Project Report QO00001

Bull selection and use in northern Australia

PROJECT: DAQ.104

FINAL REPORT

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Part 1 Project Summary

Project Title: Bull selection and use in northern Australia

Project No: DAQ.104

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Duration of project

The project ran from 1992 to 1997 with MRC funding from January 1995 to October 1997.

Objectives

- To improve the selection of bulls with high genetic merit (particularly growth and carcase traits) and calf output by developing management packages based on identifying premating predictors of bull fertility.
- to make management recommendations on bull selection criteria that will allow producers to reduce bull joining percentage without jeopardising herd fertility

Summary
The project was conducted on 3 research stations and 8 co-operator properties in Queensland and 1 research farm in the Northern Territory. There were about 1000 bulls, mainly 2-to 4-year-old Santa Gertrudis, 5/8 Brahman, Brahman, Belmont Red and Belmont Red cross, that were subjected to physical and reproductive examinations prior to mating.

The bulls came from properties where there was already in place a selection policy on physical and reproductive traits. Thus, many of the extremes in physical conformation, scrotal size, excessive pendulous sheaths and poor temperament had been culled from the population.

The key findings of the project were:

(i) The systematic physical examination of a bull is the foundation of a breeding soundness examination. The moderate to high repeatabilities for key physical traits (eg scrotal circumference) demonstrated that bulls may be selected accurately on the basis of an annual pre-breeding examination.

(ii) Semen examination, including assessment of sperm morphology, should be incorporated into bull selection programs and premating examinations to ensure that bulls have at least 50% normal sperm. Fertility recommendations should not be based solely on semen or sperm motility. Assessments of semen heparin-binding protein profiles are unlikely to enhance the evaluation of bull fertility.

(iii) Brahman and Santa Gertrudis bulls are capable of performing in a serving capacity test although the degree of expressions of sexual behaviour, particularly serves, is less than in *Bos taurus*. The main value of the serving capacity test in these breeds is a means of identifying whether a bull is capable of serving and not as a predictor of calf output when mated in multiple-sire herds.

(iv) Behaviour as expressed through social dominance has a significant influence on calf output of bulls in multiple-sire mated herds under extensive management systems. Bulls are very territorial, a behaviour which is presumably related to social dominance; bulls expressing this behaviour to the highest degree tended to sire more calves.

(v) DNA typing is an accurate method of identifying paternity of calves resulting from multiple-sire matings. There was no one single physical or reproductive trait that was consistently related to calf output in multiple-sire herds. Even so, selecting on combinations of traits did not explain all of the variation in calf output. Bulls should be selected for physical and reproductive traits that lie above threshold values.

(vi) Multiple-sire mating Brahman and *Bos indicus* derived bulls which are reproductively-sound at a rate of 2.5% of cycling females will not jeopardise herd fertility under most conditions in extensive parts of northern Australia.

Part 2 Executive Summary

1. BACKGROUND AND INDUSTRY CONTEXT

There are about 11M cattle in northern Australia (north of 29°S) and about 4M of these are breeding cows and bulls. The majority of these cattle are of *Bos indicus* or *Bos indicus* derived content. The vast majority of these cattle would be run at stocking rates of 1 adult to 5-30 ha. As a consequence, cattle on properties are spread over large areas although there tends to be a concentration of animals at stock watering points.

Little is known of the individual reproductive performance of bulls in extensive environments. Low and variable bull fertility was identified as a constraint on reproductive rates in beef cattle in an extensive, multiple-sire mating system in the Northern Territory. Erratic conception patterns were attributed to a high proportion of bulls with low breeding soundness evaluation scores, a large number of aged bulls and having mixed-age bull mating groups. This variation in bull fertility has been identified also in a study of single-sire mating groups with *Bos indicus* cross bulls in north Queensland. Even though screening tests for bull fertility were applied, 4% of mated bulls did not produce any progeny and a further 4% were associated with mating groups which had less than 20% pregnancy rates. These failures could have been due to libido or serving ability problems.

Herd bull replacement is a major cost for commercial cattle breeders in northern Australia. The economic impact of bull management depends on two issues. The first is the capital cost per calf branded, incurred by the bull. This is a function of the purchase price of the bull, its working life and the number of calves it produces. For example, if a $2000 bull has a working life of 5 years at a bull:cow ratio of 5%, the bull cost per calf ranges from $30 per calf at 50% branding rate down to $19 per calf at 80% branding rate. The second aspect of economics of bull management relates to the genetics imparted by the bull. Major financial benefits are achieved by using bulls whose progeny have higher productivity through improved fertility, growth, temperament, survival and carcase attributes.

2. OBJECTIVES

The project had 2 objectives:-

- to improve the selection of bulls with high genetic merit (particularly growth and carcase traits) and calf output by developing management packages based on identifying premating predictors of bull fertility.
- to make management recommendations on bull selection criteria that will allow producers to reduce bull joining percentage without jeopardising herd fertility.

3. METHODS

The Bull Power project ran from 1992 to 1997 and was a co-operative project between Queensland Department of Primary Industries, The University of Queensland, James Cook University, Northern Territory Department of Primary Industry and Fisheries and the Meat Research Corporation. MRC provided funding from January 1995 to October 1997.

The project team was RG Holroyd (project leader), JD Bertram, BM Burns, NJ Cooper, J DeFaveri, VJ Doogan, G Fordyce, RG Miller, AJ Teakle and BK Venus (Queensland Department of Primary Industries), MR McGowan, D Baker, S Johnston, N Phillips and DM Vankan (The University of Queensland), LA Fitzpatrick, C Coleman and P Findlay (James Cook University), GA Jayawardhana (Northern Territory Department of Industry and Fisheries) and MJ D'Occhio (CSIRO).

The Bull Power project was conducted on 3 research stations and 8 co-operator properties in Queensland and 1 research farm in the Northern Territory. There were about 1000 bulls, mainly 2-to 4-year-old Santa Gertrudis, 5/8 Brahman, Brahman, Belmont Red and Belmont Red cross, that were subjected to physical and reproductive examinations prior to mating. All bulls used in this research were acclimatised to their study environment. They had not been recently purchased through auction sales or fattened for this purpose.

The bulls came from properties where there was already in place a selection policy on physical and reproductive traits. Thus, many of the extremes in physical conformation, scrotal size, excessive pendulous sheaths and poor temperament had been culled from the population. Measurements included:

Age

Liveweights

Body condition

Structure of musculosketetal system

Scrotal contents were assessed by manual palpation. ***Testicular tone*** and ***resilience*** were determined and ***scrotal circumference*** was measured with a standard metal tape.

Prepuce and navel measurements when relaxed, included:

Distance of preputial orifice below knee-hock line (cm).
Width of navel (cm). At some sites this was referred to as sheath width.
Depth of prepuce (cm). Vertical distance from the ventral abdominal wall to the preputial orifice.
Angle of preputial orifice (degrees). In Brahman and 5/8 Brahman bulls only.
Navel thickness. Estimated thickness of the remnant of the navel stump.
Preputial protractor muscle.
Skin thickness
Prepuce score.

Semen collection and evaluation using either standard electroejaculation techniques, or in the case of some Santa Gertrudis bulls by massage of the ampullae.

Heparin-binding proteins from a subset of bulls in 1995.

Libido and serving capacity measurements. Initially, the serving capacity test was adapted from *Bos taurus* studies using females restrained in service crates. In most cases females were treated to synchronise oestrus. The test was for a 20 minute period from the time of first mount or for 30 minutes in the yard with the oestrus females.

The following modifications to the test were evaluated using mainly 2-year-old Santa Gertrudis bulls.

(i) Providing sexual experience to virgin bulls prior to testing.

(ii) Use of restrained females either in oestrus or not in oestrus

(iii) Use of restrained or unrestrained females

A group of 12, 5/8 Brahman bulls at site 9, were serving capacity tested with both restrained and unrestrained females. When used with unrestrained females they were tested with a bull to female ratio of 1:4-6.5. Bulls tested with restrained females in crates were tested with a ratio of bull to female ratio of 1:1-1.5. Testing was conducted pre- and post-mating for 2 years at site 9.

Dominance. A dominance hierarchy was estimated by recording agonistic behaviour.

Paddock behaviour. At site 9, a movement range index (MRI) was developed to determine locations of bulls within a paddock.

Calf output. Over 4 years, calf output was collected on 212 bull observations (92 Santa Gertrudis, 24 5/8 Brahman and 96 Brahman) from 37 mating groups on 9 properties. The number of bulls per mating group ranged from 2 to 24. Bulls were from 2 to 7 years of age and in most cases, ages within mating groups were similar or overlapped by a year, eg 2- and 3-year olds or 4- and 5-year olds. Joining periods were from 3 to 12 months and bull mating percentages ranged from 2.5% to 6% but most were 3% to 4%. Bulls and calves were bled for DNA typing to determine paternity.

4. RESULTS

4.1 Prepuce, testicular and other physical traits

Tables 1 and 2 provide means and ranges for a selection of the physical measurements recorded.

Table 1. Summary statistics of physical traits of Santa Gertrudis and Belmont Red bulls

	Santa Gertrudis				Belmont Red			
	2-year-olds (n=378)		3-year-olds (n=56)		1-year-old (n=176)		2-year-old (n=107)	
	mean	range	mean	range	mean	range	mean	range
Liveweight (kg)	586	327-850	788	636-911	265	198-365	565	442-680
Condition score	5.3	3.0-8.0	5.4	3.0-7.0	4.4	3.0-5.0	4.7	4.0-6.0
Scrotal circum (cm)	36.4	29.0-48.0	39.0	32.5-45.5	24.3	18.5-29.5	34.5	30.0-38.5
Testicular tone	2.8	1.0-3.0	2.8	2.0-3.0	3.0	2.5-3.0	2.9	2.3-3.0
Prepuce depth (mm)	206	110-275	217	145-280	75	25-175	102	50-150
Prepuce score	4.6	2.0-8.0	4.6	3.0-8.0	7.9	4.0-9.0	7.9	4.0-9.0

Table 2. Summary statistics of physical traits of 5/8 Brahman and Brahman bulls

	5/8 Brahman				Brahman			
	4-year-olds (n=9)		≥5-year-olds (n=13)		2-year-old (n=108)		3-year-old (n=59)	
	mean	range	mean	range	mean	range	mean	range
Liveweight (kg)	580	536-616	673	576-762	441	328-640	480	385-640
Condition score	6.2	6.0-7.0	6.3	5.0-7.0	5.2	4.0-7.0	6.3	4.0-7.0
Scrotal circum (cm)	33.7	30.0-37.0	36.5	31.5-41.0	33.7	26.0-42.5	34.3	27.0-41.0
Testicular tone	2.9	2.5-3.0	3.0	3.0-3.0	2.9	2.0-3.0	2.95	2.5-3.0
Prepuce depth (mm)	142	70-230	132	80-200	200	100-355	172	80-250
Prepuce score	6.5	6.0-7.0	7.5	6.0-9.0	4.7	2.0-7.0	5.1	3.0-8.0

In all breeds, liveweight and scrotal circumference increased with age ($P<0.05$). In addition, in Santa Gertrudis bulls, prepuce depth and prepuce score increased with age ($P<0.05$).

Scrotal circumference, prepuce depth and prepuce score were moderately to highly repeatable.

Across breeds a number of traits were consistently correlated. In all breeds except 2- and 3-year old Belmont Red bulls, bodyweight was positively correlated with scrotal circumference ($r = 0.29$ to 0.78; $P<0.05$). However there was no significant relationship between scrotal circumference and testicular tone score. Prepuce depth was negatively related to prepuce score ($r = -0.48$ to -0.81; $P<0.01$) but was not significant in 2-year-old Santa Gertrudis bulls ($r = -0.10$). Prepuce depth was also positively correlated to umbilical cord thickness in 2-year-old Brahman ($r = 0.36$; $P<0.05$), 2-year-old Santa Gertrudis ($r = 0.16$; $P<0.01$) bulls and 1-year-old Belmont Red ($r = 0.44$; $P<0.01$) bulls.

In 2-year-old Santa Gertrudis bulls, body weight was positively correlated with number of serves achieved in the serving capacity test ($r = 0.13$; $P<0.05$) and the percent motile spermatozoa ($r = 0.27$; $P<0.01$). However, body condition score was negatively correlated with number of serves ($r = -0.13$; $P<0.05$) but not percent motile spermatozoa in 2-year-old Santa Gertrudis bulls. Body condition score was generally not correlated with any of the testicular, semen or serving capacity traits in Brahman bulls except for 2-year-old Brahman bulls, body condition score was positively correlated with scrotal circumference ($r = 0.20$; $P<0.05$).

In 1-year-old Belmont Red bulls, weight and condition score were positively correlated with mounts ($r = 0.16$ and 0.17; $P<0.05$), respectively, and weight with serves ($r = 0.22$; $P<0.01$) in a serving capacity test. In these yearling bulls scrotal circumference was positively correlated with mounts and serves ($r = 0.16$; $P<0.05$ and $r = 0.25$; $P< 0.01$ respectively). In 2-year-old bulls, scrotal circumference was positively correlated with serves ($r = 0.25$; $P<0.05$).

In 2-year-old Brahman bulls, scrotal circumference was positively correlated with percent normal spermatozoa ($r = 0.34$; $p<0.05$) but not in 3-year-old Brahman bulls. Of the Santa Gertrudis and Brahman bulls which had scrotal circumferences greater than or equal to the threshold measurements recommended by the AACV, 22% and 38% respectively had less than 70% normal spermatozoa. In both breeds, 15% had less than 50% normal spermatozoa.

There was a low incidence of physical abnormalities detected in the Brahman and 5/8 Brahman bulls. In Santa Gertrudis bulls, the incidence of physical abnormalities was swelling of the medial and/or lateral bursae of the hocks (27.8%), swelling of the pastern and hocks (6.8%), excessively straight hind legs ('posty-leg syndrome') (1.2%), lameness (hind or forelimb) (0.3%), upward fixation of the patella (0.5%), testicular hypoplasia (1.4%), chronic epididymitis (3%), persistent frenulum (3.4%), ventral deviation of the penis (0.5%) and balanoposthitis (1.8%). The latter penile abnormalities were detected during serving capacity testing.

In Belmont Red bulls, premature spiral deviation of the penis (detected during serving capacity testing) was the most frequent penile defect observed. In 2-, 3- and 4+ year old bulls the incidence was 1.9, 5.7 and 13.5% respectively. Other defects included penile deviation (1.9%), swollen hocks (3.8 and 4.5% in 3- and 4-year-olds respectively) and 'posty-leg' syndrome (1.0 and 1.9% in 2- and 3-year-old bulls respectively).

The systematic physical examination of a bull provided the foundation of a breeding soundness examination. The moderate to high repeatabilities for key physical traits (eg scrotal circumference) demonstrated that bulls may be selected accurately on the basis of an annual pre-breeding examination.

4.2 Semen traits

Means and ranges for the semen traits measured are presented in Table 3. In general, motility traits of semen (mass activity) and spermatozoa (% motile and % progressively motile) were moderately repeatable and correlated with each other. The distribution of heparin-binding protein profiles for the Brahman/Brahman cross (n=46) and Santa Gertrudis bulls (n=27) tested in this study was: 51% A, 42% B, 4% C, 3% D.

Repeatabilities of semen traits ranged from low to high although repeatability of percent normal or either percent abnormal mid-pieces was moderate to high at each site. The most common sperm defects seen, particularly in Brahman bulls from the more northern herds, were distal mid-piece or tail reflexes associated with cytoplasmic droplets.

Table 3. Summary statistics of semen traits from 2-, 3- and 4+-year old Brahman and Santa Gertrudis bulls

Breed	Age	Semen Trait (Mean, with range in parenthesis)				
		Colour (0 - 5 scale)	Density (x 10^7/ml)	Mass Activity (0 - 5 scale)	% Motile	% Normal
Brahman	2 years (n = 67)	3.0 (0 - 5)	218 (4 - 721)	2.9 (0 - 5)	66 (0 - 90)	70 (19 - 98)
	3 years (n = 45)	3.4 (0 - 5)	359 (13 - 267)	3.2 (0 - 5)	62 (10 - 90)	68 (9 - 93)
	4+ years (n = 20)	3.0 (1 - 4)	214 (4 - 499)	3.0 (0 - 5)	70 (40 - 90)	88 (63 - 97)
Santa Gertrudis	2 yrs (n = 182)	-	-	2.5 (0 - 5)	64 (0 - 96)	73 (10 - 98)
	3 yrs (n = 6)	-	-	3.0 (1 - 5)	63 (40 - 80)	86 (80 - 93)
	4+ yrs (n = 22)	-	-	2.4 (0.0 - 4.5)	66 (30 - 90)	79 (17 - 94)

The studies concluded that semen examination, including assessment of sperm morphology, should be incorporated into bull selection programs and premating examinations to ensure that bulls have at least 50% normal sperm. Fertility recommendations should not be based solely on semen or sperm motility. Assessments of semen heparin-binding protein profiles are unlikely to enhance the evaluation of bull fertility.

4.3 Serving capacity testing

Adaptation of the serving capacity test.

(i) Providing sexual experience to virgin bulls prior to testing.

Giving 2-year-old Santa Gertrudis bulls sexual experience increased the number of serves in the test from 0.5 to 1.4 (P<0.05) and from 1.0 to 2.2 (P<0.05) at the 2 sites. Respective increases in libido scores were 3.3 to 7.5 (P<0.01) and 7.6 to 9.0 (P<0.05). There was no effect of treatment on the number of times bulls showed interest or mounted without serving.

(ii) Use of restrained females either in oestrus or not in oestrus

At both sites, the oestrus status of the restrained females had no significant effect on expressions of the various sexual behaviours in the test. The overall recordings across sites and treatments, were interest (average of 3.1 to 4.2), mounts (average of 2.5 to 8.6) and serves (average of 0.4 to 1.4).

(iii) Use of restrained or unrestrained females

More mounts were achieved when females were restrained than when they were unrestrained (6.5 *v* 3.3; respectively; $P<0.05$). However there was no difference in the expressions of interest, serves or in libido score.

With 5/8 Brahmans at site 9, there was no difference in the number of mounts (2.9) and serves (1.0) when using either restrained or unrestrained heifers; however, interest expressed was double when unrestrained heifers were used (6.9 v 3.7). In Brahmans, there did not appear to be any differences in sexual behaviour in serving capacity tests when using restrained or unrestrained heifers.

Bull age and breed effects on expressions of sexual behaviour

(i) Sexual behaviour using restrained females

There were more expressions of sexual behaviour in Belmont Red and the Angus cross than Brahman or 5/8 Brahman bulls with Santa Gertrudis intermediate. In Belmont Red bulls there was an increase in serves, mounts plus serves and libido score from 1 to 2 years of age with a smaller increase from 2 to 3 year olds. Belmont Red crosses displayed more serves than pure bred Belmont Red bulls at 1 year of age. Both Belmont Red groups displayed more serves than either Santa Gertrudis or Brahman bulls. In Santa Gertrudis there was a small increase in mounts, serves and libido score from 2 to 3 years of age.

Santa Gertrudis bulls displayed more sexual behaviours than Brahmans except for interest only. Between 11% and 12.5% of Santa Gertrudis bulls did not display any sexual interest during the test whilst the corresponding values for Brahmans ranged from 5% to 50%. Between 48% and 54% of Santa Gertrudis bulls displayed 1 or more serves and 7% to 26% displayed 3 or more serves in the serving capacity test. The number of serves displayed by Brahmans was lower (30% for 1 or more serves, 0-7% for 3 or more serves). Except for 1-year-olds, Belmont Red bulls displayed more serves than the other breeds.

(ii) Sexual behaviour using unrestrained females

Expressions of various sexual behaviours in the serving capacity test were greater in 5/8 Brahmans than in Brahmans, particularly in mounts and serves, serves and libido score; eg the average number of serves in 4+-year olds was 0.4 in Brahmans compared with 1.3 for 5/8 Brahmans. Although the differences were not significant, there was a trend in Brahmans for expressions of sexual behaviours to increase up to 3 years of age. In 1-year-old Brahman bulls very few serves were recorded although they did show interest and mounting activity.

Repeatability of sexual behaviours

All of the sexual behaviours of Santa Gertrudis bulls at site 2 were moderately repeatable when tested at a 1 month interval. At site 4, only serves and libido score were moderately repeatable in Santa Gertrudis bulls when tested 8 months apart. Values for 5/8 Brahman and Brahman were generally very low. The exceptions were for serves in 5/8 Brahmans using restrained females and for serves and libido score in Brahmans using unrestrained females. At site 6, serves were moderately repeatable when measured first in 2-year-old bulls and then again as a 3-year-old. Other measures were poorly repeatable in the Belmont Red and their crosses.

The studies concluded that Brahman and Santa Gertrudis bulls are capable of performing in a serving capacity test although the degree of expressions of sexual behaviour, particularly serves, is less than in *Bos taurus*. The main value of the serving capacity test in these breeds, is as a means of identifying whether a bull is capable of serving, and not as a predictor of calf output when mated in multiple-sire herds.

4.4 Social behaviour

Paddock behaviour
At site 9, 10 of the 12 bulls had a movement range index (MRI) >0.7 which corresponded to a range of ~500 ha. The two bulls with the highest MRIs each sired about 20% of the calves. The lowest-MRI bulls each sired <5% of the calves. Calf output for the other 8 bulls was generally intermediate, but variable.

