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Mortality, wastage, and lifetime productivity of *Bos indicus* cows under extensive grazing in northern Australia
1. Seasonal mating in the speargrass region

P. K. O'Rourke[AB], *G. Fordyce*[C], *R. G. Holroyd*[A] *and I. D. Loxton*[D]

[A] Queensland Department of Primary Industries, GPO Box 46, Brisbane, Qld 4001, Australia.
[B] Present address: Department of Social and Preventive Medicine, University of Queensland, Medical School, Herston, Qld 4006, Australia.
[C] Queensland Department of Primary Industries, Swan's Lagoon, Millaroo via Ayr, Qld 4807, Australia.
[D] Queensland Department of Primary Industries, PO Box 6014, Rockhampton Mail Centre, Qld 4702, Australia.

Summary. Mortality and wastage rates and lifetime productivity for seasonally mated, *Bos indicus* cows were studied over 8000 cow year records from 1972 to 1992 at Swan's Lagoon in the subcoastal speargrass region of North Queensland. The proportional hazards model was used to estimate age-specific mortality and wastage rates, adjusted for cohort and genotype effects. The 1970–72 cohorts had an average mortality of 1.7% (range 0–4.2%), with this low overall rate tending to increase with age. The average mortality rate for the 1973–87 cohorts was 1.2% (range 0.5–2.6%), with no pattern with age.

For 1970–72 cohorts, the average wastage rate was 8.9% and ranged from 2.1 to 18.3% with no clear age pattern. However, there was a clear age pattern for the 1973–87 cohorts, with an average wastage rate of 9.2% comprising very high rates (27.5%) for 2-year-olds and low rates (2.8–8.9%) for 3–7-year-olds, increasing to 11.9% for 8-year-olds and 14.2% for 9-year-olds. The heifer replacement rates to maintain a stable herd size were 17.5 and 19.2% for the 2 herds.

Lifetime productivity was very low, with 1970–72 cohorts rearing 3.3 calves over 4.7 years at a rate of 57.5% calves per year, and 1973–87 cohorts rearing 3.1 calves over 4.9 years at a rate of 45.0% calves per year. Total weaner weights reared up to 10 years of age were 578 kg for 1970–72 cohorts and 315 kg for 1973–87 cohorts. However, variability between individual cows was high, indicating scope for selection based on productivity, provided that better performing cows can be identified from predictors early in life.

Introduction

The northern Australian beef industry is based on low inputs to relatively large herds grazing native pastures. Productivity tends to be low and to vary with seasonal conditions. The collation of research results from northern Australia by Holroyd and O'Rourke (1989) reported a scarcity of data on cow mortality and identified this as an area of high priority for future research because of the impact of cow mortality on female turnoff and enterprise profitability. Their summary indicated mortality rates <5% in the more favoured areas, up to 15% in harsher areas, and as high as 30–40% in poor seasons. Estimates of wastage rate, which combines mortality and culling, would also be unreliable for extensive beef herds in northern Australia. Wastage rate is a critical parameter for herd dynamics and economic modelling to determine the profitability of management options. Azzam *et al.* (1990) reviewed 10 sets of data from North American studies on age-specific probabilities of culling and highlighted the need for more population analyses of beef cattle, supporting the conclusions of Holroyd and O'Rourke (1989) for northern Australia.

The primary measure of lifetime productivity of a cow is the total weight of calves reared by her plus her turnoff weight (Sacco *et al.* 1989; Cundiff *et al.* 1992). Secondary lifetime traits include productive time in the herd, number of calves reared, calf weaning weight, and a range of efficiency ratios. Hence, lifetime productivity gives the total value that each cow contributes to the breeding enterprise.

Lifetime data have yet to be examined for research herds in northern Australia. Newman *et al.* (1990) present results from South Australia for longevity in the herd, number and cumulative weight of weaners, and turnoff weight for the cow. Hearnshaw *et al.* (1993) demonstrated the greater longevity of Brahman cross than British cows across a range of pasture qualities in northern New South Wales. Morris *et al.* (1993) reported limited scope for within-breed selection on lifetime productivity traits in New Zealand. North American studies of lifetime productivity include those of Fredeen *et al.* (1981) and Arthur *et al.* (1992; 1993) in Canada, Schons *et al.* (1985) in Wyoming, Tanida *et al.* (1988) in Arizona, Sacco *et al.* (1989) in Texas, Bailey (1991) in Nevada, and Cundiff *et al.* (1992) in Nebraska.

The present study aimed to establish mortality and wastage rates and lifetime productivity for herds from 2 extremes of extensive management in northern Australia; to identify some of the factors affecting these traits; to compare productivity in northern Australia with that from other environments; to derive parameters for use in herd dynamics and economic modelling; and to attempt to determine early predictors of lifetime productivity to aid in selection of replacement heifers. This paper presents lifetime information from 2 herds at Swan's Lagoon where a 3-month mating period, cow–calf identification, and close management were practiced. A second paper presents similar information from Kidman Springs under continuous mating and minimal management in a harsh environment, and a third paper compares the effects of a range of possible culling strategies on herd dynamics and lifetime performance at these 2 sites.

Materials and methods

Location

The study was conducted from 1969 to 1992 at Swan's Lagoon (20°05'S; 147°14'E), 100 km south of Townsville in the subcoastal speargrass region of the dry tropics of North Queensland. The climate of the region is warm and subhumid, having a distinct hot, wet summer period (wet season) and a warm, dry winter period (dry season). Three-quarters of the average annual rainfall of 887 mm falls over the summer wet season of December–March, with a pronounced dry period from June to October. The principal native pasture species are black speargrass (*Heteropogon contortus*), tropical tall grasses, medium grasses, pioneer grasses, and legumes. The trees form an open savannah woodland, with *Eucalyptus* spp. as the principal tree species. Pasture burning was generally not a management practice, but occasional fires did occur. Breeding cows grazed these native pastures at stocking rates of 4–6 ha/head. A more detailed description of the site is provided by Holroyd *et al.* (1990*a*).

