateauing above 50% for age 12 years and older. Branding rates were low overall but highest among maiden heifers (59.3%), low at ages 3 and 4 years (37.7%), slightly higher from ages 5 to 12 (43.8%), lowest at age 13 (22.0%), and unstable at older ages.

Back-transformed and simple year effects followed the same pattern for mortality rate, but back-transformed wastage rates were considerably higher than simple wastage rates because of the disproportionate impact of the low numbers of cows of ages 14–17 years. For

Table 2. Age and year effects from survival or least squares analysis for mortality, wastage, and branding rates (%)

	No. of cows at risk	Mortality rate	Wastage rate	Branding rate
		Age		
2 years	690	9.6	13.2	59.3
3 years	576	9.0	12.9	36.3
4 years	542	9.4	11.5	39.0
5 years	556	9.6	12.1	47.0
6 years	505	9.7	11.1	44.8
7 years	446	11.3	14.4	42.9
8 years	402	12.0	13.9	42.9
9 years	365	10.3	13.7	46.7
10 years	295	15.5	21.1	43.1
11 years	206	17.9	34.3	40.1
12 years	123	21.8	57.9	43.0
13 years	53	37.9	57.7	22.0
14 years	21	24.3	55.1	48.0
15 years	8	24.9	41.1	33.2
16 years	4	23.2	25.0	72.9
17 years	3	0.2	62.2	62.6
		Year		
1981	542	9.2	20.1	28.6
1982	562	24.8	41.1	46.4
1983	542	11.9	21.6	44.2
1984	526	7.8	22.7	47.9
1985	531	5.7	15.5	58.7
1986	550	15.4	31.0	34.8
1987	513	11.1	20.3	49.9
1988	520	12.5	24.2	47.3
1989	509	13.2	26.7	49.3
Overall	4795	11.5	24.1	45.2

mortality rate, this impact was masked by the low mortality rate at age 17 (0.2%) compared with the high wastage rate at that age (62.2%). Simple and least squares means were similar at each year for branding rate.

The size of the herd was similar over the 9-year period with a range of 509–562 cows (Table 2). Overall mortality (11.5%) and wastage (24.1%) rates were high and branding rate (45.2%) was low. The high mortality and wastage rates in 1982 correspond with a botulism outbreak. Apart from this, 1985 had the highest performance and 1986 the lowest.

Cow mortality was closely linked with calving and rearing the calf. Culled cows were predominantly nonpregnant and nonlactating (48.5%) or had just weaned a calf (49.2%), with very few pregnant (2.3%). Virtually all culled cows aged 2–4 years (96.7%), and most aged 5–9 years (56.3%), were nonpregnant and not lactating, but 75.3% of culled cows aged ≥10 years had just reared a calf.

Losses after confirmed pregnancy

The overall annual reproductive performance over all cow years can be summarised as follows: 44.6% of cows reared a calf to branding; 8.1% had a completed pregnancy but failed to brand a calf; 25.7% were still pregnant at the end of the year; and 21.6% remained nonpregnant throughout the year.

Table 3. Cow age effects for losses (%) from confirmed pregnancy to first muster post calving and to branding

Age at start of period (years)	No. at risk	Failure to lactate	Failure to brand
2	429	11.8	20.7
3	257	10.5	18.3
4	266	10.1	21.3
5	335	13.9	23.9
6	274	8.5	19.4
7	229	11.5	18.5
8	233	16.2	25.8
9	213	11.6	21.2
10	150	6.7	19.1
11	72	7.6	16.7
12	27	9.0	19.8
13	9	21.6	23.7
Overall	2506	11.5	20.8

The fate of the 690 heifers during their first year in the herd up to age 3 years can be summarised as 10.4% dead, 4.5% culled or infertile, 12.2% pregnant for the first time, 3.8% failed to rear first calf and still nonpregnant, 9.0% failed to rear first calf and pregnant, 50.0% rearing first calf and nonpregnant, and 10.1% rearing first calf and pregnant.