Dominance
At site 4, calf output was unrelated to the established hierarchy within these 2-year-old bulls.

At site 8, it appeared that the dominance hierarchy established using the described method during feeding of bulls together in a small paddock differed significantly to apparent dominance during group feeding. This strongly suggests that the technique was inappropriate. However, at the time, it had been the only way to clearly establish a dominance hierarchy within the group which had settled down well together. Subsequently, calf output was not related to the measured dominance hierarchy.

At site 9, dominance hierarchy within the bull group was moderately repeatable ($r = 0.45$). The correlation between rankings in September 94 and May 95 was 0.36, suggesting inaccurate assessment, but was 0.92 a year later. In 1995/96, but not in 1994/95, dominant bulls spent more time with cows than did subordinate bulls ($r = -0.45$) and sired more calves ($b = -0.15$, $P<0.001$). At site 10, dominance was clearly established in this bull group. It was strongly related to calf output and accounted for 75% of the deviance in calf output.

At site 12, the dominance hierarchy could not be established. There was virtually no overt agonistic behaviour between these 2-year-old bulls that had been reared together.

Behaviour as expressed through social dominance has a significant influence on calf output of bulls in multiple-sire mated herds under extensive management systems. Bulls are very territorial, a behaviour which is presumably related to social dominance. Bulls expressing this to the highest degree tended to sire more calves. The behavioural studies support the recommendation that a mating ratio of 2.5% reproductively sound bulls is adequate for Brahman cattle in the tropics.

4.5 Calf output and predictors of fertility of bulls in multiple-sire herds

Paternity testing
Overall, the paternity of 87.0% of calves could be resolved with a standard panel of 12 DNA markers. The accuracy of paternity resolution was close to the predicted accuracy estimates where the paternity exclusion probability calculated for Brahman and Santa Gertrudis breeds was 0.99 for a single bull. The majority of unresolved paternities after testing with this standard panel were able to be resolved by testing with additional DNA markers. Paternity resolution averaged 97.7% across all sites with a range of 96.1% to 100% although this included some sites where additional markers were not used to improve the resolution of the standard marker panel.

The percentage of calves with no potential (missing) sire averaged 9.5% with a range of 0 to 50.8%. Only 11 of the 37 separate mating groups analysed had no missing sires. The numbers of missing sires varied widely between mating groups and affected the reliability of sire allocations. When the percentage of calves with no known sires was high (50.8% in one mating group), the reliability of sire allocations was only 86% whereas sire allocations were 100% reliable when there were no missing sires.

Calf output of individual bulls

Of the 212 bull matings observed, 58% individually sired 10% or less calves in each of their respective mating groups with 7% not siring any calves. In contrast, 13% sired over 30% of the calves in each of the respective mating groups. When bulls were mated in groups of 8 to 24, the maximum percentage of calves sired by individual bulls was 26 ± 7% (range of 11-36%). However when bulls were mated in groups of 2 to 7, the maximum percentage of calves sired by individual bulls was 59 ± 19% (range of 24-94%).

Repeatability of calf output

In 4 of the 5 sites, repeatability was moderate and in the range of 0.46 to 0.67.

Log-linear models of traits contributing to calf output

In 2 matings there was a strong negative relationship between dominance hierarchy and calf output in the models (the most dominant bull sired the most calves). In the other 2 matings, there was no relationship.

Scrotal circumference was related to calf output in 2 of 17 matings; in one case the relationship was positive, in the other it was negative. Similarly, the relationships of prepuce depth, skin thickness, and umbilicus thickness with calf output were inconsistent and variable.

The percentage of motile sperm was positively related to calf output in 3 of 16 matings; there was no relationship in the other 13 matings. Percent normal spermatozoa was positively related to calf output in models for 10 of 15 matings. At site 10, where percent normal spermatozoa was negatively related to calf output, dominance exerted such a marked effect on calf output within the model that this result is probably spurious. However it should be noted that when percent normal spermatozoa was considered on its own at site 10, it was positively related to calf output ($P<0.001$). In 2 matings where all bulls had in excess of 50% normal sperm, percent abnormal mid-pieces was negatively related to calf output.

Heparin-binding protein profiles were not related to calf output. In the one group of matings where response to GnRH was assessed, there was a negative relationship between post-GnRH plasma testosterone and calf output.

When serving capacity tests were conducted using restrained heifers, there was some positive relationships with measures of sexual behaviour and subsequent calf output. Of the 8 matings, mounts were related in 1 mating, mounts + serves in 2 matings and serves in 1 mating. When serving capacity tests were conducted using unrestrained heifers, there were very few relationships with measures of sexual behaviour and subsequent calf output in the 8 mating groups. Libido score was positively related to calf output in 2 matings.

The models did not explain all of the variation in calf output and the percent of deviance explained ranged from 18% to 98%. In most cases, residual deviance was significant indicating a lack of fit of the model, ie the traits we measured and considered in these models only partly explained the variation in calf output.

The studies determined that DNA typing is an accurate method of identifying paternity of calves resulting from multiple-sire matings. There was no one single physical or reproductive trait that was consistently related to calf output in multiple-sire herds. Even so, selecting on combinations of traits did not explain all of the variation in calf output. Bulls should be selected for physical and reproductive traits that lie above threshold values.

4.6 Bull:female ratios

The principle study was carried out on Kamilaroi Station (Site 11). Two paddocks were used: Whitewood (60 km^2) and Smithdale (84 km^2). The cattle used were all Brahmans. The available bulls were divided into two equivalent groups based on weight and reproductive soundness. Smithdale paddock had 24 bulls for a 6% bulls:females group, representing usual heifer mating practice for the station. Ten bulls rated as having the best reproductive soundness were selected (% normal sperm not used) from the second group of bulls for a 2.5% bulls:females group were used in Whitewood paddock.

In both years, it appeared that many females conceived in the first 4-6 weeks of mating: ~30% in 1994/95 and ~40% in 1995/96. Following this period in both years, there was a steady and parallel increase in cumulative pregnancy rates in both paddocks; for heifers this was ~4% per week in 1994/95 and ~1.3% per week in 1995/96. In both 1994/95 and 1995/96, conception rates were 8% and 6% higher, respectively, in Smithdale (6% bulls) than in Whitewood (2.5% bulls). In May 1995, 91% and 83% of Smithdale and Whitewood heifers were pregnant, respectively. Pregnancy rates in Smithdale in May 1996 were higher than in Whitewood for all female classes: 93% *v* 88% in heifers; 89% *v* 79% in non-lactating cows and 25% *v* 9% in lactating cows.

There were no significant differences between any conception patterns for bulls in both years within Whitewood (2.5% bulls). In Smithdale (6% bulls), only 1% of the bull conception pattern comparisons showed significant differences, and these differences were only marginal. Although total calf output was repeatable (r = 0.62), it varied less in 1995/96 than in 1994/95. In both years, the variation in calf output was lower with a lower percentage of bulls (total variance of 67 *v* 193 in Smithdale and 183 *v* 344 in Whitewood in 1994/95 and 1995/96, respectively).

The 6-8 highest calf producers in each paddock made up 2% bulls:cycling females. These bulls sired 80-90% of the calves in Whitewood (2.5% bulls). In Smithdale (6% bulls), where there was a high ratio of bulls:cycling females, they sired 60% of calves. In both paddocks, the top 6-8 calf-output bulls achieved an average 1-8 pregnancies/week during peak mating.

At Swan’s Lagoon (Site 9), Sandalwood paddock (22 km^2) was used. Calf output was variable, but repeatable (r=0.67). In 1994/95 and 1995/96, there were only 4 significant differences (but of small magnitude) in conception patterns between bull pairings. The top 6 calf getters made up 2% bulls:cycling females. These achieved 80% of the pregnancies and attained an average of 1-4 pregnancies/week during the 3-4 month peak mating period each year.

Data from 4 Santa Gertrudis herds located in southern and central Queensland were used *viz.* Gyranda, Marrett, Ravensbourne and Birra Birra. Paddocks ranged from 160 to 1460 ha. Calf output was variable. Repeatability could not be estimated. In all but one of the 22 matings, the equivalent of 2% bulls:cycling females achieved an average of 1-4 calves per week during peak mating; at 18% bulls:cycling females, there was virtually no opportunity for bulls to achieve an average of 1 pregnancy/week in the single mating and no bulls achieved this level. In matings with <10% bulls, 2% bulls sired 50-90% of calves. In matings where at least 4 bulls and at least 10% bulls:cycling females was used, 2% bulls sired as few as 20% of the calves.

These studies concluded that mating reproductively-sound bulls at a ratio of 2.5% of cycling females is probably adequate for *Bos indicus* and *Bos indicus* infused cattle mated under most conditions in extensive parts of northern Australia.

5. CONCLUSIONS

The following conclusions are for *Bos indicus* and *Bos indicus* derived bulls, adapted to local range conditions and mated in multiple-sire groups in extensive herds in northern Australia.

The conclusions do not apply to bulls prepared for sale or post sale, bulls in AI centres, *Bos taurus* bulls or bulls used in single-sire matings.

5.1 Selection for calf output

- Single-trait selection is dangerous. There was no one single physical or reproductive trait that was always related to calf output. However, the percentage of normal sperm was positively related to calf output in the majority of matings
- Selection on a number of traits does not explain all of the variation in calf output
- A systematic physical examination is the foundation for a breeding soundness examination
- Semen should be routinely examined as part of a breeding soundness examination; determination of the percentage of morphologically-normal sperm should always be part of a semen evaluation.

Physical traits

- Key physical traits were moderately to highly repeatable
- AACV recommendations of values for physical traits remain valid, although thresholds need more accurate definition
- Within the currently-recommended thresholds, there were no consistent relationships between measures of physical traits and calf output
- Mild posty-leg syndrome was not repeatable in young growing bulls.

Semen quality

- Percent live sperm as measured by eosin-nigrosin staining was not repeatable under field conditions
- The motility of semen and spermatozoa were moderately repeatable and correlated with each other
- Neither semen nor sperm motility were consistently related to calf output
- Repeatability of semen traits ranged from low to high
- Bulls with fewer than 50% morphologically-normal sperm at a pre-mating examination usually sired few calves
- 93% of the 73 bulls examined had “A” or “B” heparin-binding protein profiles
- There was no relationship between heparin-binding protein profile and calf output.

Behaviour

- Santa Gertrudis, Brahman and Brahman cross bulls can perform in a serving capacity test; however expression of sexual behaviour in a test was less than that expressed by *Bos taurus* bulls
- Provision of sexual experience to virgin Santa Gertrudis bulls increased their performance in a serving capacity test
- Sexual behaviour in a serving capacity test was not consistently related to calf output, even when measures other than serves were used
- The serving capacity test should be used as a test of serving ability rather than as a predictor of calf output
- Use of restrained females enhances the ability to detect clinical problems.

5.2 Management of bulls to achieve high calf output

Mating percentages

- The paternity of 98% of calves was solved through DNA testing of progeny and bulls
- Calf output varied greatly between bulls and was moderately repeatable between years
- 58% of bulls sired <10% of calves, and 13% of bulls sired >30% of calves within mating groups; 7% of bulls sired no calves
- Physically-sound bulls with above-threshold, semen-quality values were able to impregnate at least 4 females per week
- 2% bulls sired a majority of the calves; a mating ratio of 2.5% bulls:females is likely to be adequate for most situations providing bulls pass a breeding soundness examination. Further information is needed to determine if this mating ratio is optimal where herd dispersion is very high or low.

Behaviour

- Our methods of assessing dominance were variably successful in establishing genuine hierarchy
- At 2 sites where dominance hierarchy was clearly established, dominant bulls sired more calves than subordinate bulls
- 5/8 Brahman bulls demonstrated distinct territorial behaviour as determined by bi-weekly observations.

6. RECOMMENDATIONS

Recommendation 1.

The final report to MLA should be widely distributed. This will be the responsibility of the project team and target groups are:

- Veterinarians. Copies of the Final Report can be distributed through the AACV upon request.
- Extension Officers and consultants throughout northern Australia (50 copies).

Recommendation 2.

The work in the Bull Power project should be subject to peer review. This has been partly done through presentations at the Buiatrics Congress in Sydney in July 1998 and at MLA 'Review of Reproduction and Genetics Projects across northern Australia' in Brisbane in December 1998. As well the group has given a commitment to publish the data in the international scientific literature.

Recommendation 3.

The results need to be explained, particularly the limitations to extrapolation, to veterinarians, producers and breed societies. The results were derived from *Bos indicus* and *Bos indicus* derived bulls adapted to the environment, mated in multiple-sire groups and were extensively managed. The study does not relate to bulls prepared for sale, bulls whose semen was collected for processing for AI, *Bos taurus* bulls, or bulls used in single-sire groups.

Recommendation 4. There are a number of strategies worthy of on-going research.

There is a need for:

(i) *more precise information on threshold values for physical and reproductive traits*. A threshold value is one above or below which there may be no improvement in fertility or no more risk of bulls being prone to injuries or breakdowns. For instance, the nominal cut-off value for percent normal recommended by the AACV is 70% but this may be reduced to 50% in multiple–sire matings; a certain sheath area is tolerable but selecting for even smaller sheaths may not improve functionality or make a bull less prone to injury.

(ii) *more understanding in the area of bull behaviour and the underlying causes of sexual stimulation and motivation in bulls*. Future work should lead to fewer bulls working better and to do this there is a need to identify bulls with reliable siring potential and then be able to manage these bulls so that they can achieve this potential. Studies in behaviour in *Bos indicus* and *Bos indicus* cross bulls in northern Australia should focus on establishing mating potential under different situations and quantify the degree to which mating potential is restricted by herd dispersion (different topography, paddock size, herd size, location of waters, climate and weather).

(iii) greater understanding of *the impact of the environment and relocation on bull management fertility.* There is anecdotal evidence that a significant percent of bulls that pass a breeding soundness examination produce very few progeny in their first year of use. This can be a function of obesity, adaptation to a new environment or use of unadapted bulls in crossbreeding programs.

(iv) determining *the aetiology of high percentages of abnormal sperm in the ejaculates of bulls.* Is it genetic, environmental or infectious in origin? Also there is a need to *develop recommendations on the management of these bulls.* Should they be culled or should further examinations be conducted?

Part 3. Final Report

1. BACKGROUND AND INDUSTRY CONTEXT

There are about 11M cattle in northern Australia (north of 29ºS) and about 4M of these are breeding cows and bulls. The majority of these cattle are of *Bos indicus* or *Bos indicus* derived content. The vast majority of these cattle would be run at stocking rates of 1 adult to 5-30 ha. As a consequence, cattle on properties are spread over large areas although there tends to be a concentration of animals at stock watering points.

Little is known of the individual reproductive performance of bulls in extensive environments. Low and variable bull fertility was identified as a constraint on reproductive rates in beef cattle in an extensive, multiple-sire mating system in the Northern Territory[1]. Erratic conception patterns were attributed to a high proportion of bulls with low breeding soundness evaluation scores, a large number of aged bulls and having mixed-age bull mating groups[1]. This variation in bull fertility has been identified also in a study of single-sire mating groups with *Bos indicus* cross bulls in north Queensland. Even though screening tests for bull fertility were applied, 4% of mated bulls did not produce any progeny and a further 4% were associated with mating groups which had less than 20% pregnancy rates. These failures could have been due to libido or serving ability problems[2].

Herd bull replacement is a major cost for commercial cattle breeders in northern Australia. The economic impact of bull management depends on two issues. The first is the capital cost per calf branded, incurred by the bull. This is a function of the purchase price of the bull, its working life and the number of calves it produces. For example, if a $2000 bull has a working life of 5 years at a bull:cow ratio of 5%, the bull cost per calf ranges from $30 per calf at 50% branding rate down to $19 per calf at 80% branding rate[3]. The second aspect of economics of bull management relates to the genetics imparted by the bull[4]. Major financial benefits are achieved by using bulls whose progeny have higher productivity through improved fertility, growth, temperament, survival and carcase attributes.

2. OBJECTIVES

The project had 2 objectives:-

- to improve the selection of bulls with high genetic merit (particularly growth and carcase traits) and calf output by developing management packages based on identifying premating predictors of bull fertility.
- to make management recommendations on bull selection criteria that will allow producers to reduce bull joining percentage without jeopardising herd fertility.

3. METHODS

The Bull Power project ran from 1992 to 1997 and was a co-operative project between Queensland Department of Primary Industries, The University of Queensland, James Cook University, Northern Territory Department of Primary Industry and Fisheries and the Meat Research Corporation. MRC provided funding from January 1995 to October 1997.

The project team was RG Holroyd (project leader), JD Bertram, BM Burns, NJ Cooper, J DeFaveri, VJ Doogan, G Fordyce, RG Miller, AJ Teakle and BK Venus (Queensland Department of Primary Industries), MR McGowan, D Baker, S Johnston, N Phillips and DM Vankan (The University of Queensland), LA Fitzpatrick, C Coleman and P Findlay (James Cook University), GA Jayawardhana (Northern Territory Department of Primary Industry and Fisheries) and MJ D’Occhio (CSIRO).

The Bull Power project was conducted on 3 research stations and 8 co-operator properties in Queensland and 1 research farm in the Northern Territory (Table 1, Figure 1). There were about 1000 bulls, mainly 2- to 4-year-old Santa Gertrudis, 5/8 Brahman, Brahman, Belmont Red and Belmont Red cross, that were subjected to physical and reproductive examinations prior to mating. As well, a number of studies were done on the expressions of sexual behaviour in various types of serving capacity tests in these genotypes.

All bulls used in this research were acclimatised to their study environment. They had not been recently purchased through auction sales or fattened for this purpose. The bulls came from properties where there was already in place a selection policy on physical and reproductive traits. Thus, many of the extremes in physical conformation, scrotal size, excessive pendulous sheaths and poor temperament had been culled from the population.

In 9 of these herds, the calf output was collected on 212 bulls from 37 multiple-sire mating groups using DNA typing for assigning paternity.

Table 1. Properties, locations, principal investigators and observation dates for each site

Site	Property	Location	Nearest centre	Principal investigator	Year
1	Marrett	28° S 150° E	Goondiwindi	JD Bertram	1992/97
2	Birra Birra	28° S 148° E	Dirranbandi	JD Bertram	1993/96
3	Ravensbourne	24° S 145° E	Blackall	JD Bertram	1993/96
4	Gyranda	25° S 150° E	Theodore	MR McGowan	1992/97
5	Eidsvold Station	24° S 151° E	Eidsvold	MR McGowan	1993
6	Narayan Research Station	26° S 150° E	Mundubbera	JD Bertram	1994/97
7	Meteor Downs	24° S 148° E	Rolleston	JD Bertram	1994/96
8	Cona Creek	24° S 147° E	Springsure	RG Miller	1993/97
9	Swan's Lagoon Research Station	20° S 147° E	Ayr	G Fordyce	1994/97
10	Fletcherview Research Station	19° S 146° E	Charters Towers	LA Fitzpatrick	1995/96
11	Kamilaroi	19° S 140° E	Cloncurry	G Fordyce	1994/97
12	Douglas Daly Research Farm	13° S 131° E	Adelaide River	GA Jayawardhana	1995/97

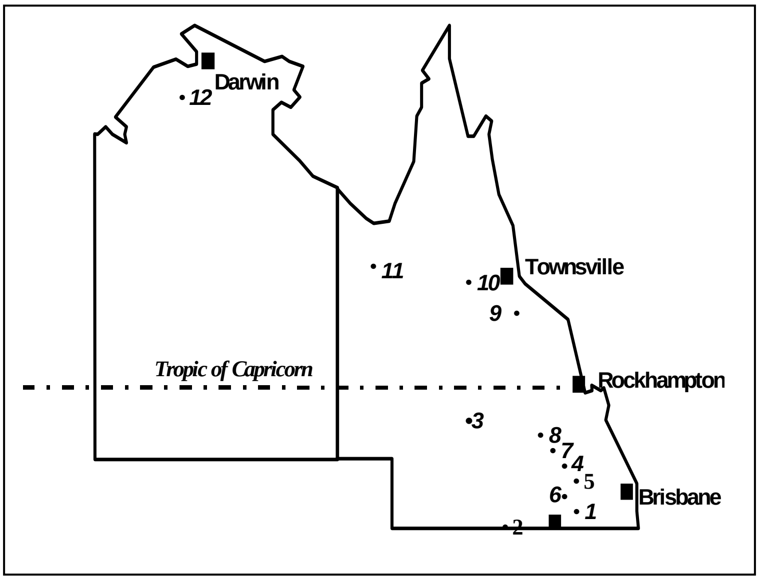


Figure 1. Experimental sites

3.1 Measurements

At each site, bulls were initially restrained in a crush to enable the systematic physical examination to be conducted. Measurements common to all of the sites are described although not all measurements were made at each site

Age.
This was determined from records of birth dates or estimated from dentition.

Liveweights.
These were recorded at or close to the time of bull examination.

Body condition.
This was recorded using a 9 point scale where 1 = emaciated, 5 = store and 9 = overfat[5].

Structure.
The musculoskeletal system was examined for defects. Subjective assessments were made of straight (post-leggedness) or sickle hock, claw abnormalities (e.g. scissor claws) and other abnormalities or lamenesses noted. These conditions were recorded as being either absent, mild or marked.