Animals and measurements

Details of the development of the genotype herds have been given by Holroyd *et al.* (1990*a*). In summary, Brahman (B) and Sahiwal (Sah) crossbred genotypes were developed in parallel from a base beef Shorthorn herd by the introduction of appropriate sires. There were 3 cohorts of the F_1 1/2 *Bos indicus,* which were branded from 1970 to 1972. Subsequent filial generation crosses of 1/2 *Bos indicus,* and backcross of 3/4 *Bos indicus,* were branded in 15 cohorts from 1973 to 1987. Up to 1980 all maiden heifers joined the breeding herd as 2-year-olds in January. A random selection of available heifers was made in later years to maintain a herd size of about 150 cows for each genotype. The Sahiwal genotypes were discontinued in 1987, and only the 1986 and 1987 cohorts for the Brahman genotypes remained in the herd at the end of the study in 1992.

The breeding herd was mustered at weaning (May–June), before calving (September), at start of mating (January), and end of mating (April). The year was considered as the period between weanings (June–June). Cows were individually identified and their ages 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. Cows were examined for pregnancy by rectal palpation at the musters at the end of mating and at weaning. Rearing status was recorded as whether a cow weaned or failed to wean a calf. All culling and transfers were carried out at the weaning muster. Until 1987, cows were inspected 3 times per week during the calving season to identify calves and to match them with their dams. Cow–calf identification was not carried out from 1988 to 1992.

Dead cows were identified during regular paddock inspections and cause and date recorded where possible. Causes of death were categorised as unknown, poverty, calving related, infection and poisoning, or accident. Poverty was assigned to deaths of poorly conditioned cows late in the dry season when available feed was scarce and of poor quality. Calving-related deaths were mainly dystokia but also included prolapse and pregnancy toxaemia. Infection and poisoning included udder pathology, suspected botulism, salmonellosis, and pneumonia.

Culling, apart from maximum age, was on poor reproductive performance, physical defects, or poor temperament. Generally, heifers that failed to rear a calf and mature cows that failed to rear a calf in 2 consecutive years were culled for low fertility. Reasons for physical culls were categorised as unspecified, poor growth of cow or calf, calving-related, bottle teats, temperament, and infection or physical. Calving-related culls included infertility, dystokia, prolapsed uterus, and agalactia. Culling for bottle teats was far more lenient for Sahiwal than for Brahman genotypes; all Brahmans with bottle teats were culled, while Sahiwals were only culled if their bottle teats were sufficiently advanced to prevent calf rearing. Infection or physical causes included reactor or potential reactor for brucellosis or tuberculosis, stringhalt, blight, *Epitheliogenesis imperfecta* carrier, lame, broken foot, abnormal growth, lumpy jaw, abnormal genitalia, abnormal vagina, and abnormal pelvis. In some years, extra cows were transferred from the herd to control excess numbers, particularly for the 3/4 B which were culled after age 7 years from 1981 onwards. Cows were generally culled on maximum age after age 9 years (when they were 10 years old). Data sets were also established to a maximum age of 8 years by editing out data for subsequent ages.

Rearing a calf to weaning (coded as 1) or failing to rear (coded as 0) was recorded for each year in the herd from 3 years old to a maximum age of 8 or 10 years. Rearing records for each cow were terminated by death, culling on physical abnormalities or failure to rear a calf in 2 consecutive years, transfer out of the herd, or by the end of the study in 1992. Number of years in the herd was determined from the number of rearing records, and the total number of calves reared was accumulated over the lifetime of each cow. Productivity in terms of total weaner weight could only be assigned for cows in the 1970–79 cohorts.

Genotype was a combination of filial generation, *Bos indicus* content, and sire breed, each with an unbalanced distribution across cohorts and years (Holroyd *et al.* 1990*a*, 1990*b*). Preliminary analysis indicated that genotype could be summarised as 6 groups. The F_1 genotypes occurred only for the 1970–72 cohorts and have been considered as a separate data set containing records for 157 F_1 1/2 B and 120 F_1 1/2 Sah. Subsequent filial generations were bulked for each 1/2 *Bos indicus* genotype, and all filial generations were bulked for each backcross 3/4 *Bos indicus* genotype, following Holroyd *et al.* (1990*a*, 1990*b*). Hence, the second data set, for the 1973–87 cohorts, contained 4 genotype groups: 486 F_{2+} 1/2 B cows from 1976–87 cohorts; 232 F_{2+} 1/2 Sah cows from 1977–84 cohorts; 817 3/4 B cows from 1973–87 cohorts; and 327 3/4 Sah cows from 1973–84 cohorts.

Early lifetime data for cows included date of birth and liveweights at weaning, end of first dry season, yearling, and start of mating. Progeny weaning weights were recorded in May–June when calves were 5–7 months old, yearling weights in the following June (aged 18 months), and those at start of mating in January (aged 26 months).

The primary lifetime productivity traits were number of years in the herd, number of calves reared to weaning, and total weaner weight. Efficiency measures were derived as number of calves reared and total weaner weight per year in the herd. Because of the incomplete life history for many cohorts, these measures could give unreasonably low estimates for some traits. By making allowance for transfers out of the herd and incomplete lifetime data for some cohorts when the study was terminated, potential years in the herd gives the maximum possible number of years each cow could have been in the herd. Estimates for the primary traits became more meaningful and practically useful when they were standardised to an equal potential years basis.

