Mortality, wastage, and lifetime productivity of *Bos indicus* cows under extensive grazing in northern Australia
3. Comparison of culling strategies

P. K. O'Rourke[AB], *G. Fordyce*[C], *R. G. Holroyd*[A] *and R. M. Sullivan*[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] Northern Territory Department of Primary Industry and Fisheries, PO Box 1346, Katherine, NT 0851, Australia.

Summary. Strategies for culling on reproductive outcome were evaluated for 2 herds at Swan's Lagoon in the northern speargrass region and 1 herd at Kidman Springs in the semi-arid tropics by editing the records from actual culling to simulate more stringent culling policies. The greatest impact was for young cows, with 13.6 and 27.5% of 2-year-old cows in the 2 herds at Swan's Lagoon failing to rear a calf, and 39.8% at Kidman Springs failing to rear a calf. The corresponding failure rates as 3-year-old cows were 48.1, 54.9, and 80.2%, respectively. Culling for 2 consecutive reproductive failures at Kidman Springs resulted in cumulative wastage of cows >60% by 4 years of age. Other strategies based on 1 or 2 failures had cumulative wastage >80% by 5 years of age and were too severe to be sustained in the harsh environment at Kidman Springs, with low productivity.

At Swan's Lagoon, heifer replacement rates were 17.5–22.2% for strategies based on 2 failures and averaged 37.3% for a single reproductive failure but were 28.7% when failure as a 3-year-old was not penalised. At Kidman Springs, heifer replacement rates were 29.3% for 2 consecutive reproductive failures and reduced to 21.3% when 2-year-olds were retained but were very high (33.7–56.7%) for stricter culling strategies. With current branding rates, only culling on 2 reproductive failures in the speargrass region and extremely limited culling on 3 failures in the semi-arid tropics can be recommended as practical options.

The lifetime number of calves reared from cows up to 10 years of age at Swan's Lagoon averaged 3.1 when culling was based on 2 failures and 2.2 for culling on a single failure; this increased to 2.8 calves reared when the strategy was relaxed for 3-year-olds. At Kidman Springs the number of calves reared was 2.3 with culling on 2 consecutive reproductive failures but was closer to the actual level at 2.9 when 2-year-old cows were not culled for reproductive failure.

Introduction

Discretionary culling of cows based on their reproductive history or potential is used by producers to remove lowly producing cows and replace them with heifers. Cows are also culled for nondiscretionary reasons including physical abnormalities, poor temperament, advanced age, and infertility. The most lenient discretionary culling strategy removes cows that fail to rear a calf in 2 or 3 consecutive years, and the most severe removes them the first time they fail to rear a well-grown calf to weaning. Use of appropriate culling policies should reduce mortality, improve herd reproductive efficiency, and increase sales (Winter *et al.* 1985; Nunez-Dominguez 1992).

Although Goddard (1980) found almost no difference between actual pregnancy rates and those that would have occurred if all nonpregnant cows had been culled in a seasonally mated herd in North Queensland, Davis *et al.* (1993) demonstrated only a slow rate of improvement in fertility by culling repeatedly nonpregnant cows. In North American studies, Azzam *et al.* (1990), Bailey (1991), and Nunez-Dominguez *et al.* (1991*a*, 1991*b*, 1992) compared actual culling on fertility with imposed culling by editing data from a lenient strategy to test more stringent rules. They demonstrated higher culling rates for infertility, a younger age structure, and lower subsequent losses from

mortality and physical culls. These herd dynamic relationships and parameter estimates under a range of alternatives are essential for the development of herd simulation models (Azzam *et al.* 1990) and for their use to evaluate a range of culling strategies to optimise management decisions.

The earlier papers in this series (O'Rourke *et al.* 1995*a*, 1995*b*) reported on wastage and lifetime productivity under the actual culling strategies used on the 2 properties. The effects of a range of culling strategies derived by editing the records from the actual culling policy to simulate more stringent ones are reported in this paper for 2 extremes of extensive grazing in northern Australia to formulate recommendations for discretionary culling.

Materials and methods

Locations

This study used data from 2 herds at Swan's Lagoon in the subcoastal speargrass region of North Queensland and a third herd at Kidman Springs in the semi-arid tropics of the Victoria River district of the Northern Territory. Both properties have a monsoonal climate with distinct hot, wet summers and warm, dry winters. More than three-quarters of the average annual rainfall of 890 mm at Swan's Lagoon and 670 mm at Kidman Springs falls over the wet season from December to March. The vegetation is open woodland with native, unimproved pastures.

Animals and measurements

The 2 *Bos indicus* crossbred herds at Swan's Lagoon comprised 277 cows in 3 cohorts, which were branded in 1970–72 and in the breeding herd from 1972 to 1982 (1970–72 cohorts); and 1862 cows in 15 cohorts, which were branded in 1973–87 and in the breeding herd from 1975 to 1992 (1973–87 cohorts). The herds were seasonally mated for 3 months from January to April, and all calves were weaned at 5–7 months of age in May–June.

The herd at Kidman Springs comprised 690 *Bos indicus* crossbred cows in the 1979–87 cohorts, with measurements from 1981 to 1990. The herd was continuously mated, and all calves were branded at the June muster. Weaning policy varied, with some calves that weighed at least 100 kg weaned in June, a second group weaned in October, and the remainder removed as yearlings in the following June.

Cows were culled at Swan's Lagoon on the basis of poor reproductive performance, physical defects, or poor temperament. Nonlactating cows that failed to conceive were culled, as was any cow with 2 successive fetal or calf losses. Cows were culled for age at 10 years, except for random culling to reduce excessive numbers.