Scrotal contents.
This was assessed by manual palpation and any obvious abnormalities in shape or size of either the scrotal sac or testes were recorded. Testicular tone and resilience were determined using the technique described by McGowan *et al*[6]. The only modification was that the scoring for testicular tone was condensed to a single value for both firmness and resilience and the values for each testicle were averaged to provide a single score. The modified scoring system was as follows: 1 = soft, low resilience; 2 = moderate firmness, moderate resilience and 3 = firm, high resilience. Different scoring systems were used for different sites but these were later standardised for data analyses.

Scrotal circumference was measured with a standard metal tape. The testes were held into the ventral scrotum with one hand and the circumference measured at the largest diameter without depressing the testes[6].

Prepuce and navel.
When the prepuce was relaxed, measurements were made of the following parameters (Figure 2):

Distance of preputial orifice below knee-hock line (cm).
Width of navel (cm).
Depth of prepuce (cm). Vertical distance from the ventral abdominal wall to the preputial orifice.
Angle of preputial orifice (degrees). In Brahman and 5/8 Brahman bulls only.
Navel rosette score (Table 2).
Navel thickness. Estimated thickness of the remnant of the navel stump from 1 = 1cm, 3 = 2 cm and 5 = 3 cm.
Preputial protractor muscle (Table 2).
Skin thickness (Table 2). At Birra Birra, this was recorded in cm.
Prepuce score (Figure 3).

Table 2. Scoring systems for skin thickness, preputial retractor muscle and navel rosette

Score	Skin thickness	Preputial retractor muscle	Navel rosette
0		Absent	Absent
1	Light	Small	Small
2	Medium	Medium	Medium
3	Heavy	Large	Large

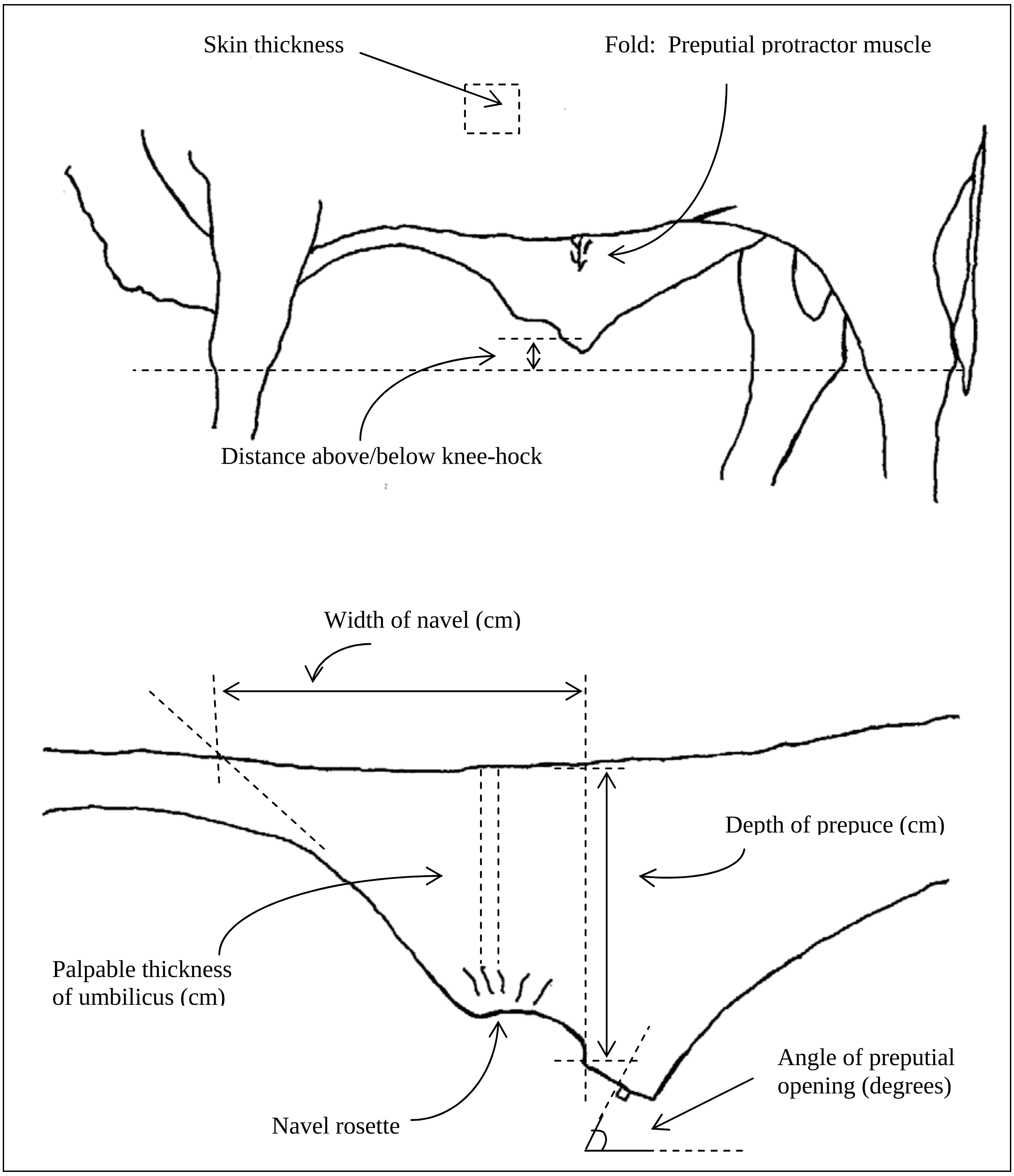


Figure 2. Measurements taken of the prepuce and navel
As defined in Sisson & Grossman[7], the prepuce consists of 2 parts, the external hair covered appendage (sheath) and the inner part – the prepuce proper.

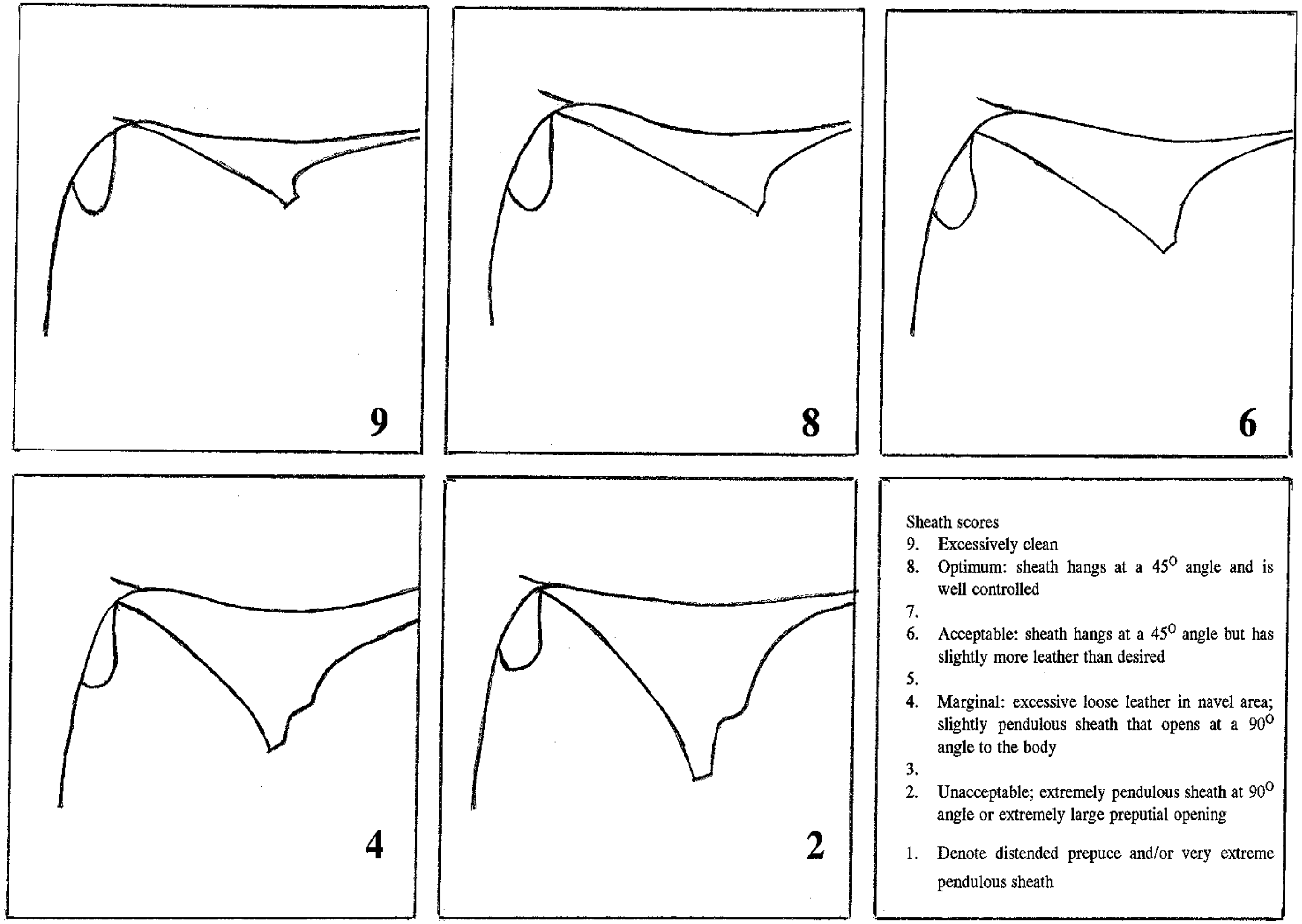
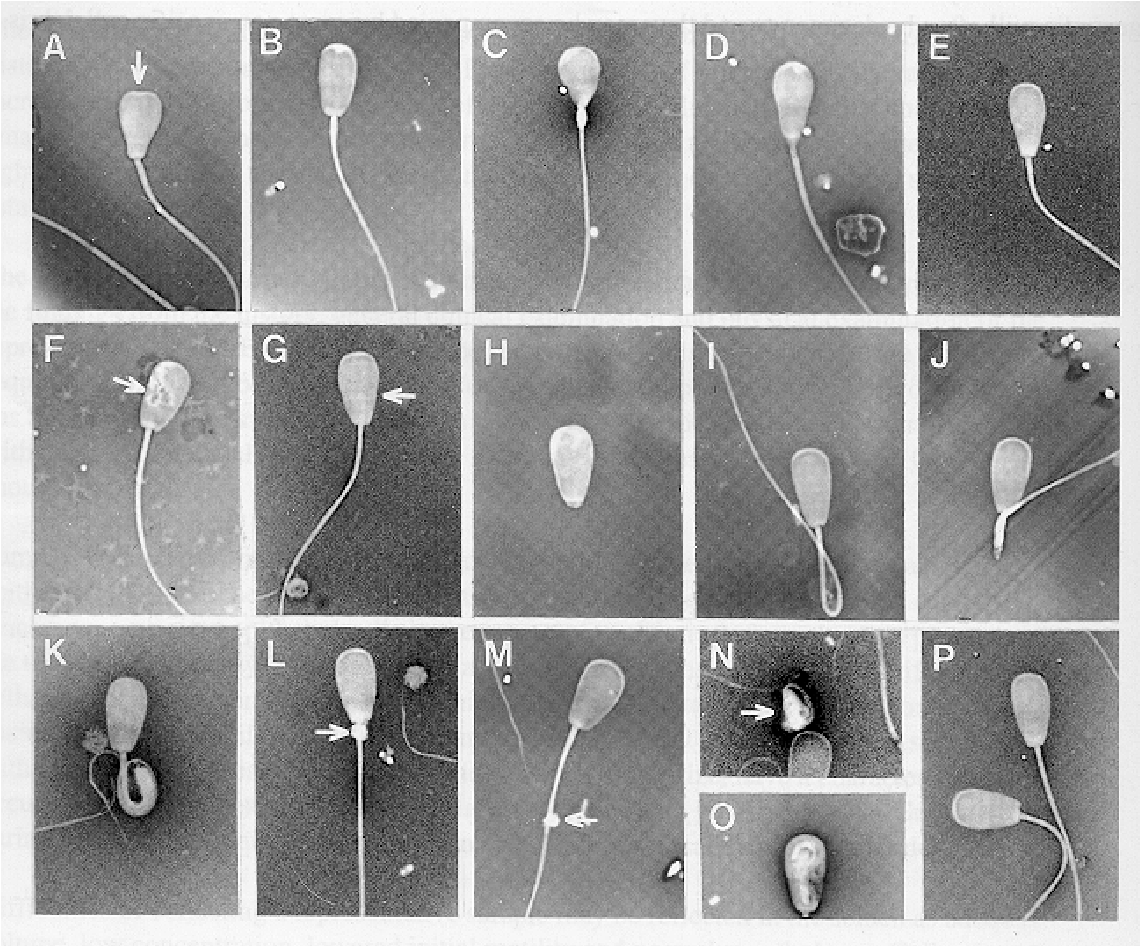


Figure 3. Prepuce or sheath scores derived from Breedplan Validation Project



A.	Knobbed acrosome (common form)	I.	Distal reflex
B.	Knobbed acrosome (beaded form)	J.	Dag-like defect (broken mid-piece)
C.	Pyriform head (severe)	K.	Dag-like defect (severely bent mid-piece)
D.	Pyriform head (moderate)	L.	Proximal droplet
E.	Pyriform head (slight)	M.	Distal droplet
F.	Nuclear vacuoles	N.	Teratoid (severe)
G.	Diadem defects	O.	Teratoid (moderate)
H.	Detached head	P.	Normal spermatozoa

Figure 4. Common sperm abnormalities (McGowan *et al.* 1995)[6]

Semen collection and evaluation.

Semen was collected using either standard electroejaculation techniques, or in the case of some Santa Gertrudis bulls by massage of the ampullae. If a satisfactory sample could not be collected within several minutes, further attempts were made at 5-10 minute intervals or the bull was released and a second attempt made later that day.

Evaluation of semen was based on the procedures of McGowan *et al.*[6]. Colour, where assessed, was graded on a 0 (clear) to 5 (creamy) scale. A drop of semen was placed immediately on a warm slide. Mass activity was assessed on a 0 (no activity) to 5 (rapid swirling motion) scale, using a phase-contrast microscope (x 40). After placing a pre-warmed coverslip on the slide, the percentage of live spermatozoa in a high-power (x 400) phase contrast microscope field was estimated. Individual spermatozoa were considered to be alive if they displayed any movement at all. Alternatively, eosin-nigrosin stained semen smears under oil immersion (x 1000 power) were also used to estimate the percent live spermatozoa in a semen sample. Motility was determined from the same high-power microscope field as for % live. Of the spermatozoa that were judged to be alive, the percentage that was progressively motile was estimated.

Samples for the assessment of morphology of individual sperm were then taken in one of two ways, depending upon the site and the laboratory preference. The laboratory of McGowan (University of Queensland) used eosin - nigrosin staining and the smear examined under oil immersion. The smear was prepared crush side by mixing a drop of semen and a drop of stain on a slide and making thin and thick bands with another slide as a spreader. The laboratory of Fitzpatrick (James Cook University) used 0.2% glutaraldehyde in phosphate buffered saline (PBSG) as a preservative and 0.02 mL of fresh semen was added to prepared vials of 4 mL of PBSG. A drop of this was placed on a slide under a coverslip and examined using phase contrast microcopy. Each laboratory counted a minimum of 100 spermatozoa (x 1000 magnification) and reported percent normal and subdivided percent abnormal into head, mid-piece and tail abnormalities, and protoplasmic droplets. The common sperm abnormalities are described by McGowan *et al*. (1995 p.54; Figure 4)[6].

Heparin-binding proteins.

At the time of collection of semen from a subset of bulls examined in 1995, a 2 mL sample of semen was placed in a sealed 5 mL tube and stored in liquid nitrogen for subsequent assay of heparin-binding proteins[8] by the laboratory of Dr Roy Ax, University of Arizona. Heparin-binding protein profiles were described as A, B, C or D.

Libido and serving capacity measurements.

The techniques varied across sites. Some sites initially used the serving capacity test described by Blockey[9, 10]. This system is based on several heifers restrained in crates in a yard then recording the behaviour, for 20 minutes, of groups of bulls introduced into this yard. Another technique was placing several bulls with 8 - 10 unrestrained heifers in oestrus and observing for 20 minutes.

Behaviours recorded at each site were transformed to three libido score scales (0 - 10) to achieve consistency across sites. One scale was to match the libido/serving ability score of Chenoweth[11]; the other two were designed to reduce data skewness by having the average scores close to 5 (Table 3).

Table 3. Standardisation of three libido scores

Score	Libido Score 1[11]			Libido score 2			Libido score 3		
	Interest (interest + false mounts)	Mounts (mounts + mounts with penile seeking)	Serves (service with ejaculation)	Interest	Mounts	Serves	Interest	Mounts	Serves
0	0	0	0	0	0	0	0-5	0	0
1	1	0	0	1-5	0	0	>5	0	0
2	2-5	0	0	>5	0	0		1-5	0
3	>5	0	0		1-5	0		>5	0
4		1	0		>5	0		0-5	1
5		2	0			1		>5	1
6		>2	0			2		0-5	2
7		0-5	1			3		>5	2
8		>5	1			4		0-5	3
9		0-5	2			5		>5	3
10		>5	≥2			>5			>3

Dominance.
A dominant hierarchy was estimated by recording agonistic behaviour (see Section 4.4.2 for full details)

Paternity testing of calves.
Blood samples were taken in 10 mL heparinised vacutainers. Bulls were bled from the coccygeal vein. Calves were bled from the jugular vein at either branding or weaning. Samples were immediately chilled and then refrigerated for 2 - 5 days before processing. At some sites samples were centrifuged, buffy coats pippetted off along with adjacent plasma and red blood cells, and stored frozen in 1.5mL microfuge tubes, then submitted later to the Equine Blood Group Laboratory, University of Queensland. At other sites, chilled blood samples were submitted immediately to the laboratory.

The first samples from the project were submitted in March 1994, shortly after the DNA laboratory opened and the final samples were received in June 1997. Over the duration of the study, the DNA laboratory has been refining both procedures and microsatellite markers used for typing. Some of the markers used earlier in the project are no longer in routine use, having been replaced by more efficacious ones.

The methods used for paternity testing involved PCR amplification of extracted DNA, incorporation of radioactive nucleotides, denaturing polyacrylamide gel electrophoresis of the amplified fragments and autoradiation. Routine testing examined a standard panel of 12 DNA markers in three separate tests. For most calves involved in the Bull Power project, if paternity was unable to be resolved using the standard test panel, additional DNA markers were examined until resolution was achieved. A mathematical model was devised to provide an estimate of the reliability of results for those mating groups where there were missing sires (M. Faddy, pers. com.). The reliability estimate is the probability that the nominated sire is the true sire.

Initially, to reduce costs, calves were tested through one group of markers at a time until paternity was resolved. Some calves would only require one DNA test for resolution whilst others would require three or more. This method of analysis is only accurate if all of the possible sires are known. One of the difficulties encountered early on in the project was the existence of unknown sires in most of the mating groups analysed. There were many reasons for these, including bulls and/or cows jumping fences or being inadvertently switched between paddocks, cows already pregnant before joining and precocious bull calves. Whatever the reason, missing sires were a constant feature of analysis that could not be attributed to problems with the test. Wherever missing sires were encountered, a full paternity analysis was performed on each calf in question. Every sire was examined individually to determine which DNA systems were excluded. Those sires excluded in only one system were noted and double-checked for the possibility of testing error or mutation.

3.2 Statistical analyses

Summary statistics by breed and age were compiled and correlations (within age and breed) between the various physical trait measurements and measures of semen quality and serving capacity were calculated. The effect of age within breeds on physical trait measurements was assessed by unbalanced analysis of variance after adjustment for site and year[12].

Repeatabilities were estimated for all traits measured in bulls. REML[12] was used to calculate variance components. The model used was:

$Y_{ij} = \mu + Date_i + Animal_j + Error_{ij}$

where: μ = overall mean; date = fixed effect for the ith date; animal = random effect of the ith animal. Repeatabilities were calculated as:

t = animal variance component + = animal variance component / (animal + error variance)

Testes, serving capacity, and calf output data were log transformed prior to repeatabilities being estimated.

It was not possible to correct estimated conception pattern (number of calves per month) error due to sire, dam, and individual effects on growth, and to gestation length variation. Assuming that these were not significant effects, bull effects on conception pattern were tested using survival analyses[13]. The conception patterns of bulls that sired at least 10 calves were tested. Confidence intervals for hazard ratios were used to compare conception patterns between bulls.

If conception pattern was not affected by bull effects, the effects of repeatable measured traits and of paddock behaviour on calf output in each year were estimated using a log-linear modelling approach[14]. Models were generally developed for each mating group of at least 8 bulls. However, some analyses incorporated data for more than one mating group where the same breed and management in similar environments was used; these models included mating group as an absorbing factor. In all, there were 17 models.

The model used was:

$\log_e(\text{calf output}) = a + \sum b_i x_i$

where x_i = the *i*th physical, seminal or behavioural trait,

b_i = the coefficient for the *i*th physical, seminal or behavioural trait.

A stepwise approach was used to select a model including significant covariates and accounting for a maximum amount of deviance. Deviance was estimated as:

$2*\Sigma\{y_i \log(y_i/f_i) - (y_I - f_i)\}$

where $y_i = i^{th}$ response

f_i = corresponding fitted value from the model.