Statistical analyses

Statistical analyses derived age-specific estimates of mortality and wastage rates using the proportional hazards model for grouped data (Bartlett 1978). The conditional probability p_{ij} that a cow from the ith treatment group would be culled at the jth age given that it survived to the (j–1)th age can be modelled as

$$p_{ij} = 1 - \exp[-\exp (t_i + a_j)]$$

where t_i are the treatment effects and a_j the age effects. The treatments were years, genotypes, and years x genotypes. The values for p_{ij} were derived by dividing the number of cows culled in a year by the number of cows in that age and treatment group (at risk) at the start of the year. For mortality rates, culling included only cows that died during the year, while wastage included cows that died and those culled for physical reasons and for low productivity.

Maximum likelihood estimates of the parameters were obtained using GENSTAT (Payne *et al.* 1987) with binomial error structure and complementary log log link function. These models have a singularity for p_{ij} values of 0 or 1 and can be unstable for values close to these limits. This singularity, which means that terms in the model cannot be estimated, results from log of 0 being undefined. When the full model led to unstable estimates because of zero rates, particularly for mortality, a simpler model was fitted, generally by omitting the interaction term. Change in deviance and residual deviance were tested against the chi-squared distribution to check on inclusion of various terms and the adequacy of the model. The parameter estimates were then back-transformed to percentages to give practical estimates of wastage rates for age, year, and genotype effects.

There were unequal numbers of cows in each cohort at each age and not all cohorts were represented for each age x year combination. This lack of balance, which is a regular feature of data on herd dynamics, led to partial confounding of factors in the model and to the need for adjustments to remove the confounding effects of other factors from those of interest. In particular, analyses examined age effects after removal of the nuisance effects from other factors. For the 1970–72 cohorts, the zero rate for 9-year-olds gave rise to a singularity which could only be overcome by fitting a simple age effects model. In this way, realistic estimates were obtained for age effects for all traits. However, estimates for year means were not always compatible with simple means because of the structure of the data sets. Although the full model was fitted for wastage rate, year effects were unstable because of the build-up of the age profile in early years and a substantially unbalanced age profile across most years of the study. The strength of the proportional hazards model is its use of incomplete, and partly confounded, data to produce realistic and robust estimates of age effects for use in population analysis.

Data were summarised as mean and standard deviation for each standardised lifetime productivity trait. For comparative analyses the least squares method for unequal subclass numbers was used (Harvey 1960; 1982). Cohort, genotype, and their interaction were included as factors in these analyses. 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. Correlation coefficients were calculated to estimate the degree of relationships between traits measured early in the cow's life and her subsequent lifetime productivity.

Results

Seasonal conditions

There was marked annual variation in rainfall over the 23 years, from 436 mm in 1983–84 to 1953 mm in 1973–74 (Table 1). The 1970s were mostly average to good years for rainfall, while the 1980s tended to be poor years. Severe droughts preceded matings in 1973, 1980, 1981, 1983, 1988, and 1992. Rainfall was substantially below average in 9 of the 23 years and above average in 7 years. Significant out-of-season rainfall was recorded in 1977, 1983, 1985, 1988, 1989, and 1990.

Age effects

Age effects were significant ($P<0.05$) for mortality and wastage rates for the 1970–72 cohorts. Breed, year × breed, and residual deviance were unimportant for mortality rate, but all were significant ($P<0.05$) for wastage rate. Overall, breed effects were minor and sometimes inconsistent across years. Hence, the adjustments to the age effect for the influence of the other factors in the model were generally small, and age was the dominant term. For the 1973–87 cohorts, all effects were significant ($P<0.05$) for mortality and wastage rates, but for the latter, age and year effects

Table 1. Seasonal and annual rainfall (mm) from July 1969 to June 1992, and long-term mean (1969–92)

	Dry season (July–Nov.)	Wet season (Dec.–Mar.)	Transition (Apr.–June)	Total
1969–70	26	526	25	577
1970–71	213	588	110	911
1971–72	134	1300	35	1469
1972–73	38	496	75	609
1973–74	379	1509	64	1952
1974–75	211	587	53	851
1975–76	245	944	6	1195
1976–77	255	850	185	1290
1977–78	42	655	109	806
1978–79	132	884	62	1078
1979–80	50	740	91	881
1980–81	44	799	153	996
1981–82	230	299	38	567
1982–83	0	288	407	695
1983–84	163	270	1	434
1984–85	157	387	113	657
1985–86	211	360	50	621
1986–87	153	307	31	491
1987–88	95	453	200	748
1988–89	219	570	349	1138
1989–90	175	491	447	1113
1990–91	43	1436	74	1553
1991–92	75	378	63	516
Long-term mean	132	642	113	887

Table 2. Age and year effects back-transformed from survival analysis for mortality and wastage rates (%) for two *Bos indicus* herds, F_1 1/2 *Bos indicus* (1970–72 cohorts) and F_{2+} 1/2 and 3/4 *Bos indicus* (1973–87 cohorts)

	F_1 1/2			F_{2+} 1/2 and 3/4		
	No. of cows at risk	Mortality rate[A]	Wastage rate	No. of cows at risk	Mortality rate[B]	Wastage rate
			Age			
2 years	277	1.1	13.6	1862	1.1	27.5
3 years	248	0.4	2.1	1365	1.1	2.8
4 years	226	0.9	12.8	1171	0.5	8.3
5 years	178	2.2	5.6	894	1.1	5.7
6 years	154	3.9	13.6	625	1.3	8.9
7 years	121	2.5	12.3	406	1.3	8.5
8 years	95	4.2	18.3	173	2.6	11.9
9 years	78	0.0	5.6	50	1.3	14.2
			Year			
1972	83	0.0	9.7			
1973	171	0.6	13.7			
1974	248	1.2	13.5			
1975	220	0.0	10.2	59	3.6	4.1
1976	186	2.2	10.7	125	0.0	5.9
1977	144	3.5	4.6	233	3.0	11.0
1978	126	3.2	5.8	295	1.7	10.1
1979	94	5.3	6.6	345	2.8	10.5
1980	66	1.5	3.4	440	3.3	16.8
1981	39	0.0	23.2	492	0.9	30.8
1982				563	6.7	14.1
1983				536	1.2	15.6
1984				535	6.0	18.0
1985				603	1.4	10.2
1986				532	1.5	8.6
1987				418	3.3	7.1
1988				420	0.0	5.1
1989				479	0.7	3.7
1990				265	1.7	2.8
1991				206	11.6	10.0
Overall	1377	1.7	8.9	6546	1.2	9.2

[A] Based on simple age effects model to avoid singularities from zeros.
[B] Based on main effects model to avoid singularities from zeros.

dominated breed and year x breed effects. Residual deviance was substantial and much higher for this data set than for the 1970–72 cohorts. Simple and adjusted age effects were similar from this large data set, except for the instability from zero rates, mainly for mortality rate.