At Kidman Springs, culling was on physical defects and poor temperament. Infertility culling was used leniently: cows were culled only if they failed to rear a calf for 2 consecutive years and were still nonpregnant, or if nonpregnant and ≥12 years of age; heifers were culled if they failed to conceive by 3.5 years of age.

Culling was carried out immediately after the weaning or branding muster in June. Two-year-old heifers entered the breeding herd at start of mating in January at Swan's Lagoon and between December and February at Kidman Springs.

Cows were individually identified on both properties, and matched with their progeny until 1987 at Swan's Lagoon. Rearing a calf to weaning or branding was recorded by lactation status for each year in the herd. Longevity was determined from the number of annual records, and total calves reared was accumulated over the lifetime of each cow. Details for animals and measurements have been given by O'Rourke *et al.* (1995*a*, 1995*b*).

Rules for culling strategies

Wastage has been partitioned into components for physical culling and culling for a range of reproductive standards. More severe culling strategies than the one actually used were synthesised by editing subsequent records from the data. A hierarchy of 7 culling strategies, progressing from lenient to severe rules, has been established. These rules have been applied to the lifetime records for heifers introduced into the herds at Swan's Lagoon and Kidman Springs. The strategies were based on weaning at Swan's Lagoon and on branding at Kidman Springs, and cows were culled as follows:

1, each year for physical abnormalities and poor temperament, including infertile cows but not those with reduced reproductive performance;

2, failing to rear a calf to weaning at Swan's Lagoon and to branding at Kidman Springs in 2 consecutive years (dry–dry), except 2-year-olds, in their first year in the herd;

3, as above but 2-year-olds failing to rear also culled;

4, failing to rear a calf in 2 of 3 consecutive years (differing from strategy 3 from age 5 years);

5, failing on the second occasion during their lifetime to rear a calf (differing from strategy 4 from age 6 years);

6, on the first occasion of failure to rear a calf, except that failure as a 3-year-old not penalised;

7, on the first occasion of failure to rear a calf.

All strategies included culling by previous rules in the hierarchy. In particular, all culling on reproductive strategies included strategy 1. The actual culling strategies that were most closely followed were 3 (Swan's Lagoon) and 1 (Kidman Springs). Strategies 1 and 2 could not be synthesised at Swan's Lagoon.

Statistical methods

Wastage rate was analysed separately for each strategy at each site using the proportional hazards

model for grouped data (Bartlett 1978). Calculation of age distributions from these age-specific estimates of wastage rate followed the procedure outlined by Greer *et al.* (1980). Standardised lifetime productivity traits were summarised by mean and standard deviation. A more detailed description of the statistical models and procedures is given by O'Rourke *et al.* (*1995a*, *1995b*). Only age effects are presented here to compare culling strategies. Year, genotype, and year x genotype effects were, for all strategies, similar to those presented for actual wastage rates in the earlier papers in this series.

Results

Age effects for wastage rates

Age effects were significant ($P<0.05$) for wastage rates for all culling strategies for the 1970–72 cohorts at Swan's Lagoon. The other factors were unimportant for strategy 6, but at least one of them was significant ($P<0.05$) for each of the other strategies. The residual deviance was significant ($P<0.05$) for strategies 3, 4, and 7. Overall, genotype 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.

There were 277 cows in 3 cohorts which joined the F_1 herd as 2-year-olds. Although the number of records (cows at risk) for mortality and culling was quite high at young ages for all strategies, it was quite low at older ages, particularly for the more severe strategies. Wastage rates were 13.5–29.8% at age 2 years, the variation being a function of adjustments from the analytical technique used (Table 1). The rates at age 3 years were low, except for strategy 7, because of the lenient rules for culling on reproductive performance at this age for all other strategies. At age 4 years, wastage rates were higher: 12.8–13.8% for the 3 strategies requiring a second failure and substantially higher at 37.6–44.6% for the 2 strategies requiring only a single failure. Rates were slightly lower at age 5 years but tended to increase with age subsequently, except for the consistently higher rates at all ages for strategy 7. The cumulative effect of these strategies is shown in Figure 1*a*. The 3 culling strategies based on a second failure had similar cumulative patterns up to age 6, but strategy 5 had higher wastage from age 6 onwards. While the 2 single-failure strategies diverged at age 3, their cumulative effects were similar from age 7 onwards. Both had very high accumulated wastage.

For the 1973–87 cohorts at Swan's Lagoon, all effects were significant ($P<0.05$) for all culling strategies with the single exception of breed for strategy 7. Age and year effects dominated genotype and year x genotype effects. Residual deviance was substantial and much higher for these cohorts than for the 1970–72 cohorts. Simple and adjusted age effects were similar from this large data set, except for some instability from rates close to zero.

Most cows from the 1973–87 cohorts at Swan's Lagoon were transferred out of the herd before 9 years of age or remained in the herd beyond 1992, so that numbers at risk were very low at higher ages and with more severe

Table 1. Number of cows at risk and age effects for wastage rate (%) for a range of culling strategies for F_1 1/2 *Bos indicus* 1970–72 cohorts and for F_{2+} 1/2 and 3/4 *Bos indicus* 1973–87 cohorts at Swan's Lagoon