Response curves were generated for a trait on calf output by using mean values for other significant influences and predicting calf output over the range of values for the target trait.

4. RESULTS

4.1 Prepuce, testicular and other physical traits

4.1.1 Introduction

A fundamental component of the reproductive examination of bulls prior to mating is a systematic physical examination of the animal, including a detailed examination of the internal and external sexual organs, and an evaluation of the bull's gait. In a large study of primarily Hereford bulls[15] the incidences of physical abnormalities of the eyes, locomotory system, scrotal contents, penis and prepuce and internal genitalia were 3.7%, 5.0%, 17.6%, 3.8% and 7.3% respectively. Ladds *et al.*[16] and Bagshaw and Ladds[17] examined the reproductive tracts of 550 mixed breed (Shorthorn, Brahman and Brahman cross) bulls from northern Australia. Significant testicular lesions were detected in 8.3% of bulls and seminal vesiculitis and ampullitis were found in 9.0% and 3.8% of bulls respectively. Chenoweth[18] reported an overall incidence of penile and preputial abnormalities of 11.1% in 702 young (16-31 months) Brahman, Africander, Shorthorn and crossbred bulls from central Queensland.

Threshold values have been established for physical, semen and serving capacity traits of *Bos taurus*, *Bos indicus* and *Bos indicus* derived bulls to be used for single-sire matings[6]. However these threshold values have not been related to calf output of bulls mated in multiple-sire groups, which is the norm for northern Australia.

Between 1992 and 1997, approximately 1000 Santa Gertrudis, 5/8 Brahman, Brahman and Belmont Red bulls were examined as part of a large study evaluating the relationships between pre-mating predictors of fertility and an individual bull's calf output. The physical traits measured, their relationships to each other and their relationships to calf output are described below.

4.1.2 Experimental groups

Groups (n=17) of 2-, 3- and ≥4-year-old Santa Gertrudis bulls were examined on 6 different properties located in southern and central Queensland. Fourteen groups of 2-, 3- and ≥4-year-old 5/8 Brahman and Brahman bulls were examined on 6 different properties located in central and north Queensland, and in the Northern Territory. At one site in the inland Burnett region of south east Queensland, 1-, 2- and 3-year-old Belmont Red bulls were examined over 4 years.

A subset of Santa Gertrudis (n=92), Brahman (n=96) and 5/8 Brahman (n=24) bulls were mated in groups to cows and heifers at bull:female percentages of 2.5% to 6%. The paternity of calves resulting from these joinings was determined by microsatellite DNA testing.

4.1.3 Results

The majority of Santa Gertrudis and Brahman bulls examined were aged 2 or 3 years. The 5/8 Brahman bulls were mainly 4- or ≥5-year-olds and the Belmont Red bulls were mainly 1- and 2-year old. However, within each age group, individual bull age at the time of examination varied by as much as ± 6 months. Most bulls were in backward store (score 4) to prime (score 7) condition. Tables 4 and 5 provide means and ranges for a selection of the physical measurements recorded.

Table 4. Summary statistics of physical traits of Santa Gertrudis and Belmont Red bulls

	Santa Gertrudis				Belmont Red			
	2-year-olds (n=378)		3-year-olds (n=56)		1-year-old (n=176)		2-year-old (n=107)	
	mean	range	mean	range	mean	range	mean	range
Liveweight (kg)	586	327-850	788	636-911	265	198-365	565	442-680
Condition score	5.3	3.0-8.0	5.4	3.0-7.0	4.4	3.0-5.0	4.7	4.0-6.0
Scrotal circum (cm)	36.4	29.0-48.0	39.0	32.5-45.5	24.3	18.5-29.5	34.5	30.0-38.5
Testicular tone	2.8	1.0-3.0	2.8	2.0-3.0	3.0	2.5-3.0	2.9	2.3-3.0
Prepuce depth (mm)	206	110-275	217	145-280	75	25-175	102	50-150
Prepuce score	4.6	2.0-8.0	4.6	3.0-8.0	7.9	4.0-9.0	7.9	4.0-9.0

Table 5. Summary statistics of physical traits of 5/8 Brahman and Brahman bulls

	5/8 Brahman				Brahman			
	4-year-olds (n=9)		≥5-year-olds (n=13)		2-year-old (n=108)		3-year-old (n=59)	
	mean	range	mean	range	mean	range	mean	range
Liveweight (kg)	580	536-616	673	576-762	441	328-640	480	385-640
Condition score	6.2	6.0-7.0	6.3	5.0-7.0	5.2	4.0-7.0	6.3	4.0-7.0
Scrotal circum (cm)	33.7	30.0-37.0	36.5	31.5-41.0	33.7	26.0-42.5	34.3	27.0-41.0
Testicular tone	2.9	2.5-3.0	3.0	3.0-3.0	2.9	2.0-3.0	2.95	2.5-3.0
Prepuce depth (mm)	142	70-230	132	80-200	200	100-355	172	80-250
Prepuce score	6.5	6.0-7.0	7.5	6.0-9.0	4.7	2.0-7.0	5.1	3.0-8.0

In all breeds, weight and scrotal circumference increased with age ($P<0.05$). In addition, in Santa Gertrudis bulls, prepuce depth and prepuce score increased with age ($P<0.05$).

The repeatability of physical trait measurements recorded at intervals of 3 to 9 months was calculated for data from 3 sites (Table 6). Scrotal circumference, prepuce depth and prepuce score were moderately to highly repeatable.

Table 6. Repeatability (r) of selected physical trait measurements

Trait	r	Comment
Scrotal circumference	0.30, 0.87, 0.92, 0.79	Moderate, to very highly repeatable
Prepuce depth	0.73, 0.74, 0.85	Very highly repeatable
Prepuce score	0.68, 0.60	Highly repeatable

Across breeds several traits were consistently correlated. In all breeds except 2- and 3-year old Belmont Red bulls, bodyweight was positively correlated with scrotal circumference ($r = 0.29$ to 0.78; $P<0.05$). However there was no significant relationship between scrotal circumference and testicular tone score. Prepuce depth was negatively related to prepuce score ($r = -0.48$ to -0.81; $P<0.01$) but was not significant in 2-year-old Santa Gertrudis bulls ($r = -0.10$). Prepuce depth was also positively related to umbilical cord thickness in 2-year-old Brahman ($r = 0.36$; $P<0.05$), 2-year-old Santa Gertrudis ($r = 0.16$; $P<0.01$) bulls and 1-year-old Belmont Red ($r = 0.44$; $P<0.01$) bulls.

In 2-year-old Santa Gertrudis bulls, body weight was positively correlated with number of serves achieved in the serving capacity test ($r = 0.13$; $P<0.05$) and the percent motile spermatozoa ($r = 0.27$; $P<0.01$). However body condition score was negatively correlated with number of serves ($r = -0.13$; $P<0.05$). Body condition score was not correlated with any of the testicular, semen or serving capacity traits in Brahman bulls except for 2-year-old Brahman bulls, body condition score was positively correlated with scrotal circumference ($r = 0.20$; $P<0.05$).

In 2-year-old Brahman bulls, scrotal circumference was positively correlated with percent normal spermatozoa ($r= 0.34$; $p<0.05$, Figure 5) but not in 2-year-old Santa Gertrudis or 3-year-old Brahman bulls. Table 7 provides details of the frequency of Santa Gertrudis and Brahman bulls with scrotal circumferences either greater than, equal to, or less than the values recommended by the Australian Association of Cattle Veterinarians (AACV) and having percent normal spermatozoa between 0 and 100%. Of the Santa Gertrudis and Brahman bulls which had scrotal circumferences greater than or equal to the threshold measurements recommended by the AACV, 22% and 38% respectively, had less than 70% normal spermatozoa. In both breeds, 15% had less than 50% normal spermatozoa.

Table 7. Frequency (n) of 2-year-old bulls with various sizes of scrotal circumferences

	Brahman		Santa Gertrudis		
Scrotal circumference	<28 cm	≥28 cm	<32 cm	32 -<34 cm	≥34 cm
% normal sperm					
0-9	0	0	0	0	0
10-19	0	1	0	0	1
20-29	0	3	0	0	4
30-39	0	2	0	1	2
40-49	0	4	0	1	6
50-59	1	4	3	2	2
60-69	0	11	1	5	5
70-79	0	15	2	9	19
80-89	0	17	2	3	26
90-100	0	9	1	2	24

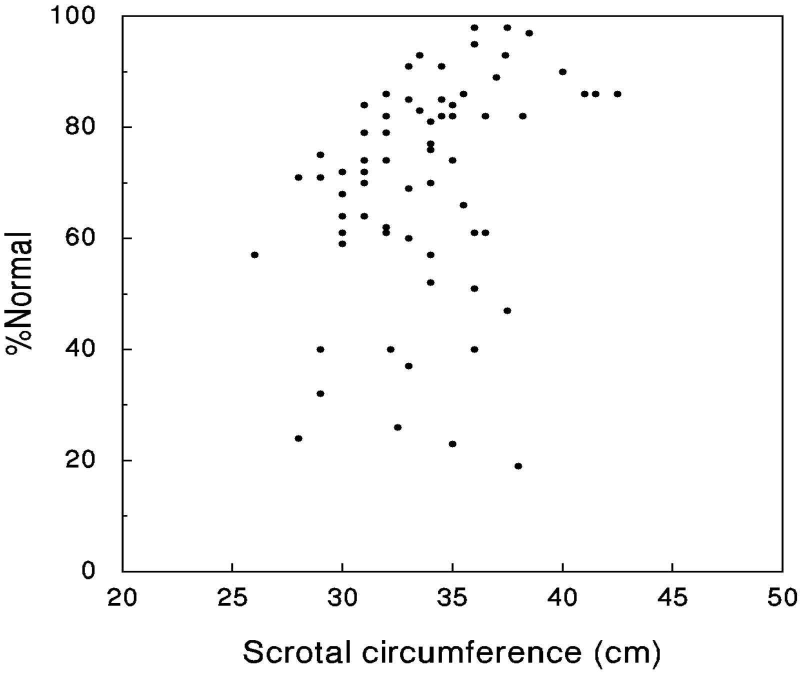


Figure 5. Relationship between scrotal circumference and percent normal spermatozoa in 2 year-old Brahman bulls

In 1-year-old Belmont Red bulls, weight and condition score were positively correlated with mounts (r = 0.16 and 0.17; P<0.05) respectively and weight with serves (r = 0.22; P<0.01) in a serving capacity test. In these yearling bulls scrotal circumference was positively correlated with mounts and serves (r = 0.16; P<0.05 and r = 0.25; P< 0.01 respectively). In 2-year-old bulls, scrotal circumference was positively correlated with serves (r = 0.25; P<0.05).

In Santa Gertrudis bulls the incidence of physical abnormalities detected at examination was swelling of the medial and/or lateral bursae of the hocks (27.8%), swelling of the pastern and hocks (6.8%), excessively straight hind legs ('posty-leg syndrome') (1.2%), lameness (hind or forelimb) (0.3%), upward fixation of the patella (0.5%), testicular hypoplasia (1.4%), chronic epididymitis (3%), persistent frenulum (3.4%), ventral deviation of the penis (0.5%) and balanoposthitis (1.8%). The latter penile abnormalities were detected during serving capacity testing.

There was a low incidence of physical abnormalities detected in the Brahman and 5/8 Brahman bulls. Several Brahman bulls displayed upward fixation of the patella during at least one examination period. In one group of 2- to 3-year old Brahman bulls, 13/31 expressed ‘posty-leg’ syndrome at some time over a 2-year period. There was no obvious associated lameness in these bulls, although hocks appeared unstable where the condition was marked (n=2). Bulls only expressed the condition at one examination and appeared normal at other times, except for one bull which consistently displayed marked expression of the condition. One bull developed a preputial abscess. Two bulls acquired broken legs (see section 4.4).

In Belmont Red bulls, premature spiral deviation of the penis (detected during serving capacity testing) was the most frequent penile defect observed. In 2-, 3- and 4+ year old bulls the incidence was 1.9, 5.7 and 13.5% respectively. Other defects included penile deviation (1.9%), swollen hocks (3.8 and 4.5% in 3- and 4-year-olds respectively) and ‘posty-leg’ syndrome (1.0 and 1.9% in 2- and 3-year-old bulls respectively).

Results of the log-linear modelling of calf output for individual mating groups revealed that of the physical traits measured, none were consistently related to calf output. However scrotal circumference and prepuce depth were significantly related to calf output in at least one mating group. Full details of log-linear models are presented in Section 4.5.

4.1.4 Discussion

At the time of examination, the majority of bulls in this study were judged to be physically and structurally sound. However there was a low incidence of physical abnormalities detected that may reduce reproductive function. The relatively high incidence of swellings of the lateral or medial bursae of the hocks in the Santa Gertrudis bulls examined is difficult to explain as most of the bulls were pasture fed. Further, in most cases the bursae swelling was mild and was not associated with lameness.

‘Posty-leg’ syndrome was not repeatable in young growing Brahman bulls, indicating lenience towards mild expression of the condition when selecting within this class of animal. This variation in expression of the condition over time contrasts with the condition in young *Bos taurus* bulls[19].

The AACV recommends that 2-year-old moderate to well fed bulls should have a scrotal circumference of ≥34 cm. The majority of the Santa Gertrudis bulls were considered to be on a moderate plane of nutrition although much of the study was conducted during a period of prolonged drought conditions. In 2- and 3- year old Santa Gertrudis bulls, 31% and 7% respectively had a scrotal circumference measurement of <34 cm. The high incidence of 2-year-old bulls with a scrotal circumference <34 cm is probably because many of the bulls were aged between 18 and 25 months at the time of examination. If only data from bulls aged ≥24 months are used, the incidence decreases to 14%. In Brahman bulls grazing spear grass pastures in the arid tropics of northern Australia the recommendation for scrotal circumference measurement at 2 years of age is ≥28 cm. Three percent of 2-year-old Brahman bulls from sites in the arid tropics had a scrotal circumference measurement of <28 cm.

In Santa Gertrudis bulls, those animals with a large umbilicus tended to have a more pendulous prepuce and achieved fewer mounts and serves in the serving capacity test. The combination of the thickened umbilical cord and enlarged ‘rosette’ may result in a mechanical interference in serving ability. Further research is required to more precisely define the relationship between prepuce and umbilical conformation, and calf output. This would enable practical recommendations on selection policy for these traits to be developed.

The relatively low incidence of functionally significant physical abnormalities in the bulls examined may have been due to a number of factors. Firstly, most bulls had been reared in single age groups and had been well handled, decreasing the likelihood of injuries due to fighting. Secondly the selection policies of the properties involved in this study included selection for normal physical conformation, adequate size testes, and selection against excessively pendulous prepuces and poor temperament.

Therefore as all bulls in many of the mating groups studied were physically sound and had above threshold values for scrotal circumference and prepuce score, it was not surprising that physical traits were not consistently found to be related to calf output in the log-linear models.

Although the correlations between physical traits and seminal and serving capacity traits should be considered with some caution (because of the low magnitude of the correlation coefficients), the findings in young Santa Gertrudis bulls of a negative relationship between body condition score, seminal and serving capacity traits are similar to that reported by Coulter [20], and consistent with field observations. The lack of correlation between physical traits and measures of serving capacity in Brahman bulls probably reflects the generally poorer response to service capacity testing of these bulls observed in this study.

4.1.5 Conclusion

The systematic physical examination of a bull provides the foundation of a breeding soundness examination. The moderate to high repeatabilities for key physical traits (eg scrotal circumference) demonstrate that bulls may be selected accurately on the basis of an annual pre-breeding examination. The results of this study support the guidelines for the physical trait thresholds outlined by McGowan *et al*.[6].

4.2 Semen traits

4.2.1 Introduction

There have been a number of attempts to relate semen characteristics such as motility and morphology of spermatozoa[21], [22] and a range of seminal plasma proteins and other factors[8, 23] to fertility of bulls. These studies have generally been carried out with *Bos taurus* cattle, particularly dairy breeds, many utilising data from bulls in AI centres.

Many tests of semen quality correlate with fertility[24, 25], however, none has been satisfactory as a predictor of superior fertility[26], and few have attempted to test the fertility of beef bulls used in multiple-sire breeding herds under conditions of extensive management[2, 21.]

While some threshold values have been suggested for semen traits of *Bos taurus*, *Bos indicus* and *Bos indicus* derived bulls to be used for single-sire matings [6], these values have not been validated by relating them to calf output of bulls mated in multiple-sire groups, which is the norm for northern Australia.

4.2.2 Experimental groups

Fourteen groups of 2-, 3- and ≥4-year-old Brahman and 5/8 Brahman bulls were examined on 6 properties located in central and north Queensland. Groups (n=17) of 2-, 3- and ≥4-year-old Santa Gertrudis were examined on a further 6 properties in southern and central Queensland. The paternity of calves sired in a subset of subsequent matings (n=212) was determined by DNA typing.

4.2.3 Results

Most of the bulls examined were 2 or 3 years of age, except for the 5/8 Brahman bulls which were mainly ≥4 years old. Within each age group, individual bull age at the time of examination varied by up to 6 months. Bulls were generally in backward store (score 4) to prime (score 7) condition.

Means and ranges for the semen traits measured are presented in Table 8. In general, motility traits of semen (mass activity) and spermatozoa (% motile and % progressively motile) were moderately repeatable and correlated with each other. In 13 of 16 analyses, sperm motility was unrelated to calf output. In 3 analyses, the relationship was positive. (See Section 4.5).

Table 8. Summary statistics of semen traits from 2-, 3- and 4+-year old Brahman and Santa Gertrudis bulls

Breed	Age	Semen Trait (Mean, with range in parenthesis)				
		Colour (0 - 5 scale)	Density (x 10^7/ml)	Mass Activity (0 - 5 scale)	% Motile	% Normal
Brahman	2 years (n = 67)	3.0 (0 - 5)	218 (4 - 721)	2.9 (0 - 5)	66 (0 - 90)	70 (19 - 98)
	3 years (n = 45)	3.4 (0 - 5)	359 (13 - 267)	3.2 (0 - 5)	62 (10 - 90)	68 (9 - 93)
	4+ years (n = 20)	3.0 (1 - 4)	214 (4 - 499)	3.0 (0 - 5)	70 (40 - 90)	88 (63 - 97)
Santa Gertrudis	2 yrs (n = 182)	-	-	2.5 (0 - 5)	64 (0 - 96)	73 (10 - 98)
	3 yrs (n = 6)	-	-	3.0 (1 - 5)	63 (40 - 80)	86 (80 - 93)
	4+ yrs (n = 22)	-	-	2.4 (0.0 - 4.5)	66 (30 - 90)	79 (17 - 94)

Table 8a tabulates the proportion of bulls in different percent morphologically-normal classes. Overall, 66.9% of bulls had greater than 70% normal spermatozoa whilst 89.4% of bulls had greater than 50% normal spermatozoa.

Table 8a. Percentage of bulls in percent morphologically-normal classes.

Bull group	Age	n	Percent normal			
			<25 %	25 - 49 %	50 - 69 %	≥70 %
Santa Gertrudis	2	121	2.5	9.9	14.9	72.7
	3	6	0	0	0	100
	4+	22	4.5	0	9.1	86.4
Brahman	2	67	4.5	10.4	23.9	61.2
	3	45	2.2	11.1	37.8	48.9
	4+	19	0	0	10.5	89.5
Brahman cross	4+	22	0	0	59.1	40.9
Total		302	2.6	7.9	22.5	66.9

Repeatability of semen traits ranged from low to high although repeatability of percent normal or either percent abnormal mid-pieces was moderate to high at each site. The most common sperm defects seen, particularly in Brahman bulls from the more northern herds, were distal mid-piece or tail reflexes associated with cytoplasmic droplets.

Table 9. Repeatability (r) of selected semen traits over two years

Trait	Site 9	Site 11
Density	0.06	0.10
% motile	0.37	0.44
% normal	0.09	0.64
% abnormal mid-pieces	0.47	0.67

Percent morphologically normal spermatozoa was consistently related to calf output. In the log-linear models developed, percent normal spermatozoa was positively related to calf output in 10 of 15 matings, while in 2 of the other 5 matings, percent abnormal mid-pieces was negatively related to calf output. In one mating, percent normal spermatozoa was negatively related to calf output. However, dominance exerted such a marked effect on calf output (due to the age structure of the bull group), that this result is probably spurious. When percent normal spermatozoa was considered on its own at this site, it was positively related to calf output (P<0.001) [See section 4.5]. In general, bulls with <50% normal spermatozoa sired few calves (Figure 6). Heparin-binding protein profiles were not related to calf output.