For the 1970–72 cohorts, mortality rate was low overall but tended to increase with age (Table 2). The pattern for wastage rate was high at age 2 years and low at 3 years, then increasing with age but with substantial fluctuations. For the 1973–87 cohorts, mortality rate was low and unpatterned (Table 2). Wastage rate was high (27.5%) at age 2, low (2.8%) at age 3, and increased

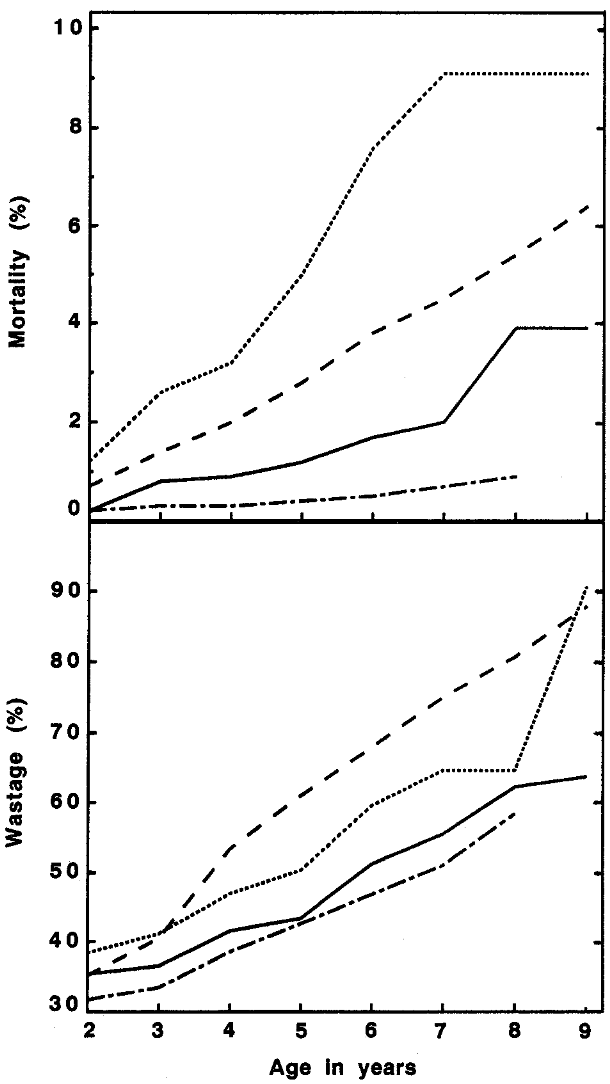

Figure 1. Cumulative age effects for mortality and wastage rates (%) for F_{2+} *Bos indicus* genotypes, 1973–87 cohorts. 1/2 B (——), 1/2 Sah (· · · · ·), 3/4 B (– – – – –), 3/4 Sah (- - - - -).

subsequently with age. The patterns for 1973–87 cohorts showed less fluctuation than for the 1970–72 cohorts as a consequence of a larger and better balanced data set.

Year effects

Simple year effects for the 1970–72 cohorts are given for mortality rates in Table 2. Mortality rates were low at 1.7% overall and reached a peak of 5.3% in 1979, but differences were not significant ($P>0.05$). Simple and back-transformed wastage rates were similar except for lower rates in the back-transformed case for 1972 and 1978–80 and higher rates for 1981. These differences correspond to the years when age profiles were poorly balanced. Simple rates varied from 5.2% in 1977 to 18.1% in 1972, and back-transformed rates from 3.4% in 1980 to 23.2% in 1981, but year effects were not significant ($P>0.05$).

Partial confounding of year effects by age was a problem in the early and final 2 years for the 1973–87 cohorts. The numbers of cows at risk reflected this build-up of the herd (Table 2). Mortality rates from simple calculation and back transformation from the main effects model were similar except for 1987–91, when the back-transformed rates were higher than the simple ones. For wastage, back-transformed rates were substantially lower throughout. Highest wastage rates were in 1981 and lowest in 1989 and 1990.

Breed effects

Breed effects for wastage rate were inconsistent across years for the 1970–72 cohorts. The overall wastage rates were 6.3% for 1/2 B and 17.3% for 1/2 Sah, but the 2 genotypes had similar rates for 1973, 1974, 1975, and 1979, and substantial differences in the other years.

Breed effects are presented as separate age profiles for the 1973–87 cohorts (Fig. 1). Mortality rates were low overall but marginally higher for Sahiwal than for Brahman genotypes. For wastage rates, the 2 Brahman genotypes had similar patterns and rates for all ages; 1/2 Sah had slightly higher rates; and 3/4 Sah had markedly higher rates.