For descriptions of culling strategies, see Materials and methods

Age (years) at start of period	Strategy:	1970–72 cohorts 3	4	5	6	7	1973–87 cohorts 3	4	5	6	7
					Number of cows at risk						
2		277	277	277	277	277	1862	1862	1862	1862	1862
3		222	222	222	222	222	1143	1143	1143	1143	1143
4		207	207	207	207	135	1008	1008	1008	1008	478
5		164	164	164	145	93	736	736	736	612	231
6		142	142	141	108	71	511	399	399	288	106
7		113	113	113	75	52	318	238	196	122	45
8		91	91	91	52	38	118	88	57	32	9
9		75	68	53	21	14	38	25	11	8	1
					Wastage rate (%)						
2		13.6	14.5	13.5	29.8	20.9	27.5	27.4	27.7	34.0	30.3
3		2.1	2.3	2.1	4.6	48.1	2.8	2.8	2.8	3.5	54.9
4		12.8	13.8	12.8	37.6	44.6	8.3	8.7	8.9	25.9	39.0
5		5.6	12.9	12.6	32.7	38.4	5.7	21.5	22.0	33.4	21.6
6		13.6	15.8	22.7	32.1	33.4	8.9	9.7	22.8	36.6	26.6
7		12.3	12.6	30.8	31.8	30.1	8.5	9.0	20.7	31.0	23.2
8		18.3	19.3	37.7	47.5	54.8	11.9	19.1	16.7	27.1	29.3
9		5.6	17.4	31.7	32.7	36.9	14.2	11.0	36.2	23.5	0.3

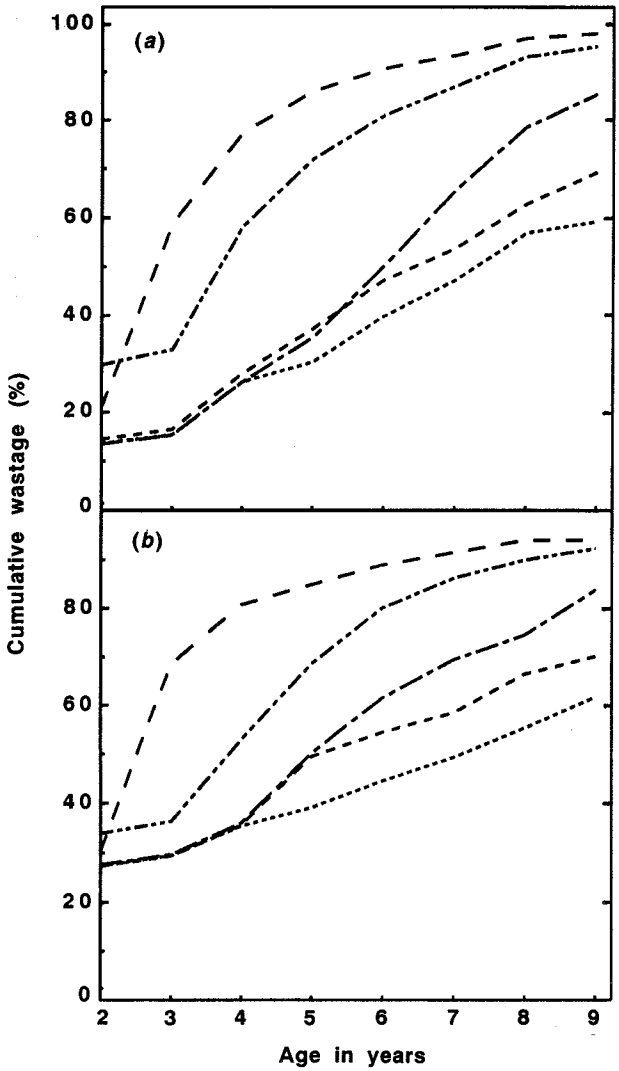

Figure 1. Cumulative age effects for wastage rate (%) for a range of culling strategies for (*a*) F_1 1/2 *Bos indicus* genotypes, 1970–72 cohorts, and (*b*) F_{2+} 1/2 and 3/4 *Bos indicus* genotypes, 1973–87 cohorts at Swan's Lagoon. Strategies 3 (- - -), 4 (– – –), 5 (— - —), 6 (– - - –), and 7 (— — —).

strategies. For the 1973–87 cohorts, wastage rates were 27.4–34.0% at age 2 years (Table 1). The smaller range here than for the 1970–72 cohorts indicates smaller adjustments for this larger, and better balanced, data set. Rates were low at age 3 years, except for strategy 7, and increased from age 4 years. They increased again with age but at different stages: age 8 years for strategy 3, age 5 years for strategies 4 and 5, and age 4 years for strategy 6. Wastage rates for strategy 7 were very high at all ages: 54.9% for age 3 years, 39.0% for age 4 years, and 21.6–29.3% for ages 5–8 years.

Table 2. Number of cows at risk and age effects for wastage rate (%) for a range of culling strategies at Kidman Springs

For explanation of culling strategies see Materials and methods

Age (years) at start of period	Culling strategy 1	2	3	4	5	6	7
	Number of cows at risk						
2	690	690	690	690	690	690	690
3	534	534	382	382	382	382	382
4	406	381	290	290	290	290	79
5	306	239	162	162	162	119	13
6	235	165	117	70	70	39	3
7	157	93	61	39	23	3	0
8	103	58	34	17	4	0	0
9	59	30	14	9	1	0	0
10	22	13	4	3	0	0	0
	Wastage rate (%)						
2	12.7	13.1	39.8	39.8	39.8	39.8	39.8
3	12.1	18.2	16.5	16.4	16.4	16.3	80.2
4	10.4	24.5	31.6	31.6	31.5	49.9	75.2
5	7.1	17.5	14.8	48.8	49.0	62.6	66.2
6	7.0	18.7	24.6	21.6	56.7	76.4	73.2
7	11.0	16.0	20.1	34.5	61.4	100.0	—
8	6.5	12.3	13.1	32.8	44.4	—	—
9	7.8	19.1	18.3	9.3	0.1	—	—
10	10.5	26.6	43.5	28.1	—	—	—

The cumulative effect for wastage rates of each of these strategies (Fig. 1*b*) shows the impact of culling at age 2 years for any of the reproductive performance strategies. Wastage accumulated very quickly in all cases. The 2 single-failure strategies had similar cumulative effects from age 7 years.