The distribution of heparin-binding protein profiles, as described by Bellin *et al.*[8, 23] for the Brahman/Brahman cross (n=46) and Santa Gertrudis bulls (n=27) tested in this study was: 51% A, 42% B, 4% C, 3% D. Therefore, 93% of bulls were classed as positive and would not have been expected to differ in calf output, according to those authors

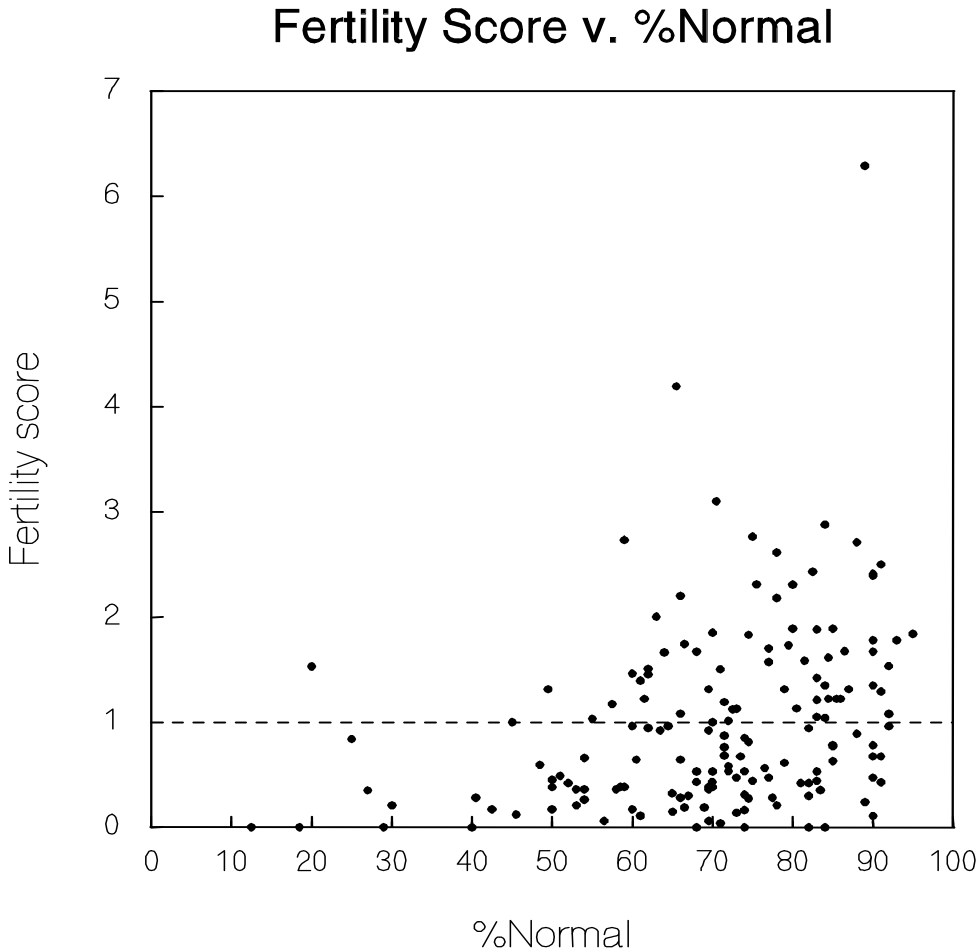


Figure 6. Pre-mating sperm morphology x calf output
Note: Fertility score of 1= average number of calves sired within mating group

4.2.4 Discussion

The study described here is one of the few that have attempted to relate a range of common semen traits to the calf output of bulls used for multiple-sire breeding under extensive conditions. Coulter and Kozub[20], using regression modelling and blood-typing to determine calf parentage, demonstrated that selection of herd sires with low levels of primary sperm defects would be expected to improve fertility of beef bulls used under extensive range conditions. Holroyd *et al.*[2] demonstrated a significant correlation between % motile sperm and pregnancy rates achieved by *Bos indicus* bulls when *inter se* mated in northern Australia. The results reported by these authors are in agreement with our findings that, for most matings, percent normal spermatozoa was consistently related to calf output.

The most common morphological defects seen in the present study were "Dag"-like defects and (or) reflex mid-pieces and tails associated with protoplasmic droplets[27]. Similar defects are commonly associated with disturbances to scrotal/testicular thermoregulation in bulls[28] and have also been observed following treatment of bulls with dexamethasone, indicating that two of the most common types of insults to spermatogenesis in bulls, heat and stress, result in similar spermiograms[29]. These changes in the morphology of spermatozoa generally reflect an increase in epididymal transport time during spermiogenesis. However, Wildeus and Entwistle[30, 31], working with *Bos indicus* x *Bos taurus* bulls, reported highly variable effects on semen morphology when the scrotums of bulls were insulated for 48 hours. In the present study, the cause(s) of the defects in semen morphology recorded were not determined.

The results of the present study question the value of testing bull semen for the presence of heparin-binding proteins in sperm membranes as a measure of a bull's potential fertility as reported by Bellin *et al*.[8]. As 93% of the subset of 73 bulls that were tested had heparin-binding proteins in their sperm membranes, the cost effectiveness (AUD $30 per test) of identifying the 7% of bulls without heparin-binding proteins in their sperm membranes is questionable.

In a review of the significance to bull fertility of morphologically abnormal sperm, Johnson[26] concluded that while many tests of semen quality bear some relationship to fertility, none have proven to be satisfactory as a predictor of superior fertility. This tenet is supported by the findings presented here, which indicate that the focus should be on removing bulls from the herd, that are likely to be of poor calf getting ability.

The findings described here are of importance for the routine examination of bulls for reproductive soundness and confirm that semen examination including sperm morphology should be standard procedure when assessing bulls for reproductive soundness.

4.2.5 Conclusions

Semen examination, including assessment of sperm morphology, should be incorporated into bull selection programs and premating examinations to ensure that bulls have at least 50% normal sperm. Fertility recommendations should not be based solely on semen or sperm motility. Assessments of semen heparin-binding protein profiles are unlikely to enhance the evaluation of bull fertility.

4.3 Serving capacity testing

4.3.1 Introduction

The serving capacity test has been developed in *Bos taurus* breeds as a procedure to identify bulls with structural and serving problems as well as rating bulls on their sexual behaviour and libido[32]. The test was developed as a yard based test to predict the performance of those bulls in paddock mating. In other words, 'Does a bull with a high level of performance in a serving capacity test produce more calves under natural mating?'

There are reported differences in the value of serving capacity testing as a procedure to increase fertility in beef herds. Bulls with higher serving capacity scores were shown to achieve higher conception rates in females at first oestrus than was achieved by bulls with low scores[33]. In contrast, another study reported that serving capacity test scores for *Bos indicus* cross and *Bos taurus* bulls failed to predict the fertility of bulls after 3-7 weeks of single-sire mating[34].

To date, particularly with bulls used in extensive herds, there has been poor adoption of serving capacity testing in *Bos indicus* and *Bos indicus* derived genotypes for a number of reasons, namely:

- the mechanics of organising and conducting the testing protocols,
- practitioner inability to consistently perform the test particularly with young bulls,
- the notion that a high proportion of *Bos indicus* bulls are shy performers particularly under close human scrutiny in a yard,
- in extensive areas, *Bos indicus* bulls can be more temperamental, and
- inconsistent outcomes from the test.

Our studies on serving capacity testing looked at 3 issues:

- the adaptation of the standard serving capacity test for use in *Bos indicus* and *Bos indicus* derived genotypes.
- determining ranges of expressions of sexual behaviours in *Bos indicus* and *Bos indicus* derived bulls of different ages, and
- relationships of test results to calf output of bulls mated in multiple-sire herds.

4.3.2 Materials and methods

Adaptation of the serving capacity test.

Serving capacity testing was based on *Bos taurus* studies using females restrained in service crates[32]. In most cases, females were treated (using either intravaginal progesterone releasing devices or prostaglandin $F_{2\alpha}$ analogues) to synchronise oestrus. Depending on the site, between 2 and 4 restrained females in crates were used with a bull to heifer ratio of 1:1 with young bulls and 1-2:4 in older bulls. The test was for a 20-minute period from the time of first mount or for 30 minutes in the yard with the oestrus females. Prior to testing, bulls were able to view, from an adjacent yard, the activities of other bulls mounting and serving in the test yard.

Data recorded during the tests included the number of times a bull showed:

- Interest: Any form of sexual interest including flehmen, licking and false mounts.
- Mounts: Any combination of a mount with penile seeking and intromission.
- Serves: A mount, followed by intromission and ejaculation.

As well, scores were transformed into a modified libido score[11] (Table 3).

The following modifications to the test were evaluated using mainly 2-year-old Santa Gertrudis bulls.

(i) Providing sexual experience to virgin bulls prior to testing.

At sites 1 and 2, bulls were allocated on weight to treatments in which they were given exposure to oestrus synchronised females. Sexual experience was at the ratio of 0, 2, 5 and 10 females per 8 bulls for 24 hours and 5 females per 8 bulls for 48 and 72 hours.

(ii) Use of restrained females either in oestrus or not in oestrus

In 1996, at sites 1 and 2, bulls were given sexual experience with females in oestrus for 24 hours at 5 females per 8 bulls. Then, prior to treatment allocation, all bulls were serving capacity tested and randomly allocated to treatments based on this serving capacity test so that each treatment had bulls with a range of sexual behaviours. Mature bulls were allocated to treatments using serves alone whilst young bulls were allocated using a combination of mounts and serves.

(iii) Use of restrained or unrestrained females
At site 2, bulls were given prior sexual experience with females in oestrus for 24 hours, at the ratio of 5 females per 8 bulls. Performance in a serving capacity test using restrained females in oestrus was used for allocation to treatments. A ratio of 1:1 bulls to females was used.

A group of 12, 5/8 Brahman bulls at site 9 were serving capacity tested pre- and post-mating for 2 years with both restrained and unrestrained females. When used with unrestrained females they were tested with a bull to female ratio of 1:4-6.5. Bulls tested with restrained females in crates were tested with a ratio of bull to female ratio of 1:1-1.5. Testing was conducted pre- and post-mating for 2 years at site 9.

Bull age and breed effects on expressions of sexual behaviour.
Data was collected prior to mating from 10 sites. Bull ages ranged from 2 to 4+ years. There were over 1100 serving capacity tests conducted using Brahman, 5/8 Brahman, Santa Gertrudis, Belmont Red and Belmont Red cross bulls. Serving capacity testing was conducted either using females restrained in service crates as described above or using 8-13 females in oestrus drafted into a large yard in which groups of 2 bulls were added for 20 minutes. The heifers were changed midway through the period of testing or if a female was unsettled in the testing crates.

Calf output
A subset including Santa Gertrudis (92 observations), Brahman (96 observations) and 5/8 Brahman (24 observations) bulls were subsequently mated in groups to cows and heifers at bull:female percentages of 2.5% to 6% and the paternity of calves resulting from these joinings determined by microsatellite DNA testing.

4.3.3 Results

Adaptation of the serving capacity test.
(i) Providing sexual experience to virgin bulls prior to testing.
Giving 2-year-old Santa Gertrudis bulls sexual experience increased the number of serves in the test from 0.5 to 1.4 ($P<0.05$) and from 1.0 to 2.2 ($P<0.05$) at the 2 sites. Respective increases in libido scores were 3.3 to 7.5 ($P<0.01$) and 7.6 to 9.0 ($P<0.05$). There was no effect of treatment on the number of times bulls showed interest or mounted without serving.

(ii) Use of restrained females either in oestrus or not in oestrus.
At both sites, the oestrus status of the restrained females had no significant effect on expressions of the various sexual behaviours in the test. The overall recordings across sites and treatments, were interest (average of 3.1 to 4.2), mounts (average of 2.5 to 8.6) and serves (average of 0.4 to 1.4).

(iii) Use of restrained or unrestrained females
More mounts were achieved when females were restrained than when they were unrestrained (6.5 *v* 3.3 respectively; $P<0.05$). However there was no difference in the expressions of interest, serves or in libido score.

At site 2 in 1996, an examination was conducted on 17 heifers the day after completion of a serving capacity test in which the heifers had been restrained. A vaginal examination with a speculum found that 13 had no visible evidence of trauma, 3 had very slight bruising and 1 had evidence of slight haemorrhage.

With 5/8 Brahmans at site 9, there was no difference in the number of mounts (2.9) and serves (1.0) when using either restrained or unrestrained heifers. However, interest expressed was double when unrestrained heifers were used (6.9 v 3.7).

In Brahmans, there did not appear to be any practical differences in sexual behaviour in serving capacity tests when using restrained or unrestrained heifers (Tables 10 and 11).

Bull age and breed effects on expressions of sexual behaviour

(i) Sexual behaviour using restrained females (Table 10).

There were more expressions of sexual behaviour in Belmont Red and the Angus cross than Brahman or 5/8 Brahman bulls with Santa Gertrudis intermediate. In Belmont Red bulls there was an increase in serves, mounts plus serves and libido score from 1 to 2 years of age with a smaller increase from 2 to 3 year olds. Belmont Red cross displayed more serves than pure bred Belmont Red bulls at 1 year of age. Both Belmont Red groups displayed more serves than either Santa Gertrudis or Brahman bulls. In Santa Gertrudis there was a small increase in mounts, serves and libido score from 2 to 3 years of age.

Santa Gertrudis bulls displayed more sexual behaviours than Brahmans except for interest only (Table 12). Between 11% and 12.5% of Santa Gertrudis bulls did not display any sexual interest during the test whilst the corresponding values for Brahmans ranged from 5% to 50%. Between 48% and 54% of Santa Gertrudis bulls displayed 1 or more serves and 7% to 26% displayed 3 or more serves in the serving capacity test. The number of serves displayed by Brahmans was lower (30% for 1 or more serves, 0-7% for 3 or more serves). Except for 1-year-olds, Belmont Red bulls displayed more serves than the other breeds.

(ii) Sexual behaviour using unrestrained females (Table 11).

Expressions of various sexual behaviours in the serving capacity test were greater in 5/8 Brahmans than in Brahmans, particularly in mounts and serves, serves and libido score; eg the average number of serves in 4+-year olds was 0.4 in Brahmans compared with 1.3 for 5/8 Brahmans. Although the differences were not significant, there was a trend in Brahmans for expressions of sexual behaviours to increase up to 3 years of age. In 1-year-old Brahman bulls very few serves were recorded although they did show interest and mounting activity.

Repeatability of sexual behaviours (Table 13).

All of the sexual behaviours of Santa Gertrudis bulls at site 2 were moderately repeatable when tested at a 1 month interval. At site 4, only serves and libido score were moderately repeatable in Santa Gertrudis bulls when tested 8 months apart. Values for 5/8 Brahman and Brahman were generally very low. The exceptions were for serves in 5/8 Brahmans using restrained females and for serves and libido score in Brahmans using unrestrained females. At site 6, serves were moderately repeatable when measured first in 2-year-old bulls and then again as a 3-year-old. Other measures were poorly repeatable in the Belmont Red and their cross.

Calf output

Measures of sexual behaviour or libido score were significant in the log-linear models for calf output in only 7 of 15 analyses. However, the significant behaviour varied (see Section 4.5); it was mounts once, serves twice, mounts + serves twice and libido score 3 times.

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Table 10. Means (ranges) of sexual behaviour of bulls tested prior to mating using restrained females.

Breed	Brahman (1 site)		5/8 Brahman (1 site)	Santa Gertrudis (5 sites)			Belmont Red (1 site)			Belmont Red cross (1 site)
Age (years)	2	4+	4+	2	3	4+	1	2	3	1
Observations (n)	42	6	22	378	54	33	176	107	52	22
Weight (kg)	482 (359-640)		635 (536-762)	586 (327-850)	788 (636-911)	895 (798-1044)	265 (198-365)	565 (442-680)	707 (584-782)	275 (230-356)
Interest	4.1 (0-17)	0.5 (0-1)	3.6 (0-7)	2.4 (0-21)	1.8 (0-17)	2.1 (0-10)	2.7 (0-14)	1.6 (0-8.0)	1.0 (0-5)	5.1 (1-12)
Mounts	2.3 (0-11)	3.3 (0-10)	2.2 (0-7)	5.5 (0-20)	5.8 (0-15)	4.4 (0-11)	7.1 (0-26)	6.9 (0-19)	6.2 (0-21)	6.5 (0-19)
Serves	0.4 (0-3)	0.7 (0-2)	1.0 (0-2)	0.9 (0-5)	1.6 (0-7)	1.2 (0-4)	0.3 (0-4)	2.5 (0-8)	2.9 (0-8)	2.6 (0-3)
Mounts and serves	2.7 (0-14)	4.0 (0-11)	3.2 (0-8)	6.4 (0-22)	7.4 (0-17)	5.6 (0-12)	7.3 (0-26)	9.4 (0-20)	9.1 (0-22)	7.1 (0-20)
Libido score	4.5 (0-11)	4.5 (0-10)	6.6 (0-9)	6.5 (0-11)	7.6 (0-10)	6.9 (0-10)	5.5 (0-11)	8.7 (0-10)	8.8 (0-10)	6.4 (2-11)

Table 11. Means (range) of sexual behaviours of bulls tested prior to mating using unrestrained females

Breed	Brahman(2 sites)				5/8 Brahman(1 site)
Age (years)	1	2	3	4+	4+
Observations (n)	45	42	39	18	22
Weight (kg)	247 (145-318)	441 (328-640)	480 (385-640)	673 (497-886)	635 (536-762)
Interest	5.7 (0-22)	4.1 (0-14)	4.6 (0-18)	11.1 (0-26)	6.5 (1-17)
Mounts	1.4 (0-10)	1.1 (0-10)	2.9 (0-14)	0.7 (0-3)	2.0 (0-8)
Serves	0.0 (0-1)	0.3 (0-3)	0.4 (0-2)	0.4 (0-2)	1.3 (0-3)
Mounts and serves	1.4 (0-10)	1.4 (0-11)	3.4 (0-14)	1.1 (0-4)	3.3 (0-9)
Libido score	3.7 (0-7)	3.4 (0-10)	5.4 (0-9)	4.8 (0-9)	7.4 (1-10)

Table 12. Bulls (%) displaying various sexual behaviours in serving capacity tests using restrained females

Breed	Age	Bulls (n)	No Interest	Interest	Mounts	Serves ≥1
Santa Gertrudis	2	443	12.4	5.2	33.9	50.1
	3	99	11.1	10.1	22.2	53.6
	4+	54	12.5	1.8	37.5	48.2
Brahman	2	42	4.8	40.5	26.2	30.9
	4+	10	50.0	20.0	0.0	30.0
Belmont Red	1	179	4.5	14.5	65.9	16.2
	2	105	1.9	0.0	17.1	80.9
	3	53	0.0	1.9	11.3	86.8
	4	22	0.0	0.0	4.5	95.5
Belmont Red cross (Angus x)	1	22	0.0	13.6	45.5	40.9

Table 13. Repeatability of sexual behaviours in the serving capacity tests

Breed	Site 2 Santa Gertrudis	Site 4 Santa Gertrudis	Site 6 Belmont Red	Site 6 Belmont Red	Site 9 5/8 Brahman	Site 9 5/8 Brahman	Site 11 Brahman
Bulls (n)	72	19	24	19	12	12	34
Bull age (years)	1.5- 3	2-3	1-2	2-3	4 - 5	4 - 5	2 - 3
Interval of measurement	1 month apart in 1995	8 months apart in 1993/94	1 year apart	1 year apart	4 times over 2 years	4 times over 2 years	4 times over 2 years
Females in test	Restrained	Restrained	Restrained	Restrained	Restrained	Unrestrained	Unrestrained
Interest	0.42	0.00	0.00	0.00	0.00	0.00	0.20
Mounts	0.41	0.03	0.00	0.02	0.09	0.03	0.13
Serves	0.54	0.48	0.04	0.37	0.25	0.01	0.27
Mounts plus serves	0.46	0.21	0.00	0.17	-	-	0.21
Libido score	0.56	0.35	0.10	0.01	0.11	0.00	0.44

4.3.4 Discussion

Belmont Red, Santa Gertrudis, Brahman and 5/8 Brahman bulls are capable of performing in a serving capacity test although the degree of expressions of sexual behaviours, particularly serves, is less than in *Bos taurus* bulls.

Belmont Red bulls as representatives of the Sanga breeds, had slightly lower levels of expression of sexual behaviour than those reported in *Bos taurus* breeds, with mean number of serves for 2 and 3 year old bulls being 2.5 and 2.9 respectively. In these bulls 4.5%, 60.4% and 72.7% of 1, 2, 3 and 4 year old bulls achieved 3 or more serves in the test.

The various expressions of sexual behaviour recorded in serving capacity tests in *Bos indicus* and *Bos indicus* derived genotypes support previous findings that these breeds have lower levels of expression of sexual behaviour than *Bos taurus* bulls. The mean number of serves reported here for *Bos indicus* and *Bos indicus* derived bulls ranged from 0 to 1.3 per test compared with 3 to 4 serves per 20 minute test for *Bos taurus* bulls. However we found that 26%, 17% and 7% of 2-, 3- and 4+- year old Santa Gertrudis bulls and 7% of 2-year-old Brahman bulls achieved 3 or more serves.

Across all the breeds tested, there was an improvement in the number of serves with age to 3 and 4 years old. Yearling bulls had relatively more mounts than serves, while 2-year-old bulls had reduced mounts and increased serves.

When using unrestrained females, it was more difficult to closely observe individual bulls for penile problems and to be confident that mating behaviour was not inhibited by attempted escapes of the female. There appeared no practical difference between the use of restrained and unrestrained females in mounts and serves. The exception is a bull:female of 1:1 when sexual behaviour was greater with restrained females. This is presumably because with few females available, a bull is less likely to get a heifer to stand for mounting if unrestrained.