Reasons for deaths and physical culls

Reasons for death and physical culls have been grouped into categories for each of the 6 genotypes across the lifetimes of the 1970–87 cohorts (Table 3). The main reasons for deaths were unknown (35.7%), poverty (28.1%), calving related (10.5%), infection and poisoning (18.1%), and accident (7.6%). This pattern was similar across genotypes except for the greater effect of botulism on the Sahiwal genotypes. Deaths were distributed across the year with monthly totals 22, 19, 7, 23, 5, 6, 5, 2, 0, 12, 34, and 36 in January–December, respectively. Most deaths (72%) occurred during the

Table 3. Number of deaths and physical culls by reason and genotype for the 1970–87 cohorts

Reason	F_1 1/2 B	F_1 1/2 Sah	F_{2+} 1/2 B	F_{2+} 1/2 Sah	F_{2+} 3/4 B	F_{2+} 3/4 Sah	Overall
Deaths							
Unknown	3	3	15	8	13	19	61
Poverty	8	1	4	3	16	16	48
Calving related	2	1	2	4	7	2	18
Infection or poisoning	1	3	4	6	1	16	31
Accident	0	1	3	1	5	3	13
Total	14	9	28	22	42	56	171
Physical culls							
Unspecified	7	6	1	1	1	0	16
Poor growth	13	4	0	1	3	3	24
Calving related	1	0	3	2	6	4	16
Bottle teats	3	18	18	5	13	35	92
Temperament	1	2	2	0	18	7	30
Infection or physical	1	2	7	5	5	11	31
Total	26	32	31	14	46	60	209

Table 4. Lifetime productivity traits (mean ± s.d.) to a maximum culling age of 8 or 10 years for two *Bos indicus* herds

	No. of cows	Maximum culling age 8 years	Maximum culling age 10 years
F_1 1/2 Bos indicus *(1970–72 cohorts)*			
No. of years in herd	277	4.06 ± 1.98	4.66 ± 2.65
No. of calves reared	277	3.01 ± 2.10	3.31 ± 2.48
No. of calves per year (%)	277	60.7 ± 34.6	57.5 ± 32.2
Weaner weight (kg)			
Total	277	529.6 ± 379.2	577.7 ± 440.7
Per year	277	105.8 ± 61.8	99.6 ± 56.6
Average	223	174.0 ± 21.3	173.2 ± 21.1
F_{2+} 1/2 and 3/4 Bos indicus *(1973–87 cohorts)*			
No. of years in herd	1862	3.79 ± 2.15	4.91 ± 2.89
No. of calves reared	1862	2.39 ± 2.17	3.12 ± 2.89
No. of calves per year (%)	1862	45.1 ± 37.5	45.0 ± 37.5
Weaner weight (kg)			
Total	826	250.8 ± 280.2	315.2 ± 363.2
Per year	826	51.2 ± 50.6	51.0 ± 50.5
Average	464	148.2 ± 22.4	148.6 ± 22.4

calving period (October–February). The high number for April (23) was boosted by a botulism outbreak in 1985.

The main reasons for physical culls were unspecified (7.7%), poor growth (11.5%), calving related (7.7%), bottle teats (44.0%), temperament (14.4%), and infection or physical (14.8%) (Table 3). Most of the unspecified culls occurred in the early years for the F_1 genotypes. Also, culling on poor growth was much higher for F_1 1/2 B than for the other genotypes. Bottle teats was the main reason for physical culling, particularly for the Sahiwal and F_{2+} 1/2 B genotypes. Most of the culling for temperament was in 3/4 B and, to a lesser extent, 3/4 Sah. Stringhalt for F_{2+} 1/2 B and *Epitheliogenesis imperfecta* carriers for 3/4 Sah made up most of the culls for infection or physical reasons.

Lifetime productivity and factors affecting it

All cows in the 1970–72 cohorts completed their full potential life of 8 reproductive cycles from mating to weaning of the resultant calves up to a maximum culling age of 10 years. However, only 206 of 1862 cows did so for the 1973–87 cohorts, because of transfers before 10 years of age and termination of the study in 1987 for Sahiwals and 1992 for Brahmans. There were 1057 cows with complete data for 6 cycles up to a maximum culling age of 8 years. For the 1970–72 cohorts, 19.5% of cows did not rear a calf. The rate was higher (35.3%) for the 1973–87 cohorts, with the 1978 (54.4%) and 1979 cohorts (84.0%) having particularly high values.

Lifetime productivity for the 2 data sets was compared for maximum culling ages of 8 and 10 years (Table 4). For the 1970–72 cohorts cows allowed an extra 2 potential years had an extra 0.6 years in the herd, reared 0.3 extra calves, and weaned an extra 47 kg calf weight. However, the efficiency measures were lower, with 3.2% fewer calves and 6 kg less weaner weight per year. Differences were higher for productivity standardised to the same potential years in the herd up to 8 or 10 years for the 1973–87 cohorts, at 1.1 extra years in the herd, 0.7 extra calves reared, and 64 kg extra weaner weight. The efficiency measures had similar values for the 2 ages. The 1970–72 cohorts had higher productivity than the 1973–87 cohorts at both ages and for all traits.

For lifetime productivity traits for 1970–72 cohorts, the cohort × genotype interaction was significant ($P<0.05$), but main effects generally were not ($P>0.05$). The 1/2 B tended to have higher productivity than 1/2 Sah (Table 5), with significant ($P<0.05$) differences for the 1970 and 1971 cohorts and reversal for the 1972 cohort. For the 1973–87 cohorts the main effects dominated, but the cohort × genotype interaction was also significant ($P<0.05$). The 1/2 Sah and 3/4 B genotypes had the highest productivity and 3/4 Sah the lowest (Table 5). The interaction resulted mainly from the structure of the data, in which the Sahiwal genotypes for the 1984 cohort had only 1 year in the herd. Other contributions to the interaction were high values for 1/2 Sah in the 1978 cohort and for 3/4 B in the 1980 cohort and low values for 3/4 B in the 1978 cohort and for 3/4 Sah in the 1982 cohort.