Age effects were significant ($P<0.01$) for all strategies at Kidman Springs. The residual and year effects were significant ($P<0.01$) in all cases, with simple and adjusted effects having similar deviance. Age profiles for numbers at risk for cows that entered the herd as 2-year-old heifers have been compared across 7 culling strategies (Table 2). Numbers at risk were reduced very quickly with increasing age at the more severe culling strategies. The reducing numbers also followed the number of cohorts represented across the 9 years with a range of 9 cohorts for age 2 years, 8 cohorts for age 3 years, through to a single cohort for age 10 years.

There was high wastage at age 2 years for those culling strategies requiring a calf to be reared by that age, so that only 60% of heifers would have remained in the herd beyond their first year. Except for strategy 7, all strategies had comparatively lenient culling at age 3 years but all had higher rates at age 4 years. Strategies 2 and 3 had lower rates at age 5 years but the remaining strategies had higher rates. This pattern continued from age 6 years onwards, with strategy 4 tending to be more similar to strategies 2 and 3. Estimates of wastage rate

became unstable or unavailable at higher ages and for the more severe culling strategies. The cumulative effects of these strategies are displayed in Figure 2. Even at the lenient strategies, wastage accumulated very quickly, and at the more severe strategies, wastage was too high for the herd to sustain stable numbers.

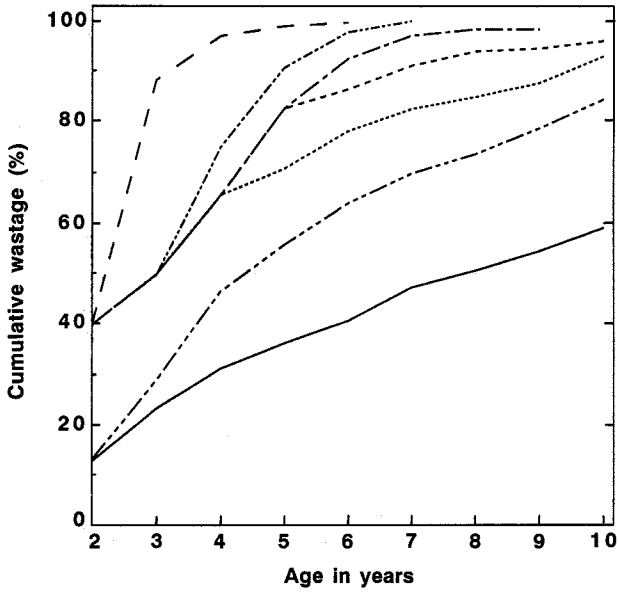

Figure 2. Cumulative age effects for wastage rate (%) for a range of culling strategies from Kidman Springs. Strategies 1 (——), 2 (— - - - —), 3 (- - -), 4 (— — —), 5 (— - — - —), 6 (- - - -), and 7 (— — — —).

Age distributions in the herds

Average age in the herd ranged from 3.4 years for strategy 7 to 4.9 years for strategy 3 for the 1970–72 cohorts and from 3.5 (strategy 7) to 5.0 (strategy 3) years for the 1973–87 cohorts (Table 3), but the median ages for both herds were 5 years for strategy 3; 4 years for strategies 4, 5, and 6; and 3 years for strategy 7. The proportion of 2-year-old cows in the herd, which indicates the replacement rate of maiden heifers needed to maintain constant herd size, increased somewhat for the strategies based on a second failure and increased substantially for those based on a single reproductive failure. For strategy 3, the heifer replacement rate varied with maximum culling age (5–9 years): 29.0, 24.1, 21.1, 19.0, 17.5% for the 1970–72 cohorts; 32.5, 27.1, 23.6, 21.1, 19.2% for the 1973–87 cohorts.

The age distribution at equilibrium became progressively more skewed towards younger ages for the more severe culling strategies at Kidman Springs (Table 4). Average age in the herd was reduced from 5.4 years for strategy 1 to 2.6 years for strategy 7. The median ages were 5 years for strategy 1; 4 years for strategy 2; 3 years for strategies 3, 4, 5, and 6; and only 2 years for strategy 7. The proportion of 2-year-old heifers required to maintain a stable herd size increased quickly with severity of the strategy from 16.6%

Table 3. Age distribution at equilbrium and average age for cows in the herd and for culled cows for a range of culling strategies for F_1 1/2 *Bos indicus* 1970–72 cohorts and for F_{2+} 1/2 and 3/4 *Bos indicus* 1973–87 cohorts at Swan's Lagoon

For explanation of culling strategies see Materials and methods

Age (years) at start of period	Strategy:	1970–72 cohorts 3	4	5	6	7	1973–87 cohorts 3	4	5	6	7
		Age distribution of cows in herd (%)									
2		17.5	18.5	19.4	28.9	36.3	19.2	20.9	22.2	28.4	38.3
3		15.1	15.8	16.8	20.3	28.7	14.0	15.2	16.0	18.8	26.7
4		14.8	15.5	16.4	19.4	14.9	13.6	14.7	15.6	18.1	12.0
5		12.9	13.3	14.3	12.1	8.2	12.4	13.4	14.2	13.4	7.4
6		12.2	11.6	12.5	8.1	5.1	11.7	10.6	11.1	8.9	5.8
7		10.6	9.8	9.7	5.5	3.4	10.7	9.5	8.6	5,7	4.2
8		9.3	8.6	6.7	3.8	2.4	9.8	8.7	6.8	3.9	3.3
9		7.6	6.9	4.2	2.0	1.1	8.6	7.0	5.7	2.8	2.3
Average age		4.9	4.8	4.6	3.9	3.4	5.0	4.8	4.6	4.0	3.5
		Age distribution of culled cows (%)									
2		13.6	14.5	13.5	29.8	20.9	27.5	27.4	27.7	34.0	30.3
3		1.8	2.0	1.8	3.2	38.0	2.0	2.0	2.0	2.3	38.3
4		10.8	11.5	10.9	25.2	18.4	5.9	6.2	6.3	16.5	12.2
5		4.2	9.3	9.3	13.7	8.7	3.7	13.8	14.1	15.8	4.2
6		9.4	9.9	14.6	9.0	4.7	5.4	4.9	11.3	11.5	4.0
7		7.4	6.6	15.4	6.1	2.8	4.7	4.1	8.0	6.2	2.5
8		9.7	9.0	13.0	6.2	3.6	6.0	8.0	5.1	3.7	2.5
9		43.1	37.2	21.5	6.8	2.9	44.8	33.6	25.5	10.0	6.0
Average age		6.7	6.4	6.2	4.5	3.8	6.2	5.8	5.5	4.5	3.6