Prior sexual experience increased the expression of behaviour of Santa Gertrudis bulls in 2 of the 3 experiments. This partially supports other work[35] where there was an improvement in serving capacity test results for low serving capacity bulls when tested after one breeding season.

We still recommend the use of females in oestrus when testing bulls, although there was no significant difference in expressions of sexual behaviour in experiments where oestrus and non-oestrus females were compared. We have found that when using females in oestrus, there seems to be less delay in getting the test into ‘full swing’ on the day of testing. This is because there is quicker initiation of sexual activity in the first group of bulls to be tested and stimulation of those bulls waiting to be tested. Ultimately this reduces the time taken to test all bulls.

Even though we incorporated measures of libido score, interest, mounts as well as serves, as compared to only measures of serves with the *Bos taurus* serving capacity test[32], sexual behaviour was not consistently related to calf output. However, the results suggested that overall there is some positive relationship between sexual behaviour and calf output but, to date, our methods of testing are not consistent enough to confirm this.

Blockey[33] showed that, as serving capacity (number of serves in a 40 minute test) of bulls increased from 1 to 7, there was a corresponding increase in heifer conception rate from 18% to 70%. The study[33] was done with stocking rates of 1 heifer to 1-2.5 ha, single-sire matings of 10 weeks and bull:female ratios of 2.5%. In contrast, our work was performed under extensive conditions of much lower stocking rates and greater herd dispersions, multiple-sire matings for longer periods (3-12 months) and higher bull:female ratios (2.5-6%).

The differences in management practices may account for our poor relationship between serving capacity test results and calf output because our bulls had lower mating loads than those in Blockey[33].

Guidelines for the conduct of a serving capacity test were outlined by Bertram *et al.*[36]. Based on results with Brahman and Santa Gertrudis breeds, we are not confident that we can use poor performance in these serving capacity tests as a culling criterion for bulls of these breeds unless they exhibit some clinical abnormality or lameness. Conversely we can use the test to select bulls capable of natural service.

4.3.5 Conclusions

Brahman and Santa Gertrudis bulls are capable of performing in a serving capacity test although the degree of expressions of sexual behaviour, particularly serves, is less than in *Bos taurus*. The main value of the serving capacity test in these breeds, is a means of identifying whether a bull is capable of serving and not as a predictor of calf output when mated in multiple-sire herds.

4.4 Social behaviour of bulls

4.4.1 Introduction

At present, there is little scientific information to substantiate recommendations on bull selection and mating practices for extensively-managed *Bos indicus* cattle. Bull:female mating ratios average 4.3% in tropical Australia[37]. Bulls achieve an estimated average of only one conception/week during the peak mating period. Bull cost per calf when using $1,500 bulls is less than $10 when annual calf output is high (30+), but over $100 when calf output is low (0-3).

Using fewer bulls (without reducing herd fertility) of higher breeding value will accelerate genetic improvement. The estimated annual net financial benefit of this for a typical north Australian beef producer with a 3,000 adult equivalent (AE) herd is ~$5/AE.

Improving recommendations on mating practices must be based on improved understanding of reproductive behaviour of bulls mated in multiple-sire herds using extensive management. This aspect is examined in this section.

4.4.2 Materials and methods

Location

Swan's Lagoon. The primary research was conducted in Sandalwood paddock (22 km^2; Figure 7). The vegetation is open eucalypt savanna woodland with a native unimproved pasture. Low-fertility duplex soils predominate in this relatively flat paddock

Other sites. These included Fletcherview Research Station north-west of Charters Towers in north Queensland; Cona Creek west of Springsure in central Queensland; Gyranda south-east of Theodore in central Queensland and Kamilaroi Station north of Cloncurry in north-west Queensland.

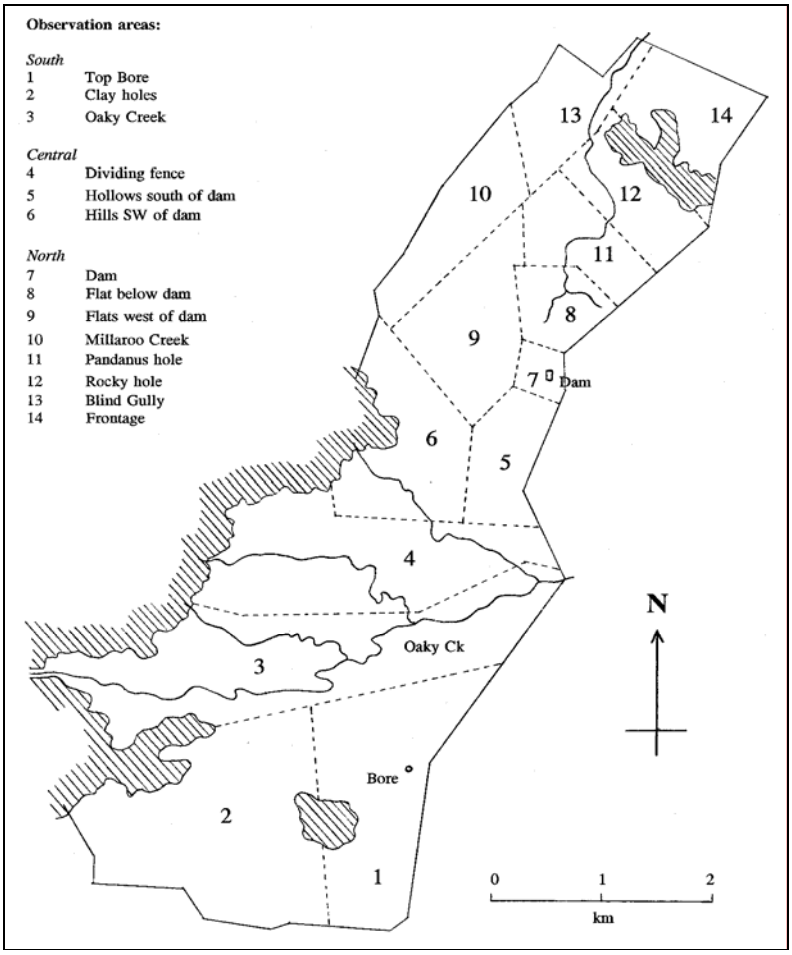

Figure 7. Swan's Lagoon project site (Sandalwood paddock)

Animals, management and measurements of behaviour

Swan's Lagoon. The cattle were a composite 5/8 Brahman x 3/8 Beef Shorthorn bred on the station. Mating was continuous with two annual musters in April/May and August/September. Vaccinations included campylobacteriosis (bulls), clostridial diseases, and leptospirosis. An average of 325 breeding females were present during the peak mating season (February-March) each year. In 1993/94, 14 No. 88-92 bulls were used (4.4% bull:female ratio). For 1994/95 and 1995/96, 4 No.91 bulls replaced 6 older bulls (12 No.89-92 bulls: 3.6% bull:female ratio). Stocking rate was a breeding female per 7ha.

Each two weeks from mid-February 1995, the location and behaviour of the bulls within the paddock were assessed between 1000 and 1200 hrs. The distribution of cows was also recorded. Movement range was estimated for each bull. Nine areas of approximately equivalent size were defined. For each bull, the number of times found in each area was recorded, and ranked. A value of 1 was allocated to the highest rank through to a value of -1 for the ninth ranking. The number of times a bull was found in each area was then multiplied by the allocated value for that area. The sum of these products, divided by the total number of observations was the movement range index (MRI).

Dominance hierarchy was estimated by recording agonistic behaviour[38] when the bull group was placed together in a yard (250-800 m^2) for 1-2 hours immediately after each muster. All interactions were entered into a matrix with dominant bulls in columns and subordinate bulls in rows. Rows and columns were then moved, while retaining the same order of bulls from the left/top, so that most interactions were beneath a diagonal from the top-left to the bottom-right of the matrix. Dominance hierarchy was then in order from the left/top.

Cona Creek. Brahman bulls were run together for 2 weeks at Biloela Artificial Breeding Centre prior to dominance hierarchy assessment which was recorded after a 24 hr fast. Dominance was determined by introducing all possible bull pairings one at a time for ~5 minutes to a yard with a restricted feed access (only one bull could feed at a time). In January 1996, eight 2- to 4-year-old bulls were transferred to Cona Creek and were mated with 200 second-calf cows for 6 months from January.

Fletcherview. Agonistic behaviour between bulls and dominance hierarchy was determined using the same method as at Swan's Lagoon. Twelve mixed-age Brahman bulls which had been on the station for at least 6 months, were mated for 3 months from January 1995 to 250 cows.

Gyranda. In November 1995, 13 Santa Gertrudis bulls selected for the 1995 multiple mating study were yarded at 0800h and kept off feed and water. They were kept in their 2 mating groups, a group of 9 and a group of 4. At 1415 h, the group of 9 were let into a wooden yard, 8 m x 21 m with a centrally placed hay rack and a water trough in one corner. Interactions between bulls were noted and wins and losses recorded. Observations were made from 1415 h to 1600 h. At the same time, the group of 4 was observed in a similar yard but there was no agonistic activity at all. The dominance hierarchy was established using the procedure described by Bielharz and Zeeb[38]. From mid-November 1995, eight of the nine 2-year-old bulls were mated to 231 heifers for 4.5 months.

Kamilaroi. The procedure to establish dominance hierarchy was abandoned as the bulls exhibited almost no discernible agonistic behaviour. Bulls were mated in 2 flat 60-84 km^2 paddocks (Smithdale and Whitewood) to 300-350 cycling females (411 and ~650 females in 1994/95 and 1995/96, respectively) for 3.5-4.5 months.

4.4.3 Results

Paddock behaviour

Swan's Lagoon. Bull control was very good with very little movement of bulls between paddocks. Over the 2 years, there were 2 bulls consistently found at the southern end of the paddock compared with 6 at the northern end. This may be related to the end of the paddock closest to their location between weaning and 2.5 years of age. It did not appear related to cow distribution (average: 40%, 17%, and 43% of females found in northern [44%], central [23%], and southern [33%] sectors), age, or other behaviours. In all areas of the paddock, bulls were found by themselves 10-20% of the time (Table 14). Bulls working the southern end of the paddock were rarely found in a bull group and were mostly found with cows. However, bulls at the northern end of the paddock were found with cows a little over half of the time. The repeatability of time spent with cows was moderate (r=0.42).

Table 14. Proportion of time bulls were observed in day time social groups in Sandalwood paddock at Swan's Lagoon

Social group	Area of paddock generally found		
	North 6 bulls	Variable 4 bulls	South 2 bulls
Alone	10%	21%	10%
Bull group	34%	12%	5%
With cows	56%	68%	85%

Ten of the 12 bulls had a movement range index (MRI) >0.7 (Table 15) which corresponded to a range of ~500 ha. The two bulls with the highest MRIs each sired about 20% of the calves. The lowest-MRI bulls each sired <5% of the calves. Calf output for the other 8 bulls was generally intermediate, but variable.

Table 15. Movement range of bulls

Bull	MRI*	Calf output (n) 94/95 mating	95/96 mating
890103	0.92	79	37
890272	0.51	10	8
900080	0.71	12	20
910016	0.72	22	14
910019	0.83	19	23
910124	0.88	23	50
910242	0.86	10	15
915687	0.84	12	8
915689	0.84	5	3
915703	0.84	2	11
920108	0.53	11	6
920239	0.74	21	22

*: 1=Never outside one area; 0=Location random

Kamilaroi. Late in the 1994/95 mating, one bull went missing (presumed dead) in Smithdale paddock. At similar times in 1996 and 1997 in Smithdale paddock, a bull was found with a fractured leg. This equates to 4-5% annual bull attrition. No bull losses were recorded in Whitewood paddock.

Dominance

Swan's Lagoon. Dominance hierarchy within the bull group was moderately repeatable (r=0.45). Changes in bull ranking appeared to be influenced by the test situation not matching paddock conditions, injuries to bulls, and maturing of bulls. The correlation between rankings in September 1994 and May 1995 was 0.36, suggesting inaccurate assessment, but was 0.92 a year later. In 1995/96, but not in 1994/95, dominant bulls spent more time with cows than did subordinate bulls (r=-0.45) and sired more calves (b=-0.15, P<0.001; Figure 8).

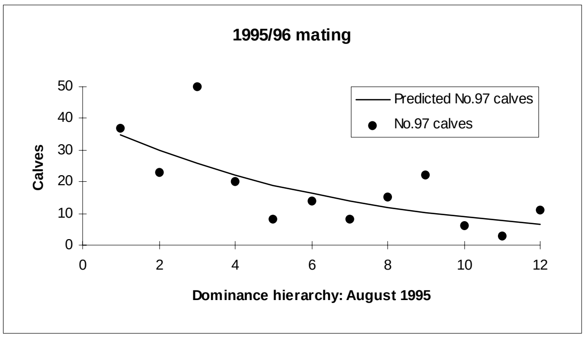

Figure 8. Dominance effects on calf output at Swan's Lagoon

Fletcherview. Dominance was clearly established in this bull group. It was strongly related to calf output and accounted for 75% of the deviance in calf output (see Section 4.5, Table 18). The relationship was very similar to that shown in Figure 8.

Cona Creek. It appeared that the dominance hierarchy, established using the described method during feeding of bulls together in a small paddock, differed significantly to apparent dominance during group feeding. This strongly suggests that the technique was inappropriate. However, at the time, it had been the only way to clearly establish a dominance hierarchy within the group which had settled down well together. Subsequently calf output was not related to the measured dominance hierarchy.

Gyranda. Calf output was unrelated to the established hierarchy within these 2-year-old bulls.

Kamilaroi. The dominance hierarchy could not be established. There was virtually no overt agonistic behaviour between these 2-year-old bulls that had been reared together.

4.4.4 Discussion

At Swan's Lagoon, bulls were observed to be very territorial. The territory claimed by each bull is presumably related to dominance behaviour, thus to calf output. Mating load was low due to peak mating extending for 3-4 months which is typical for mixed-age, northern Australian herds. A low proportion of bulls covered a high percentage of the cows with no apparent detrimental effects on herd pregnancy rates (~90%). This suggests that the 4% bulls:cycling females used was excessive, particularly as bulls rarely achieved an average of >1-2 pregnancies/week. The range of bulls was ~500 ha; or was it the range of ~75 females, or a range determined by bull numbers? Under the low mating load, 2 bulls per typical movement range would probably suffice; the second would be needed if the first suffered reproductive failure. This equates to 8 bulls in the paddock used, or a 2.5% bull:female ratio. This supports the conclusions from concurrent studies (see Section 4.6).

In a previous study at Swan's Lagoon, ~90% of Brahman cross bulls, mated as single sires each sired >20 calves over 3 months[2]. Sperm competition, which encompasses all functions from bull access to females through to fertilisation, may explain the variation in calf output in multiple-sire herds, particularly where the ratio of bulls:cycling females is high. Where dominance hierarchy was clearly established and appeared consistent with ranking during mating (Swan's Lagoon and Fletcherview), social dominance was confirmed as a primary contributor to this competition, presumably because dominant bulls achieve more services per oestrus female and better timing of services[39]. A lower bull:cycling female ratio may reduce the competition for females (ie reduce the apparent effect of dominance on calf output), thus reducing the variation in calf output between bulls as seen at Kamilaroi (see Section 4.6).

Dominance hierarchy was only clearly established in mixed-age mature bull groups. The test situation used was inadequate or inconsistent for establishing the hierarchy within groups of young bulls which had been reared together (Gyranda, Kamilaroi), or even settled down over a couple of months (Cona Creek). At Swan's Lagoon and Cona Creek there was also evidence that dominance hierarchy established in a yard test was not always highly correlated with that observed in the paddock. These observations together indicate that accurate assessment of dominance hierarchy within groups of *Bos indicus* or *Bos indicus* derived bulls requires observation over extended periods in their normal grazing environment.

It is a perception by many cattle producers in northern Australian that 'harder-working' bulls finish the mating season in poorer body condition. Our study refutes this as there was no difference in body condition between bulls mated at low and high percentages at Kamilaroi. As well there was no relationship within paddocks between calf output and bull condition. However, regular bull attrition occurred when 6%, but not 2.5%, bulls:females was used at Kamilaroi. Presumably, agonistic behaviour increased as the ratio of bulls:females increased. This would increase energy demand resulting in both body condition loss and bull injury. Our experience with bulls mated in paddocks of ~20-30 km^2 at Swan's Lagoon is that a bull:female ratio of >3.5% leads to broken fences and other problems.

Behavioural studies are integral to confidently improving recommendations of bull mating management to maximise calf output per bull without risking lower herd fertility. Studies need to encompass herds with a high degree of dispersion caused by multiple watering points, large herds, large paddocks, high tree density, uneven topography, and weather extremes. For example, our principal behavioural studies used paddocks with only sparsely-located artificial waters. Most oestrus expression occurs at night[40] when cattle are dispersed (even when cattle must congregate daily on controlled watering points), thus confusing the impact of watering point distribution on the number of bulls needed. Studies using fewer than 2.5% bulls:cycling females are also required to more accurately define mating potential of *Bos indicus* bulls under extensive management.

4.4.5 Conclusions

Behaviour as expressed through social dominance has a significant influence on calf output of bulls in multiple-sire mated herds under extensive management systems. Bulls are very territorial, a behaviour which is presumably related to social dominance; bulls expressing this to the highest degree tended to sire more calves. The behavioural studies supported the recommendation that a mating ratio of 2.5% reproductively sound bulls is adequate for Brahman cattle in the tropics. Further information is needed to establish optimal mating ratios where herd dispersion is very high or low.

4.5 Calf output and predictors of fertility of bulls in multiple-sire herds

4.5.1 Introduction

In multiple-sire herds, cattle producers have no objective means of evaluating whether individual bulls are siring progeny or determining paternity of progeny. Having identified the appropriate genetics for particular markets through either investment in replacement bulls or breeding their own bulls, producers want to be able to maximise the number of progeny of selected bulls so that there can be continued selection within the herd for replacement sires, or to evaluate existing sires to maintain genetic progress. Therefore, producers need to:

- have a means of efficiently and cost effectively determining paternity in multiple-sire herds,
- be aware of expected ranges of calf outputs of individual bulls, and
- know of physical and reproductive traits that are related to calf output in multiple-sire herds.

This section addresses these issues.

4.5.2 Materials and methods

Over 4 years, calf output was collected on 212 bull observations (92 Santa Gertrudis, 96 Brahman and 24 5/8 Brahman) from 37 mating groups on 9 properties. The number of bulls per mating group ranged from 2 to 24. Bulls were from 2 to 7 years of age and in most cases, ages within mating groups were similar or overlapped by a year, eg 2- and 3-year olds or 4- and 5-year olds. Joining periods were from 3 to 12 months and bull mating percentages ranged from 2.5% to 6% but most were 3% to 4%.

Each bull had been subjected to a general physical and reproductive examination and, in the majority of cases, included an assessment of sexual behaviour in various serving capacity tests. Except for one paddock at site 11, only bulls judged to be physically sound were used for mating. Most bulls had a scrotal circumference greater than or equal to recommended threshold values. Bulls with extremes such as very pendulous prepuces were not mated. Bulls were not selected for mating on the basis of percent normal spermatozoa. Bulls and calves were bled for DNA typing.

Dominance was recorded at sites 4, 9, 10 and 11. Bulls were placed in a yard for several hours and numbers of wins/losses recorded on altercations between bulls. A dominance hierarchy was calculated from a matrix developed by G Fordyce (unpublished) or, at site 4, on the procedure of Beilharz and Zeeb[38].

The effects of repeatable measured traits on calf output in each year were estimated using a log-linear modelling approach[14] (see section 3.2). There were 17 models developed for each mating group of at least 8 bulls.

4.5.3 Results

Paternity testing

Overall, the paternity of 87.0% of calves could be resolved with a standard panel of 12 DNA markers (Table 16). The accuracy of paternity resolution was close to the predicted accuracy estimates where the paternity exclusion probability calculated for Brahman and Santa Gertrudis breeds was 0.99 for a single bull. The majority of unresolved paternities, after testing with this standard panel, were able to be resolved by testing with additional DNA markers. Paternity resolution averaged 97.7% across all sites with a range of 96.1% to 100%, although this included some sites where additional markers were not used to improve the resolution of the standard marker panel. The percentage of calves with no potential (missing) sire averaged 9.5%, with a range of 0 to 50.8%. Only 11 of the 41 separate mating groups analysed had no missing sires. The numbers of missing sires varied widely between mating groups and affected the reliability of sire allocations. When the percentage of calves with no known sires was high (50.8% in one mating group), the reliability of sire allocations was only 86%, whereas sire allocations were 100% reliable when there were no missing sires.