There was no cohort effect on lifetime productivity for the 1970–72 cohorts (Table 5). For the 1973–87 cohorts, the structure of the data led to highest values for numbers of years and calves reared for the 1984, 1986,

Table 5. Differences between *Bos indicus* genotypes (B, Brahman; Sah, Sahiwal) and cohorts in lifetime productivity to 10 years of age

Genotype means followed by the same letter are not significantly different at $P = 0.05$

	No. of cows	No. of years	No. of calves reared	Total weaner weight (kg)
		Genotype		
F_1 1/2 B	157	4.86	3.52	617.6
F_1 1/2 Sah	120	4.36	2.98	516.8
F_{2+} 1/2 B	486	4.68c	3.05b	327.2ab^A
F_{2+} 1/2 Sah	232	5.52a	3.50a	416.8a
3/4 B	817	5.08b	3.38a	371.2a
3/4 Sah	327	4.71c	2.73b	289.6b
		Cohort		
1970	83	4.41	3.07	527.2
1971	94	4.35	3.12	537.6
1972	100	5.06	3.57	636.8
1973	59	4.73	3.16	500.0
1974	75	5.02	3.13	500.8
1975	135	4.13	2.33	363.2
1976	124	4.34	2.30	341.6
1977	128	4.78	2.70	416.0
1978	149	3.30	1.61	236.8
1979	156	2.03	0.65	101.6
1980	145	4.94	2.97	
1981	113	4.21	2.34	
1982	115	5.24	3.41	
1983	227	6.02	3.96	
1984	100	6.22	4.74	
1985	94	5.90	4.10	
1986	135	6.70	4.87	
1987	107	7.42	5.17	
s.d.		2.86	2.84	384.1

^{A} Cell numbers for this trait were 158, 77, 401, and 190, for the F_{2+} genotypes, respectively.

and 1987 cohorts. At the other extreme, the 1978 and 1979 cohorts had very low productivity. Total weaner weight was highest for the 1973 and 1974 cohorts, and weaner weight per year in the herd followed similar patterns.

Early predictors of lifetime productivity

Liveweights at weaning, yearling, and start of mating were 142.4 ± 25.2, 248.6 ± 27.7, and 302.3 ± 31.5 kg, respectively, for the 1970–72 cohorts. The 1972 cohort had highest weaning weight (154.9 kg) but this group lost weight (12 kg) during its first dry season, so that the 1970 cohort had highest weights at yearling (255.7 kg) and start of mating (330.1 kg). Weight gains after weaning averaged 1.1 ± 16.4 kg up to 12 months, 105.6 ± 22.4 kg up to yearling (18 months), and 159.1 ± 34.5 kg up to start of mating (26 months) for the 1970–72 cohort data set. For the 1973–87 cohorts, liveweights were 159.4 ± 24.2 kg at weaning, 250.5 ± 29.0 kg at yearling, and 287.9 ± 29.3 kg at start of mating. The highest weights were for the 1985 cohort at weaning (186.6 kg) and for the 1977 cohort at start of mating (342.2 kg), while lowest values were for the 1983 cohort at weaning (130.2 kg) and the 1979 cohort at start of mating (215.5 kg). Weight gains after weaning for the 1973–87 cohorts averaged 5.1 ± 16.7 kg up to 12 months, 89.9 ± 28.1 kg up to yearling, and 132.5 ± 46.0 kg up to start of mating.

Table 6. Correlation coefficients (x 100) between traits measured early in life and lifetime productivity per potential year for F_{2+} 1/2 and 3/4 *Bos indicus* 1973–87 cohorts

	No. of years	No. of calves reared	Total weaner weight
Liveweight			
Weaning	7	8	10
Yearling	30**	28**	23**
Start of mating	37**	34**	35**
Weight change			
Weaning–12 months	21**	20**	32**
Weaning–yearling	34**	31**	19**
Weaning–start of mating	35**	31**	37**
Yearling–start of mating	20**	17*	29**
Date of birth	–4	–2	4
Progeny weight from first mating	16*	17*	21**

* $P<0.05$; ** $P<0.01$.

For the 1970–72 cohorts, correlation coefficients (r) of lifetime productivity with liveweights from weaning to start of mating, weight gains, and date of birth were low ($r = -0.07$ to $+0.08$). Progeny weight from mating as 2-year-olds was significantly ($P<0.01$) correlated with number of years in the herd ($r = 0.24$), number of calves reared ($r = 0.25$), total weaner weight ($r = 0.34$), and weaner weight per year in the herd ($r = 0.38$), but not with the number of calves per year ($r = 0.12$). The corresponding correlations for the 1973–87 cohorts were generally higher than these values (Table 6). Liveweights at weaning were poorly correlated ($r = 0.07$–0.10) with lifetime productivity but the weights at yearling and start of mating were moderately correlated ($r = 0.23$–0.37). Weight gains over various periods between weaning and start of mating also had moderate correlations with lifetime productivity. Date of birth was not related and progeny weight from the first mating was only weakly related to lifetime productivity.

Discussion

Productivity in these herds was low despite annual breeder mortalities of 1–2% and annual wastage rates of 9%, with weaning rates of 61% (Holroyd *et al.* 1990*a*, 1990*b*) and losses from pregnancy diagnosis to weaning of 14% (Holroyd 1987). Typical lifetime productivity was 3.2 calves reared over 4.8 years in the herd. The high year-to-year and animal-to-animal variability indicated scope to improve productivity if cows with higher potential can be identified and selected.

Mortality rates and patterns

The low annual mortality rates were similar to the 1–2% reported for *Bos indicus* crossbreds in central Queensland (Frisch 1973; Coates *et al.* 1987; Burns *et al.* 1992) but lower than other reports from North Queensland (Loxton *et al.* 1983; Holroyd *et al.* 1988). Overseas studies reviewed by Azzam *et al.* (1990), and those of Fredeen *et al.* (1981), Bailey (1991), and Arthur *et al.* (1992), reported mortality rates <1–2% per year and with similar rates for all age groups in the herd.