Table 4. Age distribution at equilbrium and average age for cows in the herd and for culled cows for a range of culling strategies at Kidman Springs

For explanation of culling strategies see Materials and methods

Age (years) at start of period	Culling strategy 1	2	3	4	5	6	7
Age distribution of cows in herd (%)							
2	16.6	21.3	29.3	33.7	36.2	40.4	56.7
3	14.4	18.5	17.6	20.3	21.8	24.3	34.1
4	12.7	15.1	14.7	16.9	18.2	20.4	6.7
5	11.4	11.4	10.1	11.6	12.5	10.2	1.7
6	10.6	9.4	8.6	5.9	6.4	3.8	0.6
7	9.8	7.7	6.5	4.6	2.8	0.8	0.2
8	8.8	6.4	5.2	3.0	1.0	0.0	0.0
9	8.2	5.6	4.5	2.1	0.6	0.0	0.0
10	7.5	4.6	3.7	1.9	0.6	0.0	0.0
Average age	5.4	4.7	4.4	3.8	3.5	3.2	2.6
Age distribution of culled cows (%)							
2	12.7	13.1	39.8	39.8	39.8	39.8	39.8
3	10.6	15.8	9.9	9.9	9.9	9.8	48.3
4	7.9	17.4	15.9	15.9	15.8	25.2	8.9
5	4.9	9.4	5.1	16.8	16.9	15.8	2.0
6	4.4	8.3	7.2	3.8	10.0	7.2	0.7
7	6.6	5.8	4.4	4.8	4.7	2.2	0.3
8	3.4	3.7	2.4	2.9	1.3	0.0	0.0
9	3.9	5.0	2.8	0.6	0.0	0.0	0.0
10	45.6	21.5	12.5	5.5	1.6	0.0	0.0
Average age	7.0	5.7	4.4	4.0	3.8	3.5	2.8

for strategy 1 to 56.7% for strategy 7. For strategy 2, the heifer replacement rate varied with maximum culling age (5–10 years): 32.1, 28.1, 25.5, 23.7, 22.3, 21.3%. Corresponding heifer replacement rates for strategy 3 were 40.8, 36.5, 33.7, 31.8, 30.4, and 29.3%.

Average age of culled cows varied markedly with culling strategy, from 3.8 to 6.7 years for the 1970–72 cohorts and from 3.6 to 6.2 years for the 1973–87 cohorts (Table 3), while median ages of culled cows for the 1970–72 cohorts were 8 years for strategy 3; 7 years for strategy 4; 6 years for strategy 5; 4 years for strategy 6; and 3 years for strategy 7. The profile was similar for the 1973–87 cohorts, except that the median ages were 6 years for strategy 4 and 5 years for strategy 5. The percentages culled for maximum age after age 9 years decreased markedly with the severity of the culling strategy.

At Kidman Springs, average age of culled cows decreased with severity of culling strategy from 7.0 years for strategy 1 to 2.8 years for strategy 7. Median ages of culled cows were 8 years for strategy 1, 5 years for strategy 2, and 3 years for the more severe strategies. Age patterns of percentage increases across strategies were similar for culled cows to those described for cows in the herd.

Table 5. Lifetime productivity (mean ± s.d.) of cows to a maximum culling age of 8 or 10 years for a range of culling strategies at Swan's Lagoon and Kidman Springs