Fetal and calf losses after confirmed pregnancy are presented in Table 3 for 2 periods: failure to lactate up to the first muster post calving, and failure to rear the calf to branding. There were no consistent patterns ($P>0.05$) for age effects for any of the measures of calf loss, but year effects were significant ($P<0.01$) in all cases.

Based on cows that calved, 11.5% failed to lactate to the first muster after calving and 20.8% failed to rear to branding. The difference of 9.3% is part of postnatal losses. There were insufficient cows available for ages 14–17 years for reliable estimates of loss rates. Losses tended to be highest for 1988, with 26.5% of cows that calved failing to rear to branding, and lowest for 1984 (11.7%), while in 1981 there were high losses (27.0%) between first muster and branding. On a seasonal basis, failures to lactate were 11.9% for June–October, 15.4% for October–April, and 7.7% for April–June.

Lifetime productivity and factors affecting it

Two cohorts of 139 cows completed their full life of up to 8 reproductive cycles, from mating to weaning of the resultant calves, to a maximum age of 10 years between 1981 and 1990. They remained in the herd an average of 5.20 ± 2.87 years, reared 2.50 ± 1.95 calves in their lifetime, and averaged 39.2 ± 24.5% calves reared per year in the herd. There were many poor performers,

Table 4. Effects of reproductive status as 2-year-old on lifetime productivity to a maximum culling age of 8 or 10 years

Within columns, means followed by the same letter are not significantly different at $P = 0.05$

Reproductive status as 2-year-old	No. of cows	No. of years in herd 8 years	10 years	No. of calves reared 8 years	10 years	Calves reared per year (%) 8 years	10 years
Lactating	92	5.02	6.53	3.07a	3.98a	65.6a	65.3a
Pregnant (6–9 months)	133	4.99	6.49	2.54b	3.34ab	46.5b	46.7b
Pregnant (5 months)	104	4.79	6.21	2.38bc	3.10bc	43.6b	43.4b
Pregnant (1–4 months)	146	5.05	6.53	2.36b	3.10bc	43.3b	43.8b
Not pregnant	215	4.96	6.46	1.99c	2.63c	35.3c	35.5c
s.d.		1.58	2.16	1.69	2.26	27.4	27.4

21.6% of these cows rearing no calf and a further 18.0% rearing only 1 calf. At the other extreme, 1 cow reared 7 calves, 7 cows each reared 6 calves, and 18.0% of cows reared ≥5 calves. When maximum age was restricted to 8 years, 4 cohorts of 277 cows completed up to 6 cycles. Average time in the herd was 4.53 ± 1.93 years; 2.21 ± 1.41 calves were reared; and there were 43.8 ± 23.9% calves reared per year in the herd. While 15.2% of cows reared no calf and 18.4% reared only 1 calf, only 2.5% of cows reared ≥5 calves from 6 opportunities.

The standardised number of years in the herd averaged 4.99 ± 1.68 up to 8 years of age and increased to 6.50 ± 2.34 up to a maximum age of 10 years. The number of calves reared increased as maximum age increased, from 2.39 ± 1.73 calves up to 8 years, to 3.14 ± 2.32 calves up to 10 years. However, the efficiency measures of calves reared per year were similar for the 2 maximum culling ages at 44.5 ± 29.0%.

By 2 years of age, 13.3% of cows were rearing their first calf, 55.5% were pregnant, and 31.2% were not pregnant. Reproductive status as 2-year-olds had a significant ($P<0.05$) effect on lifetime number of calves reared and number of calves per year in the herd, but not on years in the herd ($P>0.05$) (Table 4). In general, cows lactating as 2-year-olds had higher lifetime productivity than cows that were pregnant at that stage. Both groups were more productive than cows that were still not pregnant. There was no difference in productivity between stages of pregnancy even though there was a tendency for higher productivity for cows in advanced pregnancy.