Table 16. Summary of DNA results

Site	Mean no. sires (range)	Calves n	Solved %	Solved +1, +2 %	Zero sire %	Reliability estimate
1	3 (2-7)	400	97.3	97.3#	12.0	97.9 - 100
2	6	67	83.6	98.5	16.4	93.2
3	5 (5)	141	92.9	97.9	13.5	94.4 - 100
4a	9(5-12)	439	93.4	96.8#	5.2	99.2 - 100
4b	26	408	89.2	96.1	21.3	95.0
7	4(4)	90	74.4	100	14.4	79.8 - 100
8a	8(6-10)	194	95.4	100	22.2	99.2
8b	28	130	91.5	100	50.8	86.5
9a	4(4)	189	99.5	100	1.1	100
9b	24(19-34)	753	83.1	98.3	4.2	96.3 - 99.9
10	12	213	92.5	#	8.0	99.2
11	25(12-34)	1043	75.1	98.5	5.6	97.4 - 99.3
12	15 (14-15)	373	93.6	97.3	1.1	99.9 - 100
All		4440	87.0	97.7	9.5	

Solved :- % of resolved paternity after testing with the standard panel of 12 markers; Solved +1, +2 :- % of resolved paternity after testing through additional marker tests. # Includes some mating groups not subjected to additional DNA tests to improve paternity resolution

Calf output of individual bulls

Of the 212 bull matings observed, 58% individually sired 10% or less calves in each of their respective mating groups with 7% not siring any calves. In contrast, 13% sired over 30% of the calves in each of the respective mating groups.

When bulls were mated in groups of 8 to 24, the maximum percentage of calves sired by individual bulls was 26 ± 7% (range of 11-36%). However when bulls were mated in groups of 2 to 7, the maximum percentage of calves sired by individual bulls was 59 ± 19% (range of 24-94%).

Impregnation rates of individual bulls

Comparisons of impregnation rates of bulls were done using survival analysis[41,42]. To enable a pattern of impregnations to be considered, any bull that sired less than 10 calves was not included. With the Santa Gertrudis mating groups, of the 7 mating groups considered, minor differences between some bulls were detected in 2 mating groups. Similarly with the 2 mating groups of Brahmans at Kamilaroi and the 1 mating group at Swan's Lagoon, the differences between impregnation rates for bulls within each mating group were minimal.

Repeatability of calf output

Table 17 summarises all the available measures of repeatability for calf output (log transformed) as measured by number of calves sired by individual bulls in 2 consecutive matings. In 4 of the 5 sites, repeatability was moderate and in the range of 0.46 to 0.67.

Table 17. Repeatability of calf output

Site	Breed	Bulls n	r
5	Santa Gertrudis	7 (not in same group in each year)	0.46
8	Brahman	6 (out of 10 in previous year)	0.12
9	5/8 Brahman	12 (same bull group)	0.67
11	Brahman	34 (same bull group)	0.62
12	Brahman	9 (not in same group in each year)	0.54

Log-linear models of traits contributing to calf output

Table 18 presents the log-linear models for calf output from 17 of the mating groups considered. For example, at Kamilaroi in Whitewood paddock for November 1995 to May 1996 mating, the model is: calf output = $e^{(3.23 - 0.08 \text{ prepuce depth} + 0.018 \text{ percent normal sperm})}$.

In 2 matings there was a strong negative relationship between dominance hierarchy and calf output in the models (the most dominant bull sired the most calves). In the other 2 matings, there was no relationship.

Scrotal circumference was related to calf output in 2 of 17 matings; in one case the relationship was positive, in the other it was negative. Similarly, the relationships of prepuce depth, skin thickness, and umbilicus thickness with calf output were inconsistent and variable.

Semen quality was an important contributor to calf output in the models. Percent normal spermatozoa was positively related to calf output in models for 10 of 15 matings. At site 10 where percent normal spermatozoa was negatively related to calf output, dominance exerted such a marked effect on calf output within the model that this result is probably spurious. However it should be noted that when percent normal spermatozoa was considered on its own at site 10, it was positively related to calf output ($P<0.001$). In 2 matings, where all bulls had in excess of 50% normal sperm, percent abnormal mid-pieces was negatively related to calf output.

The percentage of motile sperm was positively related to calf output in 3 of 16 matings; there was no relationship in the other 13 matings.

Heparin-binding protein profiles were not related to calf output. In the one group of matings where response to GnRH was assessed, there was a negative relationship between post-GnRH plasma testosterone and calf output.

When serving capacity tests were conducted using restrained heifers, there were some positive relationships between measures of sexual behaviour and subsequent calf output. Of the 8 matings, mounts were related in 1 mating, mounts + serves in 2 matings and serves in 1 mating. When serving capacity tests were conducted using unrestrained heifers, there were very few relationships with measures of sexual behaviour and subsequent calf output in the 8 mating groups. Libido score was positively related to calf output in 2 matings.

The models did not explain all of the variation in calf output and the percent of deviance explained ranged from 18% to 98%. In most cases, residual deviance was significant indicating a lack of fit of the model, ie the traits we measured and considered in these models only partly explained the variation in calf output.

Table 18. Log-linear models of traits contributing to calf output

Site	1	1	4	4	4	4	4	4	8	8	9	9	10	11	11	11	11	12	12
Property	Marrett	Marrett	Gyranda	Gyranda	Gyranda	Gyranda	Gyranda	Gyranda	Cona	Cona	Swans	Swans	Fletchv.	Kamil	Kamil	Kamil	Kamil	DDaly	DDaly
Paddock	Pooled	Pooled	Cattle Ck	Cattle Ck	Peach	Pooled	Lightn	Pooled			Sandlew	Sandlew		Whitew	Whitew	Smithdale	Smithdale	Gp 1	Gp 1
Time of mating	Oct94-Jan95	Oct95-Jan96	Nov92-Jan93	Nov93-Apr94	Nov93-Apr94	Nov93-Apr94	Nov95-Apr96	Nov95-Apr96	Jan94-Apr94	Jan96-Apr96	Aug94-Jun95	Aug95-Jun96	Jan95-Apr95	Dec94-May95	Nov95-May96	Dec94-May95	Nov95-May96	Jan95-May95	Jan96-May96
Date of bull examination	Jul-Aug94	Jul-Sep 95	Oct92	Oct93	Oct93	Oct93	Oct95	Oct95	Dec93	Dec95	Sep94	Aug95	Jan95	Dec94	Sep95	Dec94	Sep95	Dec94	Dec95
Progeny group	No. 96	No. 97	No 94	No 95	No 95	No 95	No 97	No 97	No 95	No 97	No 96	No 97	No 96	No 96	No 97	No 96	No.97	No 96	No 97
Bulls (n)	16	10	10	7	8	24	8	12	10	8	12	12	10	10	9	24	23	7	6
Bull age	2 - 4	2 - 4	2	2	2	2	2	2	2-3	3-4	3-6	4 - 7	2 – 6	2-3	3 - 4	2 - 3	3-4	2 – 4	2 - 4
Breed	SG	SG	SG	SG	SG	SG	SG	SG	Brah	Brah	5/8 Brah	5/8 Brah	Brah	Brah	Brah	Brah	Brah	Brah	Brah
Constant	†	†	-2.33	-8.92	2.708	†	-7.180	†	-6.89	-2.88	2.197	3.348	7.661	-10.41	3.231	3.38	1.108	-6.66	-0.005
Age (years)	m	m	m	m	m	m	m	m	1.120**	ns	m	m	m	m	m	m	m	ns	ns
Weight	0. 050**	ns	ns	0.018**	ns	ns	ns	ns			ns	ns	ns	ns	ns	ns	ns	ns	ns
Body condition	m	m	m	m	m	m	m	m			ns	ns	ns	ns	ns	ns	ns	ns	ns
Dominance							ns			ns	ns	-0.151***	-0.483***						
Scrotal circumference	ns	0.502**	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	-0.149*	ns	ns	ns	ns	ns
Testicular tone	ns	ns	ns	ns	ns	ns	ns	ns			m	m	m	m	m	m	m		m
Prepuce depth	-0.045*	0.030*		ns	ns	ns	0.024**	ns			0.121***	0.050*	ns	ns	-0.080**	ns	ns		ns
Prepuce angle											ns	ns	ns	0.11**	ns	-0.08***	ns		
Skin thickness											***	ns		**	ns	***	ns		
1.											0.00			0.00		0.00			
>1.											-1.664			1.47		0.90			
Umbilical thickness	*	ns		ns	***	***	ns	ns					m						m
Score <2	0.00					0.00													
Score 2	-3.273				0.00	-1.422													
Score 3	0.343				-1.003	-1.288													
Score >3	-3.074					-2.485													
Sperm output									ns	ns									
% motile sperm		ns		0.023*	ns	0.014***	ns	ns	0.034**	ns	ns	ns	m	ns	ns	0.03***	ns	ns	ns
%progressively motile											ns	ns	ns	ns	ns	ns	ns		
% normal sperm	ns	ns	0.035*				0.049**	0.0338***	0.056**	0.057*	ns	ns	-0.036**	0.10***	0.018*	0.03***	0.019***	0.102**	0.034*
% abnormal mid-pieces											-0.104**	-0.090**	ns	ns	ns	ns	ns		
Heparin-binding protein	m						ns	m				m	m	m	m	m	m		
LH post-GnRH							ns	ns											
Testosterone post-GnRH							ns	-0.0736**											
Serving capacity test (restrained)																			
Mounts	ns	ns	0.482***	ns	ns	ns	ns	ns			m	m							
Serves	ns	ns	ns	ns	ns	ns	ns	ns			*	ns							
0.											0.00								
1.											0.220								
2.											0.959								
Mounts + serves	0.306*	ns	ns	ns	ns	ns	0.243**	ns			m	m							
Libido score 1	ns	ns	ns	ns	ns	0.168**	ns	ns			m	m							
Serving capacity test (unrestrained)																			
Mounts											m	m	m	m	m	m	m		m
Serves											m	m	m	ns	ns	ns	ns		ns
Mounts + serves											m	m	m	m	m	m	m		m
Libido score 1											m	m	ns	0.21*	ns	0.13***	ns		ns
% deviance explained	98	74	60	88	26	64	97	63	55	34	82	77	89	85	79	85	18	77	47
Significance of residual deviance	ns	<0.01	<0.001	ns.	<0.001	<0.001	ns	<0.001	<0.001	<0.001	<0.001	<0.001	<0.05	<0.001	ns	<0.001	<0.001	ns	<0.001

† No constant term available since it depends on the mating group   ns = considered in model but not significant   m = measured but not considered in models

.5.4 Discussion

DNA typing proved to be a powerful tool for the identification of paternity of calves resulting from multiple-sire matings. The assignment of calves to bulls matched or was better than predicted accuracy estimates. The inclusion of additional markers allowed a resolution rate in excess of 97.5% even when bull groups of up to 34 were used for the paternity analysis. These results are better than values quoted for parentage testing using blood typing which involves the additional bleeding and testing of cows [1, 21]. The percentage of calves with no potential sires was 9.5% across all sites indicating, even in these well managed herds, there are managerial issues such as bulls or cows jumping fences, cows pregnant before mating, precocious bull calves and the mixing of calf groups that can reduce the accuracy of sire allocation. Since problems with unknown sires producing calves exist in most mating groups, DNA typing results can also be used to monitor the effectiveness of property herd management practices.

The large variability of calf output by individual bulls is supported by other data[1, 43.] However our results add new information in that, providing the composition of bull mating groups remain relatively similar, then individual calf output tends to be moderately repeatable. In most of our cases, bull ages within mating groups were similar which discounts the concept that mating similar age groups of bulls evens out calf distribution from individual sires[44]. Factors other than age contribute to this variability in calf output. In most cases there was no obvious clinical reason for those bulls not siring any calves.

One of the reasons that physical traits such as scrotal circumference were not consistently related to calf output may be that the majority of bulls used had above considered threshold values for *Bos indicus* derived bulls in northern Australia. These threshold values are ≥28 cm in 2-year-old Brahman bulls grazing native pasture or ≥34 cm for moderate to well fed 2-year-old bulls[6]. Similarly with the inconsistent relationship between prepuce depth and calf output, because there were no bulls mated with excessively pendulous prepuces, there wasn't the variation in the data to allow expression of this trait as a predictor of calf output. However, at several sites, prepuce depth was positively related to calf output suggesting that within the range of prepuce depth observations, increasing depth did not affect calf output.

Semen quality, particularly percent normal spermatozoa was important and consistently related to calf output in a majority of matings. However bulls were not selected for mating on percent normal spermatozoa and the range in values in mated bulls was marked (10-92%), thus allowing the expression of this trait in the models as a predictor of calf output. Our results suggest that morphological examination of semen should be part of bull reproductive examinations. However threshold values for sperm morphological characteristics need to be refined for *Bos indicus* bulls in multiple-sire matings although 50% normal spermatozoa is a guideline for satisfactory semen quality. Our results also suggest that sperm motility should not be ignored; however, emphasis in semen examination should shift from motility to morphology.

The inconsistency of relationships between measures of sexual behaviour in the various serving tests indicates that these measures are of limited value as a predictor of calf output in multiple-sire herds with Brahman and Santa Gertrudis bulls. However, the value of serving capacity testing may be in determining serving ability and eliminating penile and preputial injuries rather than for ranking bulls for high or low libido.

In 2 matings, there was a strong relationship between dominance hierarchy and calf output, ie the most dominant bull sired the most calves, but not in the other 3 matings. The inability to measure dominance hierarchy at one site because of lack of agonistic interactions suggests that better testing procedures to measure dominance need to be developed, ie in the paddock and over extended periods. As well there is a need to control the influence of dominance on calf output in multiple-sire herds so that selected bulls have the opportunity to sire calves.

In 11 of the 17 matings, the traits in the loglinear models explained between 71% and 97% of the deviance. This is markedly better than similar procedures used by Coulter and Kozub[21] in more intensively managed *Bos taurus* herds in Canada. Our analyses differed in that most of our models were derived from individual mating groups rather than pooled across sites and years. In many cases, the residual deviance was significant indicating that there were factors other than the traits we measured which were contributing to calf output.
This work has demonstrated that no one single trait can be used as a predictor of calf output. However the models did identify a number of important traits that should be incorporated into bull examination procedures. Once physical and reproductive traits are above threshold levels, there may be little value in placing an emphasis on selecting for traits such as large scrotal circumference to improve calf output of individual bulls in multiple-sire herds in extensive matings.

These studies have shown that we may not be able to identify the really high fecund bulls ('super bulls'), but a systematic physical and reproductive examination will identify a large number of bulls that will be poor contributors to calf output in multiple-sire herds.

4.5.5 Conclusions

DNA typing is an accurate method of identifying paternity of calves resulting from multiple-sire matings. There was no one single physical or reproductive trait that was consistently related to calf output in multiple-sire herds. Even so, selecting on combinations of traits did not explain all of the variation in calf output. Bulls should be selected for physical and reproductive traits that lie above threshold values. There is a need to develop management practices in multiple-sire herds to maximise calf output of all mated bulls.

4.6 Bull:female ratios

4.6.1 Introduction

At present, there is little scientific information to substantiate recommendations on bull selection and mating practices for extensively-managed *Bos indicus* cattle. Bull:female mating ratios average 4.3% in tropical Australia[37]; bulls achieve an estimated average of only one conception/week during the peak mating period. Bull cost per calf when using $1,500 bulls is less than $10 when annual calf output is high (30+), but over $100 when calf output is low (<3).

Using fewer bulls (without reducing herd fertility) of higher breeding value will accelerate genetic improvement. The estimated annual net financial benefit of this for a typical north Australian beef producer with a 3,000 adult equivalent (AE) herd is ~$5/AE. Our research examined the hypothesis that conception pattern in extensive herds will be delayed when using reproductively-sound bulls if the bull:female mating ratio is reduced to 2.5%.

4.6.2 Materials and methods

Location
Kamilaroi. The principle study was carried out on Kamilaroi Station (140^{O} 2'E, 19^{O} 25'S) in the dry tropics of north Queensland's 'gulf country'. Two paddocks were used (Figure 9.): Whitewood (60 km^2) and Smithdale (84 km^2). The topography is flat with low-fertility, black, clay soils. Trees grow on a little over half of each paddock; an open plain covers the south-central area of Whitewood and the north-central area of Smithdale. Average annual rainfall over the study period was 375 mm with most falling between late December and March.

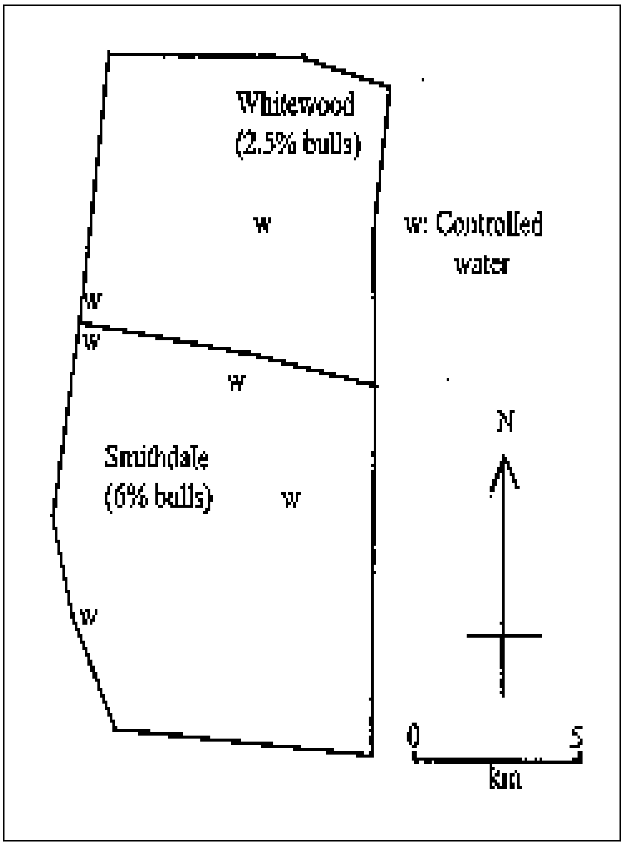

Figure 9. Kamilaroi project site

Swan's Lagoon. Sandalwood paddock (22 km^2; Figure 7) was used on Swan's Lagoon Beef Cattle Research Station (20^o 05'S, 147^o 14'E) in the subcoastal black spear grass region of north Queensland. The vegetation is open eucalypt savanna woodland with a native unimproved pasture. Low-fertility duplex soils predominate in this relatively flat paddock. The 1994-95 period was a very poor season with the first wet season rainfall in late December and total annual rainfall was 350 mm. The subsequent 2 years were good seasons with early wet season starts (August and November) and close to average total rainfall (860 mm).

Santa Gertrudis herds. Data from 4 herds located in southern and central Queensland were used in the study *viz.* Gyranda, Marrett, Ravensbourne and Birra Birra. Paddocks ranged from 160 to 1460 ha.. Seasonal conditions over the years of study (1992/93 to 1995/96) were generally poor.

Animals and management

Kamilaroi. The cattle used were all Brahmans. The 50 available No.92 (ie born between July 1991 and June 1992) and No.93 Brahman bulls used were bred 1,000 km to the east of Kamilaroi and trucked in immediately prior to the study. Bulls were vaccinated against botulism and campylobacteriosis. The available bulls were divided into two equivalent groups based on weight and reproductive soundness. One bull in the first group was removed because of very poor temperament leaving 24 bulls for a 6% bulls:females group, representing usual heifer mating practice for the station (Smithdale paddock). Ten bulls rated as having the best reproductive soundness were selected (% normal sperm not used) from the second group of bulls for a 2.5% bulls:females group (Whitewood paddock).

Mating was for 3.5 and 4.5 months in 1994/95 and 1995/96 respectively, commencing in mid- and early December, respectively. Numbers were managed so that 300-350 females were expected to cycle within the mating period in both paddocks in both years. In 1994/95, 2 groups of 411 heifers (2 years old, 245-390 kg, 80%<300 kg) were mated. Those conceiving within the first 3 months of mating were retained for 1995/96 when a further 350 heifers were added to each paddock.

Swan's Lagoon. The cattle were a composite 5/8 Brahman x 3/8 Beef Shorthorn bred on the station. Mating was continuous with two annual musters in April/May and August/September. Average annual weaning rate was 85%. Vaccinations included campylobacteriosis (bulls), the clostridial diseases, and leptospirosis. An average of 325 breeding females were present during the peak mating season (February-March) each year. In 1993/94, 14 No.88-92 bulls were used (4.4% bull:female ratio). For 1994/95 and 1995/96, 4 No.91 bulls replaced 6 older bulls (12 No.89-92 bulls: 3.6% bull:female ratio).

Santa Gertrudis herds. Most bulls used were 2 years of age, the balance being 3- and 4-year-olds. All herds were seasonally mated for between 3 and 6 months.

Measurements: Females
At Kamilaroi, pregnancy diagnosis was used to estimate day of conception for each cow. In May 1996, body condition and lactation status were recorded; weigh scales were unavailable. Only No.94 heifers had individual identification. Date of conception was estimated from twice-yearly pregnancy diagnoses at Swan's Lagoon, and from post-mating pregnancy diagnoses and calving dates for the Santa Gertrudis herds.

Measurements: Physical traits of bulls
At Kamilaroi musters in December 1994 and August 1995 (pre-mating) and in May (post-mating) of each year, measurements were made of weight, body condition, structural soundness, prepuce, navel, penis, testes, semen and serving capacity of each bull. Similar measures were made twice yearly (May and September) at Swan's Lagoon and pre-mating in the Santa Gertrudis herds.

Measurements: Calf output
Blood samples from bulls and calves were used for DNA testing to determine paternity. At Kamilaroi, this was carried out for all No.96 calves (from 1994/95 mating), and the heaviest 250 male and 250 female No.97 calves (corresponding to the earliest 1995/96 conceptions). Paternity of all progeny was estimated at Swan's Lagoon and in the Santa Gertrudis herds. At both Kamilaroi and Swan's Lagoon, monthly conceptions were estimated for each bull; calculations used estimated conception patterns, estimated gestation lengths, calf weights, estimated calf birth weights, and paternity data.