For explanation of culling strategies see Materials and methods

Maximum age and culling strategy	No. of years in herd	No. of calves reared	Total weaner weight (kg)
F_1 1/2 Bos indicus, 1970–72 cohorts			
8 years			
Strategy 3	4.06 ± 1.97	3.01 ± 2.10	529.8 ± 379.2
Strategy 4	4.06 ± 1.97	3.01 ± 2.10	529.8 ± 379.2
Strategy 5	4.06 ± 1.97	3.01 ± 2.10	529.8 ± 379.2
Strategy 6	3.73 ± 1.84	2.76 ± 2.00	486.6 ± 363.0
Strategy 7	3.07 ± 1.78	2.27 ± 2.02	396.6 ± 365.4
10 years			
Strategy 3	4.66 ± 2.65	3.30 ± 2.48	577.6 ± 440.8
Strategy 4	4.63 ± 2.62	3.29 ± 2.46	574.4 ± 437.6
Strategy 5	4.58 ± 2.56	3.25 ± 2.42	566.4 ± 430.4
Strategy 6	3.99 ± 2.22	2.88 ± 2.21	504.8 ± 393.6
Strategy 7	3.26 ± 2.12	2.34 ± 2.18	407.2 ± 388.8
F_{2+} 1/2 and 3/4 Bos indicus, 1973–87 cohorts			
8 years			
Strategy 3	3.79 ± 2.15	2.39 ± 2.17	250.8 ± 280.2
Strategy 4	3.69 ± 2.10	2.33 ± 2.16	231.0 ± 266.4
Strategy 5	3.67 ± 2.08	2.31 ± 2.15	225.6 ± 259.2
Strategy 6	3.50 ± 2.00	2.19 ± 2.08	202.8 ± 233.4
Strategy 7	2.81 ± 1.81	1.71 ± 1.96	132.0 ± 180.6
10 years			
Strategy 3	4.91 ± 2.89	3.12 ± 2.89	315.2 ± 363.2
Strategy 4	4.78 ± 2.82	3.03 ± 2.87	288.0 ± 344.0
Strategy 5	4.73 ± 2.79	3.00 ± 2.86	277.6 ± 331.2
Strategy 6	4.50 ± 2.69	2.84 ± 2.78	248.8 ± 300.0
Strategy 7	3.62 ± 2.46	2.23 ± 2.62	161.6 ± 233.6
Kidman Springs 1979–87 cohorts			
8 years			
Strategy 1	4.99 ± 1.68	2.39 ± 1.73	
Strategy 2	4.66 ± 1.73	2.22 ± 1.78	
Strategy 3	3.83 ± 2.05	1.79 ± 1.88	
10 years			
Strategy 1	6.50 ± 2.34	3.14 ± 2.32	
Strategy 2	6.00 ± 2.43	2.88 ± 2.38	
Strategy 3	4.94 ± 2.80	2.32 ± 2.50	

Lifetime productivity

Lifetime productivity was similar for strategies 3, 4, and 5 for the 1970–72 cohorts, with an average of 3.3 calves and 573 kg of weaner weight reared over 4.6 years in the herd; somewhat lower for strategy 6 with 2.9 calves and 505 kg reared over 4.0 years; and substantially lower for strategy 7 at 2.3 calves and 407 kg reared over 3.3 years (Table 5). For the 1973–87 cohorts, there was a general trend to lower productivity with increasing severity of culling strategy. Productivity averaged 3.0 calves and 294 kg of weaner weight reared over 4.8 years in the herd for the strategies based on 2 failures and was particularly low for strategy 7, with 2.2 calves and 162 kg reared over 3.6 years. All indices

showed higher productivity per year up to 8 years than to 10 years, and for 1970–72 cohorts than for 1973–87 cohorts. Standard deviations were high relative to the means, indicating a big range in productivity for individual cows.

Lifetime productivity at Kidman Springs was compared under 3 culling strategies up to a maximum culling age of 8 or 10 years (Table 5). Productivity was slightly lower than actual (3.1 calves reared over 6.5 years in the herd) when strategy 2 was implemented (2.9 calves reared over 6.0 years), but substantially lower under strategy 3 (2.3 calves reared over 4.9 years). Patterns and levels for productivity were similar across the 3 culling strategies for maximum ages of 8 or 10 years.

Discussion

Wastage rates and patterns

The decline with age in the number of cows at risk relative to the number of cows for the actual strategy gives a lagged measure of the severity and impact of the different culling strategies. For instance, at Swan's Lagoon 10.5 and 16.3% of available cows were discretionary culls for failure to rear a calf as 2-year-olds and a further 34.8 and 52.6% failed to rear as 3-year-olds under strategy 7 for the 2 herds, respectively. The corresponding rates at Kidman Springs were 28.5 and 72.8%. Several strategies were identical at younger ages and became distinct only after 6 years of age, as shown in Figures 1 and 2. The 7 strategies form a hierarchy of culling from lenient to severe, whose use is dependent upon the level of property development and productivity. The most lenient strategies are appropriate under harsh, extensive conditions and the more severe ones under more intensive and highly productive situations.

The strategies may be grouped: no culling on fertility, culling on 2 failures, culling on a single failure. Within the first group, which represents the minimum possible level of wastage, there was no age trend at Kidman Springs. Mortality was the main component of this wastage at Kidman Springs, but physical culls had a bigger influence at Swan's Lagoon (O'Rourke *et al.* 1995*a*, 1995*b*). The 5 studies reviewed by Azzam *et al.* (1990) had low wastage rates for culling based on health alone but a trend for higher rates as age increased. Reports in the literature are divided on the relative rates for mortality and physical culls. At 2 sites in Canada, Fredeen *et al.* (1981) found a greater contribution from mortality (9.8 and 6.6%) than from culling for infertility (1.8 and 2.6%). Rohrer *et al.* (1988) and Nunez-Dominguez *et al.* (1991*a*) found similar contributions from the 2 components. Bailey (1991) reported 4% breeder mortality and 11% of cows removed as physical culls up to 10 years of age. Arthur *et al.* (1992) reported a lower rate of lifetime mortality (8.8%) than of culling on physical traits (27.8%) in Alberta. Greer *et al.* (1980) reported low and consistent mortality rates with age from 1.0 to 1.7% but a steady increase in physical culls from 2.2% as 2-year-olds to 10.9% as 10-year-olds. Hence, the patterns at Swan's Lagoon were similar to the findings of Greer *et al.* (1980) and Bailey (1991), while the herd at Kidman Springs had much higher mortality rates than any of the overseas reports.

The major impact on wastage rate occurred with the culling of 2-year-old cows that failed to rear a calf. Rates for strategy 2 at Kidman Springs were much lower than those for strategy 3 at 2 years of age, as expected, but paralleled strategy 3 at subsequent ages, with no tendency towards compensation. The impact of the other strategies based on 2 reproductive failures was an increase in wastage rates at higher ages relative to that for strategy 3. Strategy 4 had much higher wastage for 5-year-olds but only slight increases subsequently. Rates for strategy 5 were also higher than strategy 3 for 5-year-olds but remained substantially higher at subsequent ages. The age-specific culling rates for management criteria of Greer *et al.* (1980), which were primarily based on fertility, were similar to those for Swan's Lagoon. There are no reports in the literature comparing the effects of this group of strategies.