Despite the very low overall mortality rates, there was still a tendency for mortality to increase with age with highest rates for 8-year-olds. The tendency for higher mortality rates at young ages due to dystokia, and minimum mortality in the middle age groups, as would have been expected from reports by Jenkins and Hirst (1966) in north-west Queensland, McCosker and Eggington (1986) in the Darwin district, and Burns *et al.* (1992) in central Queensland, was not observed in this study. The heifers were well grown at the start of mating, with 84% heavier than the threshold weight of 250 kg for response in pregnancy rate (Doogan *et al.* 1991). This weight advantage, coupled with good management, supervision during their first year in the herd, and relatively lower birth weights for *Bos indicus* than for *Bos taurus* (Newman and Deland 1991), all contributed to mortality rates being lowered for 2-year-olds.

Year-to-year variation was 0–5.3% for the 1970–72 cohorts and up to 11.6% for the 1973–87 cohorts, but in drought years segregation of cows in poor body condition for survival feeding would have prevented higher losses. The very high mortalities in poor seasons of up to 24%, as reported by Taylor *et al.* (1982) and Fordyce *et al.* (1990) in North Queensland, were prevented by strategic supplementation, regular weaning, and segregation for survival feeding. Hence, under good systems of management and even with minimal supervision, mortality rates can be kept very low so that they make only a small contribution to wastage rates.

Wastage rates and patterns

The average wastage rates in the present study were lower than the rates summarised by Azzam *et al.* (1990) for 10 data sets from North America. They 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, and an average of 20.3% with a range 16.4–25.2% when the herds were standardised to a maximum age of 8 years. The lower wastage rates at Swan's Lagoon were a consequence of transfer out of the herd at a comparatively young age and feeding of supplements to cows in low body condition to avoid mortalities.

Wastage rates were highest for 2-year-olds, mainly because they were culled if they failed to rear a calf from this mating. Rates were lowest for 3-year-olds and increased after 6 years of age. Overseas reports of age effects on wastage rates generally found higher rates for 2-year-olds, lowest rates for young to mature ages, and sharply increased rates with ageing cows (Etienne and Martin 1979; Greer *et al.* 1980; Schons *et al.* 1985; Bailey 1991; Arthur *et al.* 1992). The cumulative lifetime wastage of 59 and 62% for the 2 herds in this study was higher than the 30% in Canada (Fredeen *et al.* 1981), 44% in Texas (Rohrer *et al.* 1988), and 34% in Nevada (Bailey 1991). For seasonal mating in northern Australia, a 5–6-month mating period is the usual duration. Under the 3-month mating period in this study, *Bos indicus* cows could have had insufficient time to overcome the stress from post partum anoestrus and lactation (Entwistle 1983), so that culling on poor reproductive performance could have been quite severe with this short mating period.

Wastage was particularly high in 1981 (23.2 and 30.8% for the 2 data sets), which reflected the very poor seasonal conditions and low pregnancy rates in 1980, so that culling rates for poor reproductive performance were very high. Apart from this year, wastage rates ranged from 3.4 to 13.7% for the 1970–72 cohorts and 2.8 to 18.0% for the 1973–87 cohorts. Overseas studies have not reported year effects directly because of at least partial confounding with cohort and age effects, and experimental designs that focus on other factors such as breed, age at introduction, or management system.

Age distributions

Age-specific wastage rates have been used here to determine various herd age distributions following the procedure outlined by Greer *et al.* (1980). The age distributions were similar for the 2 herds, with a steady decline from 17.5 and 19.2% as 2-year-olds to 7.6 and 8.6% as 9-year-olds. The average age of cows in the herds was similar at 4.9 and 5.0 years. These average ages fit within the range 4.7–6.7 years for the 10 studies reviewed by Azzam *et al.* (1990). The age profiles were similar to those reported by Greer *et al.* (1980).

The age distribution of cows leaving the herd had high values for 2-year-olds, low values for 3-year-olds, and very high values for 9-year-olds. The high value for 2-year-olds corresponded with culling of cows that failed to rear a calf and that for 9-year-olds was for cows that had completed their allotted maximum life in the herd. Given that the cows joined the breeding herds as 2-year-olds, they completed an average of 5.7 reproductive cycles from mating to weaning of the resultant calves for the 1970–72 cohorts and 5.2 cycles for the 1973–87 cohorts, with 13.6 and 27.5% present for only 1 cycle and 43.1 and 44.8% present for 8 cycles.

These lifespans at Swan's Lagoon are within the range 5.4–9.9 years of age when cows left the herd in the studies reviewed by Azzam *et al.* (1990). Relative to the present study, the proportions of cows remaining in the herd for ≥8 cycles were low (11–23%) in the studies of Greer *et al.* (1980) and Schons *et al.* (1985), similar (39–44%) in the studies of Etienne and Martin (1979) and Morris *et al.* (1993), and considerably higher (57–69%) in the studies of Rohrer *et al.* (1988) and Nunez-Dominguez *et al.* (1991*a*). The proportions present for only 1 cycle varied from 2 to 22% (Azzam *et al.* 1990).

Indices of lifetime productivity

The standardised number of calves reared in a cow's lifetime indicated very low productivity. Of equal importance is the high standard deviation for each of these herds, which indicates the scope for selection of higher performing cows provided they can be identified. This is further illustrated by the number of cows that did not rear any calves, and at the other extreme, a small proportion of cows approaching the ideal of rearing a calf for each year in the herd.