Cohort effects on lifetime productivity were significant ($P<0.05$) for the standardised number of calves reared, with highest numbers for the 1985 cohort (4.05) and lowest for the 1980 cohort (2.66). Although there was no significant ($P>0.05$) difference between cohorts for the percentage of calves reared per year in the herd, the 1981 (50.3%) and 1985 (52.8%) cohorts tended to have the highest values and the 1980 cohort (40.5%) the lowest.

Early predictors of lifetime productivity

Liveweights at branding and at yearling were closely related to subsequent reproductive status as 2-year-olds, with higher weights for those with more advanced reproductive status (Table 5). Cohort differences were also significant ($P<0.05$), with highest yearling weights for the 1981, 1982, 1984, and 1985 cohorts (256.7 kg) and lowest for the 1987 cohort (206.0 kg). Although cohort x reproductive status interactions were significant ($P<0.05$), they were of a lower order than the main effects and made only minor changes to the main effect patterns. These interactions could be a consequence of more effective segregation of heifers from bulls in the later years before entry into the breeding herd, which would diminish the main effect of reproductive status. Liveweight at 2 years of age was lowest for lactating cows and increased with advancing pregnancy status. Lactating cows had the highest weight gains from

Table 5. Effects of reproductive status as 2-year-old on liveweights and weight changes up to 2 years of age

Within columns, means followed by the same letter are not significantly different at $P = 0.05$

Reproductive status as 2-year-old	Liveweight (kg) Branding (1)	Yearling (2)	2-year-old (3)	Liveweight change (kg) 1–2	2–3	1–3
Lactating	159.7a	264.2a	232.3d	102.8a	–32.3d	70.0b
Pregnant (6–9 months)	157.9a	241.8b	323.1a	83.4c	81.9a	165.2a
Pregnant (5 months)	142.7b	232.8c	306.9b	90.1bc	76.0ab	166.6a
Pregnant (1–4 months)	134.2b	231.3c	299.5b	93.6ab	70.2b	165.9a
Not pregnant	121.0c	215.5d	280.9c	92.7b	64.7c	158.1a
s.d.	36.4	29.8	36.0	29.4	21.7	35.8

branding to yearling, lost weight as a consequence of calving and lactation up to 2 years, and had the lowest weight gain from branding to 2 years. Nonpregnant cows had lower weight gains than pregnant cows from yearling to 2 years of age but similar weight gains up to yearling and overall. However, liveweights of nonpregnant cows were lower than those of pregnant cows at all stages. Cows 6–9 months pregnant had higher liveweights than those at earlier stages of pregnancy at all ages, but weight changes were similar.

Liveweights at branding and at yearling and liveweight change from branding to yearling were weakly correlated (r = 0.05–0.23) with lifetime productivity. Correlations of liveweight at 2 years old and liveweight gain from branding to 2 years old with lifetime traits were low and non-significant, probably because a proportion of cows had calved and were lactating by 2 years of age. Stage of pregnancy and lactation status as 2-year-olds were positively correlated (r = 0.15–0.29) with lifetime productivity. All correlations with number of years in the herd were low and non-significant.

Discussion

This study and the complementary one at Swan's Lagoon (O'Rourke *et al.* 1995) have quantified mortality and wastage rates for 2 contrasting environments in northern Australia, to provide some basic data for use in herd dynamic analyses and models to assess their impact on profitability of breeding enterprises in the north. Productivity was particularly low in the harsh environments of the north-west, where Kidman Springs is located, with breeder mortalities averaging 12%, wastage rates 17%, branding rates 45%, and losses from confirmed pregnancy to branding 21%. Typical lifetime productivity with lenient culling up to 10 years of age was 3.1 calves over a lifetime of 6.5 years in the breeding herd at a rate of 44.5% calves reared per year in the herd. Productivity was higher than this but still low at Swan's Lagoon, in subcoastal North Queensland (O'Rourke *et al.* 1995).