Wastage rates were very high at all ages for the strategies based on a single failure, with the logical exception of 3-year-olds for strategy 6. Rates at Kidman Springs were higher than those at Swan's Lagoon, reflecting the higher reproductive rates at Swan's Lagoon.

While the main difference between strategies 1 and 3 occurred as 2-year-olds, rates were also higher subsequently at Kidman Springs. Strategy 7's main impact was on 3-year-olds but wastage rates were higher than for strategy 3 at all subsequent ages. Bailey (1991) found lifetime wastage rates of 15.0% under strategy 1, 30.2% under strategy 3, and 66.1% under strategy 7 up to 9 years of age. Nunez-Dominguez *et al.* (1991*b*) reported higher lifetime wastage up to 12 years of age of 43.2, 66.8, and 80.5%, respectively, for the 3 strategies. Wastage rates were higher for strategy 7 than 3 at all ages after 3 years.

Cumulative wastage integrates the age-specific rates with the proportion of cows remaining in the herd until that age. Hence, the rates at younger ages have much higher impact, as shown by the distinctive patterns for strategies 2 and 7 and similar patterns for strategies 3, 4, and 5 (Figs 1 and 2). Although strategies 6 and 7 separate at 3 years of age they converge at later ages. The other strategies tend to have similar patterns after their initial separation. Overseas reports of cumulative wastage under strategy 3 were much lower at 15–20% (Fredeen *et al.* 1981; Rohrer *et al.* 1988; Bailey 1991), or slightly lower at 45% (Nunez-Dominguez *et al.* 1991*a*), than for Swan's Lagoon (60%) and Kidman Springs (84%).

Age distributions

As the severity of the culling strategy increased, a greater proportion of the herd was concentrated in the younger ages, and the average age and reproductive life were lowered. The 2 herds at Swan's Lagoon had similar age profiles and average ages. Average ages were higher at Swan's Lagoon than at Kidman Springs for the strategies based on reproductive performance because of the low branding rates at Kidman Springs (O'Rourke *et al.* 1995*b*). The number of replacement heifers needed to maintain a stable herd size increased beyond the productivity of the herd for strategy 7 at Swan's Lagoon and for strategies 3–7 at Kidman Springs. Heifer replacement rate is a sensitive index of the severity of the culling strategy and of the productivity of the herd. Azzam *et al.* (1990) reported a heifer replacement rate lower by 5.3%, and average age higher by 0.9 years, for strategy 3 than 7 when averaged over 3 studies. Nunez-Dominguez *et al.* (1991*a*) reported similar comparisons, with differences averaging 4.3% for heifer replacement rate and 0.8 years for average age. The corresponding differences at Swan's Lagoon and Kidman Springs, respectively, were 19.0 and 27.4% for heifer replacement rate and 1.5 and 1.8 years for average age, which were considerably greater differences than for the overseas studies.

The age distribution of cows leaving the herd became markedly more skewed towards younger ages as the culling strategy became more severe. Average age and number of reproductive cycles declined in the same way. The proportion of cows reaching maximum age declined from high to low values (44.8 to 2.9%) with strategy severity at Swan's Lagoon and was very low (0–21.5%) for all reproductive culling strategies at Kidman Springs. The 2 herds at Swan's Lagoon had similar age profiles for cows leaving the herd, average ages, and proportions reaching maximum age across all the culling strategies, except for the higher proportion of 2-year-old cows failing to rear a calf for the 1973–87 cohorts. In the 3 studies reviewed by Azzam *et al.* (1990), the average age of culled cows was higher by 1.7 years for strategy 3 than 7. The difference between these strategies in average age was somewhat higher, at 2.8 years, for Swan's Lagoon but similar, at 1.6 years, for Kidman Springs.

Lifetime productivity

At Swan's Lagoon, the 3 strategies based on 2 reproductive failures gave similar levels of lifetime productivity, with only a slight decrease with severity of strategy for the 1973–87 cohorts. This was expected as the strategies were identical up to 4 or 5 years of age, by which time most of the critical culling decisions had been made. Productivity was much lower with culling on a single reproductive failure, with the biggest impact from culling for failures as 3-year-olds. This emphasises the importance of fertility, firstly as a 2-year-old and then as a 3-year-old, on herd productivity, and points to the need for research into, and careful management for, fertility of maiden heifers and first-calf cows (Entwistle 1983). Culling on a single reproductive failure, compared with culling on 2 consecutive reproductive failures, resulted in 1.7 fewer calves weaned and 338 kg less weaner weight for crossbred cows in Nebraska (Cundiff *et al.* 1992) and 2.5 mating seasons and 2.0 fewer calves for Brahman crossbred cows in Nevada (Bailey 1991). Those differences were substantially larger than found in the present study (average 0.9 fewer calves reared and 150 kg less weaner weight), a consequence of the lower fertility and productivity in the northern Australian environment.

Removing cows that do not rear a calf at least every second year is considered lenient, even under the harsh environmental condition of northern Australia (Winter *et al.* 1985). At Kidman Springs, use of strategy 3 resulted in a short life in the herd and very low productivity. Deferring the culling of cows that fail to conceive as 2-year-olds returned productivity to a level closer to the actual level with no culling on fertility. Hence, most of the impact of culling at this lenient level for fertility would be from the earlier removal of cows that fail to conceive in their first 18 months in the herd. These cows could be sold as stores to boost income and to reduce grazing pressure on the property. More severe culling strategies were not sustainable with such low levels of productivity.