Reports from overseas, and in more intensively managed environments, of lifetime number of calves reared generally indicate much higher productivity than for these herds in northern Australia. Only Donaldson (1968) reported similarly low productivity of 2.3 pregnancies during the lifetime in a Brahman cross herd in North Queensland. Brahman cows had lower productivity (3.1 calves weaned) than Angus and crossbred cows in Texas (Rohrer *et al.* 1988; Sacco *et al.* 1989); however, Bailey (1991) found much higher productivity of 6.6 calves for Brahman cross cows in Nevada. Other reports of lower productivity included 2.5 calves weaned under a strict culling regime in Alberta (Arthur *et al.* 1993), 3.5 calves weaned from a Hereford herd in Arizona (Tanida *et al.* 1988), and 3.8 calves weaned from an Angus herd in Wyoming (Schons *et al.* 1985). Newman *et al.* (1990) reported much higher productivity of 7.2 calves weaned in a crossbreeding experiment in a more favourable temperate environment in South Australia. Cundiff *et al.* (1992) also reported high productivity of 6.7 crossbred calves and 5.7 straightbred calves weaned in Nebraska. The lower productivity in this study could be attributed to a combination of management, inherent fertility of the cattle, more stringent culling, and fewer years in the herd.

The number of productive years in the herd is a direct consequence of wastage rates and an indirect measure of productivity. For the cohorts with complete data, number of years in the herd was quite low at 4.7 for the 1970–72 cohorts and 3.2 for the 1973–79 cohorts, but was somewhat higher at 4.9 when data were standardised to the same number of potential years for the 1973–87 cohorts. These short lifespans contribute to lowering of the number of calves reared during the cow's lifetime. Short lifespans of 4–5 years were also reported in North Queensland by Donaldson (1968), and overseas by Schons *et al.* (1985), Tanida *et al.* (1988), and Arthur *et al.* (1993). In contrast, Bailey (1991) reported Brahman cross cows in the herd for an average of 7.7 years while Rohrer *et al.* (1988) found crossbreds with an average lifespan of 12 years and crosses involving Brahman having the greatest lifespan of 13.3 years. Morris *et al.* (1993) reported an average life in the herd of 6.9 years in a summary of 15 studies from Australia, Canada, USA, and New Zealand.

Total weaner weight was much higher for the 1970–72 than the 1973–87 cohorts (578 *v.* 315 kg). This difference would be caused by a combination of greater hybrid vigor for the F_1 genotypes than for later filial generations (Mackinnon *et al.* 1989) and a better run of seasonal conditions for the earlier cohorts, particularly during the late 1970s. It also represents the accumulated advantage to the 1970–72 cohorts from greater numbers of calves reared and calves per year and greater average weaner weights (Table 4). Hence, the advantage was in terms of fertility, maternal ability, and longevity: the elements of lifetime productivity (Cundiff *et al.* 1992).

Brahman cows reared 570 kg weaner weight in Texas (Sacco *et al.* 1989), similar to that produced from the 1970–72 cohorts. Fredeen *et al.* (1981) reported slightly higher output of 641 kg in a range environment and 864 kg under semi-intensive pasture management in Canada. However, Arthur *et al.* (1993) reported a lower average weight of calves weaned (483 kg) with a stringent culling regime in Alberta. Cundiff *et al.* (1992) and Newman *et al.* (1990) had very high outputs of weaner weights from crossbred cows under favourable temperate environments of 1350 and 1635 kg, respectively.

Genotype and cohort effects

The trend for 1/2 B to have higher lifetime productivity than 1/2 Sah for the F_1 genotypes was consistent with results for pregnancy and weaning rates for this herd (Holroyd *et al.* 1990*a*) and for weaner weights (Winks *et al.* 1978). The cohort x genotype interaction is also consistent with these earlier reports. For the F_{2+} genotypes, cohort differences dominated but genotype effects were significant overall and for some cohorts. The 1/2 Sah had higher productivity than 1/2 B for the F_{2+} generations, but 3/4 B outperformed 3/4 Sah, so that 3/4 Sah had the lowest lifetime productivity. Again, these trends are similar to those for pregnancy and weaning rates (Holroyd *et al.* 1990*b*) and for weaner weight (Fordyce *et al.* 1993) for this herd. Those authors concluded that 3/4 B was the most appropriate of these genotypes for the dry tropics of northern Australia because of lower losses up to weaning in the Brahmans and higher growth rates for the 3/4 crosses than the 1/2 crosses. Such conclusions are supported by the present study.

Cohort differences were clearly related to seasonal variation but it is difficult to relate lifetime productivity to a particular season. The exception is the link between the low productivity of the 1978 and 1979 cohorts and the poor seasons in 1980 and 1982. The similarity in productivity of the 1970–72 cohorts to that of the 1973 and 1974 cohorts corresponds with a run of good years during the late 1970s. Individual year effects on productivity at Swan's Lagoon have been reported previously by Holroyd *et al.* (1990*a*, 1990*b*) and Fordyce *et al.* (1993). Cohort effects for liveweights between weaning and start of mating, and particularly weight changes over these periods, can be more closely related to seasonal conditions (Doogan *et al.* 1991). Although it is somewhat diluted as a component of cohort effects, seasonal variability is the dominant influence on beef cattle productivity in northern Australia.

Predictors of lifetime productivity

Relationships of early liveweights and liveweight changes with lifetime productivity were positive and reasonably strong for the 1973–87 cohorts but nonexistent for the 1970–72 cohorts. The latter data set corresponded with a series of good seasons and relatively high productivity, while the opposite occurred for the former data set. Weaning weights, which have a large maternal component, were not related to lifetime productivity. However, later liveweights and weight changes were useful predictors when overall productivity was relatively low. The literature suggests that early measures of liveweight or weight gain are poorly related or unrelated to lifetime productivity (Carter and Cox 1973; Etienne and Martin 1979; Tanida *et al.* 1988; Bailey 1991; Arthur and Makarechian 1992). However, levels of productivity were much higher in these studies than those for the 1973–87 cohorts.

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