Mortality rates

The overall mortality rate of 11.5% per year at Kidman Springs was much higher than that at Swan's Lagoon (1–2%). Reasons for the higher mortality rates at Kidman Springs include the less favourable environment, less property subdivision preventing close supervision of the herd, uncontrolled calving dates from year-round mating, limited culling for maximum age, and no strategic supplementation during poor seasons. The capacity for potential reductions in mortality in this environment was demonstrated by McCosker *et al.* (1991), with 3.7% mortality associated with a seasonal mating, weaning, and year-round supplementation regime, and by Sullivan *et al.* (1992), with 4.5% mortality for cows calving in-season and weaned in June.

Mortality rates were similar for ages 2–9 years but increased very quickly to >20% for older cows. There was no tendency for lowered rates at the middle ages, as would have been expected from the studies of Jenkins and Hirst (1966) in north-western Queensland and McCosker and Eggington (1986) in the Darwin district. Cows were under severe stress at all ages as indicated by low branding rates and low liveweights (Sullivan *et al.* 1992), so that mortality rates remained high after the first year in the herd. There was a clear indication from increases in mortality rates with increasing age that cows should be culled at a maximum age of 10 years in this environment.

Year-to-year variation was moderate for mortality rate, ranging from a low of 5.7% to a high of 15.4%, if the high value resulting from the botulism outbreak in 1982 is considered unrepresentative. The extreme mortalities reported from north-western Australia all exceed these levels: 23% (Gardiner *et al.* 1983), 26% (McCosker *et al.* 1991), and 20.5% (D. Pratchett pers. comm.). These high rates emphasise the harshness of the environment and the effects of minimal managerial intervention. Perhaps the limited management from weaning at Kidman Springs was somewhat successful in reducing annual mortalities below these extremes.

Wastage rates and patterns

The overall wastage rate was best represented by the simple mean of 16.7% per year. The back-transformed mean was distorted by the undue influence of high rates based on small numbers of older cows, specifically the culling of 2 of 3 cows that were 17 years old. Cell numbers were very low and poorly represented across cohorts for the older cows. These combined to give instability among estimates from near-singularities in the fitted proportional hazards model and, consequently, unreasonably high estimates for the year means, even though the pattern of differences between years was unaffected. Wastage was much higher than the 9% at Swan's Lagoon (O'Rourke *et al.* 1995).

Wastage contains components for mortality, physical culls, and discretionary culls, the latter component being related to environment, management, and productivity. In a harsh environment with minimal management and low productivity, such as at Kidman Springs, only minimal discretionary culling can be used if herd size is to be maintained. In a better situation at Swan's Lagoon, cows could be culled at a maximum age of 10 years or if they failed to rear a calf in 2 consecutive years. As the production environment and level of management improve, higher standards for productivity can be set for cows that remain in the herd.

Although there are no studies specific for wastage rates in beef cattle herds in Australia, a producer survey in northern Australia found that, on average, 59% of heifers were retained as breeders, with a higher level of 81% in the most extensive areas and 48% in more favoured areas (O'Rourke *et al.* 1992). These commercial rates are much higher than those suggested from wastage rates in research herds and could include such extraneous variables as herd build-up following a disease eradication campaign or following drought, or the opportunity for a second round of selection based on early reproductive performance. Hence, heifer replacement rates may be substantially higher than herd wastage in a commercial setting when numbers are increasing.

Azzam *et al.* (1990) summarised 10 data sets from across the USA and reported an average wastage rate of 16.3% per year with a range of 11.2–22.7% for the actual culling strategies and lifespans used in each study. Although these wastage rates were similar to those for Kidman Springs, management and productivity also differed, so that the limited culling on productivity and maximum age and very low reproductive rates at Kidman Springs contrasted markedly with the USA studies.