Lifetime productivity at Swan's Lagoon and Kidman Springs can also be compared under strategy 3. While number of years in the herd was similar for the 3 herds (4.7, 4.9, 4.9 years), there was a substantially higher number of calves reared at Swan's Lagoon (3.3, 3.1) than at Kidman Springs (2.3). The similar longevity in the 3 herds indicates the dominance of strategy 3 over environmental and managerial differences. The lower number of calves reared indicates the difficulties at Kidman Springs, in spite of greater opportunities from continuous mating and the fact that rearing was required only to branding rather than to weaning.

Because of increasing mortality and decreasing fertility with age, it is common to maintain a maximum age for culling of cows from the herd. Sale of these cull cows can contribute significantly to total turnoff, adds to property income, and reduces stocking pressure. At Swan's Lagoon, productivity was somewhat higher up to 10 years than up to 8 years but the efficiency measures were superior at the lower age. For maximum culling ages 6–10 years, the numbers of calves reared at Kidman Springs increased: 1.8, 2.1, 2.5, 2.8, 3.2. Hence, 7 years is the lowest culling age by which a cow can generate her own replacement and for which herd

numbers can be maintained in this environment. Since wastage rate increases from 10 years of age (O'Rourke *et al.* 1995*b*), the highest culling age is 10 years. In the northern speargrass areas (e.g. Swan's Lagoon), 77% of producers cull on maximum age, with 8 years (24%) and 10 years (40%) being the most common choices. In the north-western spinifex areas (e.g. Kidman Springs), most of the 67% of producers who cull on maximum age reported culling cows predominantly at either 8 years (38%) or 10 years (36%) (O'Rourke *et al.* 1992). A maximum age of 8–10 years is therefore recommended for herds in northern Australia.

Practical considerations

Culling decisions made on the basis of reproductive history and performance anticipate reproductive potential, so that removal of a low-performing cow will improve the future productivity of the herd. Rudder *et al.* (1976), Seifert *et al.* (1980), and Mackinnon *et al.* (1989) reported moderate to high repeatability for fertility in *Bos indicus* genotypes in central Queensland and phenotypic responses to selection for fertility. Entwistle (1983) suggested that repeatability of fertility might be less important than lactational and nutritional stresses in harsh areas of northern Australia, so that where reproductive rates are low, culling on fertility should be restricted to cows with consecutive failures. However, where environmental conditions are less stressful and fertility levels are reasonably high, rigid culling on reproductive performance should lead to improvements in fertility.

In North Queensland, Bamualim *et al.* (1984) found significant, partially repeatable differences between bulls for the pregnancy rate of cows to which they were mated. Davis *et al.* (1993) reported that divergent selection of bulls for pregnancy rate in this same herd using estimated breeding values (EBV) resulted in symmetric direct response in pregnancy rate and favourable correlated responses in days to calving and post weaning calf growth rates. This study also demonstrated the progress that could be achieved when EBVs were used to select bulls to improve female reproduction. Improvements equivalent to 20 years of culling females were made with a single round of sire selection. However, it was not possible in their study to determine whether continuous progress could be made. Associated culling of cows on fertility would lead to further advances, but greater emphasis should be placed on bull selection to improve productivity.

In general, culling on fertility should be as severe as herd productivity will permit. When replacement heifers are to come from within the herd, as is usual in northern Australia, the available heifers comprise one half of the progeny branded 2 years previously minus losses from branding to start of mating. Replacements will be required for breeder mortalities and physical culls as well as the discretionary culls based on productivity. Also, the pool of heifer replacements needs to be sufficiently large to exclude unsuitable heifers and to select on the basis of the breeding objectives set by management.

The advantages of more severe culling on productivity include more cows available for sale, lower mortality from prior removal of survival risks, reduced grazing pressure on pastures, higher herd fertility, and genetic gains from shorter generation intervals. The reduced number of heifers for sale is more than countered by the increased sales of higher valued cows. The disadvantages include less selection pressure on heifers, greater cost to rear replacements for 2 nonproductive years, and a high proportion of young cows in the herd. Mature cows generally have higher fertility, rear heavier weaners, and have lower mortality than heifers and cows in their first lactation. Nonlactating cows are also more likely to conceive early and to wean heavier calves in the next season.

The key to choosing the most appropriate culling strategy is overall productivity and profitability. With current branding rates of 61% typical of the speargrass region in the dry tropics and 45% for the semi-arid tropics, maximum heifer replacement rates from within the herd are 30 and 22%, respectively. Hence, the most severe culling strategies that can be sustained are culling at the first occasion of failure to rear a calf (except for 3-year-olds) in the speargrass region and culling on failure to rear a calf to branding in 2 consecutive seasons (except for 2-year-olds) in the semi-arid tropics. These strategies allow no scope of heifer selection, so that only culling on 2 reproductive failures can be recommended for the speargrass region and extremely limited culling for 3 failures in the semi-arid tropics. Branding rates need to approach the economic optimum of 70–75% (Entwistle 1983) before culling on a single reproductive failure can be sustained. Improved nutrition and management which boosts productivity will permit the sustainable use of more rigid selection for, and culling on, fertility. These biological rates and patterns for age-specific mortality, wastage, and reproduction provide input for economic analyses of herd performance. Basic assumptions would be required for herd size and management practices, and to assign prices for cull cows and surplus heifers and values for weaners. These models generate simple economic parameters to indicate the dollar value of various strategies.

Acknowledgments

We are grateful for the assistance of Mrs K. L. Hoyes and Miss J. A. Neale with computing and data analysis, and the management and technical staff at Swan's Lagoon and Kidman Springs for data collection and animal management.

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Received 5 April 1994, accepted 22 November 1994