Wastage rates had a more pronounced quadratic trend with age than was evident for mortality. Lowest wastage was for ages 4–6 years, increasing very quickly after 10 years of age. These patterns conformed more closely with those expected from the mortality rates in other studies in northern Australia and overseas (O'Rourke *et al.* 1995). The cumulative lifetime wastage of 60% in this study was similar to that at Swan's Lagoon but higher than in overseas reports (Azzam *et al.* 1990; O'Rourke *et al.* 1995). Patterns of variation from year to year in wastage rates were similar to those for mortality at Kidman Springs with a range of 10.9–21.6%.

Age distributions

Age distributions calculated from age-specific wastage rates had a steady decline from 16.3% of 2-year-olds to a negligible proportion of 15-year-olds. Most cows were ≤5 years of age, only 9% were >10 years, and the average age of cows in the herd was 5.7 years. This average age was slightly higher than the average ages at Swan's Lagoon (O'Rourke *et al.* 1995) and fitted within the range 4.7–6.7 years for the 10 studies reviewed by Azzam *et al.* (1990) but was lower than the average of 6.9 years for the 15 studies summarised by Morris *et al.* (1993). Studies without culling on maximum age had age profiles similar to that for Kidman Springs, with most cows ≤5 years of age and with similar proportions of cows >10 years (Etienne and Martin 1979; Schons *et al.* 1985).

The age distribution of cows leaving the herd declined steadily with increasing age, from 13.2% for 2-year-olds to 5.3% for 9-year-olds but with somewhat higher rates from 10 to 12 years of age (8.7%), as cows that were poorly productive and a survival risk were identified for culling. Average age when cows left the herd was 7.1 years and 38.6% of cows completed ≥8 reproductive cycles. These lifespans were slightly longer than those at Swan's Lagoon, where cows were culled on maximum age, but within the range reported for studies in North America (Azzam *et al.* 1990; O'Rourke *et al.* 1995).

Reasons for, and timing of, wastage

Causes for mortalities could not be assigned because of the extensive situation and lack of herd supervision. The period of calving and rearing a calf was the most significant time for cow mortality in this study, as was the case with seasonal calving at Swan's Lagoon (O'Rourke *et al.* 1995) and in central Queensland (Burns *et al.* 1992) and North America (Fredeen *et al.* 1981).

Virtually all of the culled cows were not pregnant and half were culled to correspond with weaning. Infertile younger cows and older cows that would be a survival risk were the main groups culled. Mortality was a much larger component of non-discretionary culling than physical reasons at Kidman Springs, but physical culls were more prevalent than mortalities at Swan's Lagoon (O'Rourke *et al.* 1995). These patterns correspond with the harsher environment and lower level of supervision of cattle at Kidman Springs.

The low productivity of the Kidman Springs herd is evident from the high proportion of cows in the herd that were not pregnant for at least a full year (21.6%) or that failed to rear a calf after a confirmed pregnancy (8.1%). The estimate of calf losses up to branding was 20.8%, which was similar to the losses reported by McCosker *et al.* (1991) in a wetter environment at Mt Bundey with minimal management. Losses were lower (8.2%) with improved nutrition and management at Mt Bundey. In a more favourable environment, Holroyd (1987) reported losses up to weaning of 13.5% over 12 years at Swan's Lagoon.

There were no differences between ages for any of the measures of calf loss, but branding rate had a distinctive pattern with age, with highest rates for 2-year-olds, lowest rates for 3–4-year-olds, and a slight decline with age after 5 years of age. Hence, it may be inferred that pregnancy rates followed the same pattern with age as branding rate.

The difference between failure to lactate and failure to brand is a component of postnatal loss. Hence postnatal losses at Kidman Springs were at least 9.3%. These losses were higher than the postnatal losses of 5.6% at Swan's Lagoon (Holroyd 1987), 3.5% at Fletcherview (Entwistle and Goddard 1984), and 1.7% for Belmont Red at Brigalow (Burns *et al.* 1992). Because of the infrequent musters and lack of supervision at Kidman Springs, only crude estimates of the period of loss can be made. Losses by failure to lactate combine prenatal, perinatal, and postnatal periods. This loss rate of 11.5% for Kidman Springs is somewhat higher than the combined pre- and peri-natal losses of 7.9% at Swan's Lagoon and 5.4% for Belmont Red at Brigalow. Losses as failure to lactate were highest in the late dry and early wet season and lowest in the late wet season, which aligns with nutritional supply from grazing.

Lifetime productivity

The average number of calves reared in a cow's lifetime was 3.1, and 15.3% of cows did not rear a calf, even though mating was continuous and culling on fertility was lenient. When cows with incomplete life records were excluded, there were 2.5 calves reared for the 1979–80 cohorts up to 10 years of age. Clearly this is very low productivity. Lifetime number of calves reared was similarly low at Swan's Lagoon but was generally higher for more favoured environments overseas and in southern Australia (O'Rourke *et al.* 1995).

The number of productive years in the herd averaged 6.5 up to a maximum age of 10 years, but even for the cohorts with complete data, number of years in the herd was quite low at 5.2. Short lifespans of 4–5 years were also reported in North Queensland and overseas, but other studies from overseas and southern Australia reported 8–13 years in the herd (O'Rourke *et al.* 1995).

Hence, on average, cows in harsh environments with minimal management and culling can produce the same total number of calves in their lifetime as cows in better areas with improved management. However, they require a longer period in the herd to do so, which increases their maintenance requirement while they are nonproductive and increases the stocking pressure on the whole property. There is also reduced income from sale of cull cows because of the higher mortality.

Predictors of lifetime productivity

Relationships of early liveweights and liveweight changes with lifetime productivity were weak, supporting the findings at Swan's Lagoon and elsewhere that measures of liveweight or liveweight gain early in life and before mating are poorly related to lifetime productivity, particularly when productivity is relatively high (O'Rourke *et al.* 1995).

The relationship between reproductive status as a 2-year-old and lifetime productivity supports the conclusion of Morris (1980) that early and lifetime reproduction are positively related. Most of the differences in the present study were between lactating, pregnant, and nonpregnant classes, with only minor association with stage of pregnancy. This emphasis on rearing a calf in the first season supports earlier findings of Donaldson (1968), who reported differences in the lifetime productivity of cows first calving as 2-year-olds (65% of potential pregnancies) and 3-year-olds (52%), and after 3 years of age (44%). Fahmy *et al.* (1971) also found higher lifetime reproduction for cows that were pregnant in their first year than for those that were not (86 *v.* 77% of potential pregnancies). These findings tend to support the advantages of yearling mating for a proportion of the herd with continuous mating and a wide spread of ages among the heifers. However, the higher subsequent mortalities for yearling-mated heifers also need to be considered.

The relationships of liveweights and liveweight changes up to 2 years of age with pregnancy rates and timing of conceptions of heifers supports the findings of Doogan *et al.* (1991). Heifers conceiving as yearlings had the greatest weight gains from branding to yearling and highest yearling weights, and those conceiving early as 2-year-olds had highest branding and yearling weights.

Although early predictors of lifetime productivity may not be generally available, the present study suggests potentially useful predictors for harsh environments where overall productivity is low. The most promising early indicators of productivity are timing of the first pregnancy and, subsequently, weaning weight of first progeny. A producer attempts to select a replacement heifer that will be most productive in terms of longevity, calf productivity, and economic return. In the first instance branding rate and survival to first mating need to be sufficiently high so that enough heifers are available to maintain herd numbers and then to allow scope for selection. Although correlations with lifetime productivity were generally low, a producer is still best advised to select as replacement heifers those with higher liveweight and without physical abnormalities. Such heifers are most likely to conceive and to do so early in the season (Doogan *et al.* 1991). A second selection is then possible after the first year in the herd of those rearing a calf and then a third selection of those rearing the heaviest progeny. However, productivity must be high enough that sufficient heifers are available for this level of selection intensity.

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