4.6.3 Statistical analyses

For bulls which sired at least 10 calves at each site, differences between conception patterns were tested using survival analyses[13]. For Kamilaroi data, generalised linear models with binomial error structure[12] were fitted to test the effects of pre-mating weight, post-mating condition score, and lactation status on pregnancy rates in May 1996 in separate analyses for No.94 heifers and No.93 cows in Smithdale and Whitewood paddocks.

4.6.4 Results

Physical traits
Kamilaroi. At allocation, bulls were in backward store to store condition (373 kg average). By the end of their first mating, they were in forward condition. Bulls in both groups gained approximately 80 kg in their first year and >100 kg in 1995/96 (visual estimate: scales unavailable).

Cattle nutrition was poorer in Whitewood (2.5% bulls) than in Smithdale (6% bulls). In Whitewood (2.5% bulls), there were only 2 waters, both on the southern side; *cf*, Smithdale where there were 4 waters in the paddock (Figure 9). This resulted in much less pasture in Whitewood within grazing range. This is reflected in the higher body condition scores of Smithdale cattle at the end of mating in May 1996: 7.6 *v* 7.5 for No.94 heifers; 4.7 *v* 4.4 for lactating No.93 cows; 7.4 *v* 7.3 in non-lactating No.93 cows; 7.7 *v* 7.3 in bulls. Estimated pre-weaning growth of Smithdale calves was also 4% higher than of Whitewood calves (average: 0.78 kg/day). Condition and weight of females was not recorded at the end of the 1994/95 mating, however, most heifers were in forward condition.

Swan's Lagoon and Santa Gertrudis herds. At Swan's Lagoon, bulls were structurally-sound and in store to prime condition throughout the study. The growth of the youngest bulls (nearing 3 years in September 1994) increased average bull weight from 594 to 719 kg during the study. Most bulls used in the Santa Gertrudis herds remained in forward store to prime condition.

Bull control

At Kamilaroi, bull control was good but not absolute. One 'Smithdale' bull spent the 1994/95 mating in Whitewood. A stray mature bull also entered Whitewood and it sired 46 calves. In 1995/96, one Whitewood bull absconded at the start of mating. Bull control at the other sites was good.

Conceptions

Kamilaroi. In both years, it appeared that many females conceived in the first 4-6 weeks of mating: ~30% in 1994/95 and ~40% in 1995/96 (Figure 10). Following this period in both years, there was a steady and parallel increase in cumulative pregnancy rates in both paddocks; for heifers this was ~4% per week in 1994/95 and ~1.3% per week in 1995/96. These results are also expressed in pregnancies/bull/week (Table 19).

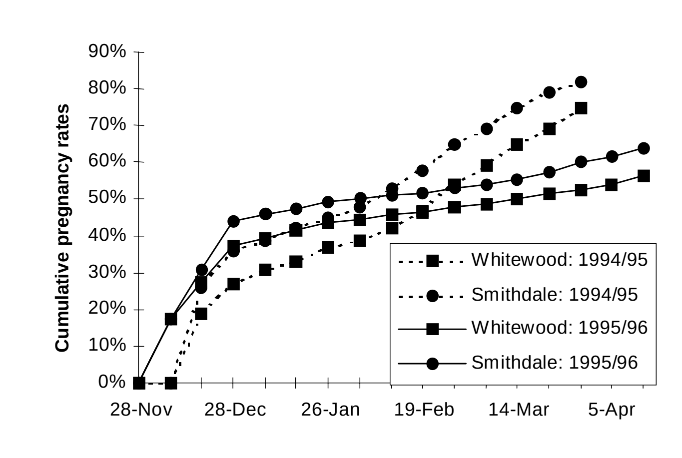

Figure 10. Cumulative pregnancy rates at Kamilaroi

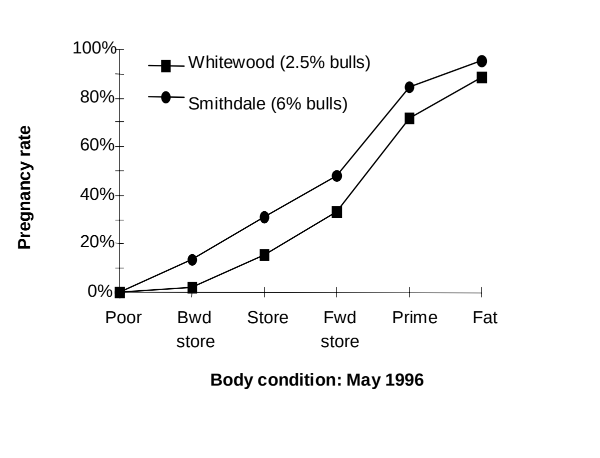

Figure 11. Body condition relationships with pregnancy rates of No.93 cows in May 1996 at Kamilaroi

Table 19. Average pregnancies/bull/week at Kamilaroi

1994/95 mating	First 4 weeks	Next 12 weeks
Smithdale (6% bulls)	1.4	0.8
Whitewood (2.5% bulls)	2.1	1.6
1995/96 mating	First 6 weeks	Next 14 weeks
Smithdale (6% bulls)	1.9	0.4
Whitewood (2.5% bulls)	4.1	1.0

In both 1994/95 and 1995/96, conception rates were 8% and 6% higher, respectively, in Smithdale (6% bulls) than in Whitewood (2.5% bulls). In May 1995, 91% and 83% of Smithdale and Whitewood heifers were pregnant, respectively. Pregnancy rates in Smithdale in May 1996 were higher than in Whitewood for all female classes: 93% *v* 88% in heifers; 89% *v* 79% in non-lactating cows; 25% *v* 9% in lactating cows.

Amongst No.94 heifers, pregnancy rates in May 1996 were unrelated to pre-mating weights except for those <275 kg in Whitewood (2.5% bulls): 84% *v* 90-93% for the 80% of heifers up to 300 kg in both paddocks ($P<0.05$). Within condition score, No.93 cows were 10% more likely to conceive in Smithdale (6% bulls) than in Whitewood (2.5% bulls) in 1995/96 (Figure 11); there was no significant independent effect of lactation status.

Table 20. Calf output distribution of bulls

Site No	Site	Breed	Mating	Padk	Bull: Cycl Fem# (%)	Preg X 0.02 *	No. of bulls at each calf output level: 0-6	7-20	21-34	35-50	>50	No. of bulls at each level of calves/week/bull during peak mating: <1	1-2	3-4	5-6	7-8
1	Marrett	SG	92/93		8.0	1	1	1	1			1	2			
			93/94	RD	12.5	1	2	2				2	2			
				W6	7.5	1	1		1			1	1			
				RE	18.0	1	1	1				2				
				LG	12.5	1		2					2			
				TY	12.0	1	1	1				1	1			
				LW	11.0	1	1	1				1	1			
			95/96	W6	5.0	1	1	1	1			1	2			
				LG	11.0	1	2	2				2	2			
				WW	5.5	1	1		1			1	1			
				E2	8.5	1		3					3			
				RN	6.0	1		1	1				2			
2	Birra Birra	SG	93/94		9.5	1	3	3				1	5			
3	Ravensb	SG	93/94		3.0	1			2				1	1		
			94/95		10.0	1	2	2	1			2	2	1		
4	Gyranda	SG	92/93	Early	6.0	3	3	5	2			2	7	1		
				Late	12.5	2	9	3				9	3			
			93/94	CC	5.0	4	4	5	2	1		4	8			
				PH	9.0	2	4	3	1			4	4			
				LI	8.5	1	2	1	1			3	1			
			95/96	LI	7.0	3	3	3	1	1		3	4	1		
				PH	4.0	2	1	1	1	1		1	2	1		
9	Swan's Lagoon	BX	93/94	SW	4.5	6	3	6	3	2		3	10	1		
			94/95	SW	3.5	6	2	5	4		1	2	9	1		
			95/96	SW	3.5	6	1	6	3	1	1	1	10	1		
11	Kamilaroi	B	94/95	SD	7.0	7	13	8	1		1	11	10	1		1
			95/96	SD	6.0	8	8	12	3			6	11	6		
			94/95	WW	4.0	6	6	1	1	4		5	3	3	1	
			95/96	WW	2.5	7		3	3	3			3	3	3	

Bulls:cycling females ≈ bulls:pregnant females * Equivalent to No. of bulls required if use 2% bull:cycling females B = Brahman, BX = 5/8 Brahman, Sh = Santa Gertrudis

Calf output

Kamilaroi. There were no significant differences between any conception patterns for bulls in both years within Whitewood (2.5% bulls). In Smithdale (6% bulls), only 1% of the bull conception pattern comparisons showed significant differences, and these differences were only marginal. Although total calf output was repeatable (r = 0.62), it varied less in 1995/96 than in 1994/95. In both years, the variation in calf output was lower with a lower percentage of bulls. (Table 20; total variance of 67 *v* 193 in Smithdale and 183 *v* 344 in Whitewood in 1994/95 and 1995/96, respectively).

The 6-8 highest calf producers in each paddock made up 2% bulls:cycling females. These bulls sired 80-90% of the calves in Whitewood (2.5% bulls). In Smithdale (6% bulls), where there was a high ratio of bulls:cycling females, they sired 60% of calves. In both paddocks, the top 6-8 calf-output bulls achieved an average 1-8 pregnancies/week during peak mating (Table 20).

Swan's Lagoon. Calf output was variable (Table 20), but repeatable (r = 0.67). In 1994/95 and 1995/96, there were only 4 significant differences (but of small magnitude) in conception patterns between bull pairings. The top 6 calf getters made up 2% bulls:cycling females. These bulls achieved 80% of the pregnancies and attained an average of 1-4 pregnancies/week during the 3-4 month peak mating period each year (Table 20).

Santa Gertrudis herds. Calf output was variable (Table 20). Repeatability could not be estimated. In all but one of the 22 matings, the equivalent of 2% bulls:cycling females achieved an average of 1-4 calves per week during peak mating; at 18% bulls:cycling females, there was virtually no opportunity for bulls to achieve an average of 1 pregnancy/week in the single mating and no bulls achieved this level. In matings with <10% bulls, 2% bulls sired 50-90% of calves. In matings where at least 4 bulls and at least 10% bulls:cycling females were used, 2% bulls sired as few as 20% of the calves.

4.6.5 Discussion

Our research shows high variability of calf output per bull in multiple-sire herds. Calf output per bull was repeatable between years. Within years, bulls had consistently low or high pregnancy rates. These results suggest that bulls can be selected and managed for high calf output in large, extensively-managed herds. The selection of bulls for high calf output is considered elsewhere (Section 4.5).

Where at least 4 bulls were mated and the bulls:cycling females ratio was <5%, 80% or more of the calves were sired by the equivalent of 2% bulls. However, when the bulls:cycling females ratio was 5-9%, 2% bulls sired as few as 50% and as many as 90% of calves. Within the top 6-8 calf producers at Kamilaroi, almost all achieved at least 3-4 pregnancies/week during peak mating when sufficient cycling females were available, ie in 1995/96 when ~75% of the females that conceived over mating were cycling at the start of mating. As embryonic loss is probably 25-30%[45], there were an estimated 1.5 conceptions per confirmed pregnancy. Therefore, these bulls were impregnating at least 5-6 females/week. This provides some indication of mating potential of Brahman bulls in multiple-sire groups under extensive management. We have no indication of the number of serves required to achieve this.

At Kamilaroi, the comparison of high with low bulls:cycling females ratios was confounded with paddock. Nutrition was generally poor due to poor seasonal conditions, and it appeared that nutrition was poorest in the paddock with 2.5% bulls, and pregnancy rates were lower, as would be expected. It appeared from the conception patterns that fewer than half of the females in each paddock were cycling at the start of mating, with a steady parallel increase in the percentage over the mating period. This strongly suggests that in the first 1-1.5 months of mating in both years at Kamilaroi, bulls in both paddocks impregnated all females cycling at that time and, over the remainder of the mating period, impregnated the constant trickle of females that commenced cycling. If the differences in conception patterns were a function of paddock nutrition, then there was no effect of bull:female ratios on conception patterns. This conclusion is supported by pregnancy frequency data. In both paddocks, bulls achieved a high frequency of pregnancies in the first 4-6 weeks; the frequency then dropped dramatically (Table 19). In 1995/96, the pregnancy frequency in Whitewood (2.5% bulls) during the last 14 weeks of mating dropped to half the level that occurred in Smithdale (6% bulls) in the first 6 weeks.

It appears, therefore, that reducing mating ratios to 2.5% of reproductively-sound bulls:cycling females does not affect conception patterns; 2% bulls achieve most of the conceptions, and the balance of the bulls would potentially cover reproductive failures. Using 2.5% bulls:cycling females appeared adequate even when mating loads were high. It is probable that bulls could achieve higher conception rates, but this requires demonstration.

In all the Santa Gertrudis matings, bull:cycling female ratios were generally very high; ie mating load was low and 2% bulls constituted only 1/4 to 1/2 of the bulls used. As at Swan's Lagoon and in Smithdale paddock in 1994/95 at Kamilaroi, very few bulls achieved an average of more than 2 pregnancies/week. With the respect to mating potential as discussed, this emphasises the opportunity to reduce bull:female mating ratios; even 2% bulls may have been excessive in Smithdale paddock in 1994/95 at Kamilaroi. However, herd dispersion may result in bulls not being able to achieve mating potential. Dispersion is caused by multiple watering points, large herds, large paddocks, high tree density, uneven topography, and weather extremes. We have no evidence that fewer than 2.5% bulls:cycling females would have been sufficient, particularly in large paddocks. Alhough we are confident in extrapolating the recommendation for 2.5% reproductively-sound bulls in most situations, we exercise caution in recommending fewer bulls in large paddocks, or bull:female ratios as low as 2.5% in high dispersion situations until we have supporting evidence on the effects of dispersion on bull mating potential. Behavioural studies are integral to this. For example, our studies used paddocks with only sparsely-located artificial waters.

4.6.6 Conclusions

Mating reproductively-sound bulls at a ratio of 2.5% of cycling females is probably adequate for *Bos indicus* and *Bos indicus* infused cattle mated under most conditions in extensive herds in northern Australia. Further information is needed to determine if this mating ratio is optimal where herd dispersion is very high or low.

5. SUCCESS IN ACHIEVING OBJECTIVES

Objective 1
To improve the selection of bulls with high genetic merit (particularly growth and carcase traits) and calf output by developing management packages based on identifying premating predictors of bull fertility.

DNA typing was pivotal in identifying premating predictors of bull fertility from multiple-sire matings. A resolution rate in excess of 97.5% was possible even when bull groups of up to 34 were used for the paternity analyses.

The studies did identify a number of important traits that should be incorporated into bull examination procedures. These include examining structure of the musculoskeletal system and gait, examination of the prepuce and navel, palpation of the scrotal contents, measurement of testicular tone and scrotal circumference, semen collection, evaluation and morphological examination. Serving capacity testing, although not related to calf output, is a means of identifying serving ability and other clinical problems. Once physical and reproductive traits are above threshold levels, there may be little value in placing an emphasis on selecting for traits such as large scrotal circumference to improve calf output of individual bulls in multiple-sire herds in extensive matings.

There was no one single physical or reproductive trait that was always related to calf output. However the percentage of normal sperm was positively related to calf output in the majority of matings. Bulls with fewer than 50% morphologically-normal spermatozoa at a pre-mating examination usually sired few calves.

The traits measured did not explain all of the deviance for calf output although in 11 of the 17 matings, the traits in the model did explain between 71% and 97% of all the deviance. In many cases, the residual deviance was significant indicating that there were factors other than the traits we measured which were contributing to calf output.

These studies have shown that we may not be able to identify the really high fecund bulls (‘super bulls’) but a systematic physical and reproductive examination will identify a large number of bulls that will be poor contributors to calf output in multiple-sire herds.

Thus, for the above reasons, this project was successful in achieving the first objective.

Objective 2
To make management recommendations on bull selection criteria that will allow producers to reduce bull joining percentage without jeopardising herd fertility.

The main data on bull:female ratios was derived from Kamilaroi Station, north of Cloncurry, where 2.5% and 6% bulls to cycling females were compared. There was also supporting evidence from Swan’s Lagoon and the other Santa Gertrudis herds.

At Kamilaroi, the comparison of high with low bulls:cycling females ratios was confounded with paddock. Nutrition was generally poor due to poor seasonal conditions, and it appeared that nutrition was poorest in the paddock with 2.5% bulls, and pregnancy rates were lower, as would be expected. It appeared from the conception patterns that fewer than half of the females in each paddock were cycling at the start of mating, with a steady parallel increase in the percentage over the mating period. In both paddocks, bulls achieved a high frequency of pregnancies in the first 4-6 weeks; the frequency then dropped dramatically.

It appears, then, that reducing mating ratios to 2.5% of reproductively-sound bulls:cycling females does not affect conception patterns; 2% bulls achieve most of the conceptions, and the balance of the bulls would potentially cover reproductive failures. Using 2.5% bulls:cycling females appeared adequate even when mating loads were high.

Although we are confident in extrapolating the recommendation for 2.5% reproductively-sound bulls in most situations, we exercise caution in recommending fewer bulls in large paddocks, or use of bull:female ratios as low as 2.5% in high dispersion situations until we have supporting evidence on the effects of dispersion on bull mating potential.

Although the data was derived from experiments which did not have replicated treatments, we believe that reducing bull percentages to 2.5% in most situations will not jeopardise herd fertility.

6. INTELLECTUAL PROPERTY

We believe that the project contains information that should be widely used by veterinarians and the beef industry. There is no need to protect the considerable creative effort that has gone into the project. There are no products that are capable of being patented, or products that will lead to the development of trademarks or designs. Copyright of the Final Report should be protected by both Meat Livestock Australia and the Queensland Department of Primary Industries.

7. PROGRESS IN, OR RECOMMENDATIONS FOR, COMMERCIAL EXPLOITATION OF RESULTS OF THE PROJECT

We believe that there is very little commercial (ie financial) gain for MLA or any of the collaborating organisations. The Final Report should be made freely available to any interested person upon request.

8. IMPACT ON THE MEAT AND LIVESTOCK INDUSTRY

The project has created an awareness not only of the accuracy but also the potential managerial problems of DNA typing as a means of paternity identification. Because of the flow-on industry demand, the Veterinary Blood Grouping Laboratory purchased, in 1998, an automated sequencer for DNA typing to improve throughput and turnaround time for parentage and paternity testing of cattle.

The project has identified the value of a thorough physical and reproductive examination as the foundation of a breeding soundness examination. This will provide veterinarians and producers with confidence in the relative importance and impact of various traits on calf output.

The project highlighted that once physical and reproductive traits are above threshold values, there may be little value in placing an emphasis on selecting for traits such as large scrotal circumference to improve calf output. Hence, producers may place more emphasis on production, carcase and meat quality traits to improve the genetic merit of their herd.

Under most conditions in northern Australia, producers can reduce bull joining percentages to 2.5% providing they use bulls that have passed a breeding soundness examination. This represents a considerable saving for producers in that less bulls need to be either bred or purchased as replacements each year. Conversely, producers can purchase less numbers of higher priced bulls of superior genetic merit (particularly growth and carcase traits).

Finally, as this project identified that 2% reproductively-sound bulls achieve most of the conceptions, producers mating bulls at this level have a means of accelerating desired genetics into the extensive herds of northern Australia.

9. TOTAL FUNDING AND MRC CONTRIBUTION

Staff and funding

	FTEs*	Organisations**	MRC	Total
1994/95	1.7	364,650	50,000	414,650
1995/96	1.95	418,275	70,000	488,275
1996/97	1.95	418,275	65,000	483,275
1997/98	2.3	493,350	25,240	518,590
	7.9	1,694,550	210,240	1,904,790

*Shared between QDPI, UQ, JCU, CSIRO, NTOPIF
**Calculated on $55,000 per FTE x 1.3 (on costs) x 3

10. CONCLUSIONS

The following conclusions are for *Bos indicus* and *Bos indicus* derived bulls, adapted to local range conditions and mated in multiple-sire groups in extensive herds in northern Australia.

The conclusions do not apply to bulls prepared for sale or post sale, bulls in AI centres, *Bos taurus* bulls or bulls used in single-sire matings.

10.1 Selection for calf output

- Single-trait selection is dangerous. There was no one single physical or reproductive trait that was always related to calf output. However, the percentage of normal sperm was positively related to calf output in the majority of matings
- Selection on a number of traits does not explain all of the variation in calf output
- A systematic physical examination is the foundation for a breeding soundness examination
- Semen should be routinely examined as part of a breeding soundness examination; determination of the percentage of morphologically-normal sperm should always be part of a semen evaluation.

Physical traits
- Key physical traits were moderately to highly repeatable
- AACV recommendations of values for physical traits remain valid, although thresholds need more accurate definition
- Within the currently-recommended thresholds, there were no consistent relationships between measures of physical traits and calf output
- Mild posty-leg syndrome was not repeatable in young growing bulls.

Semen quality
- Percent live sperm as measured by eosin-nigrosin staining was not repeatable under field conditions
- The motility of semen and spermatozoa were moderately repeatable and correlated with each other
- Neither semen nor sperm motility were consistently related to calf output
- Repeatabilities of semen traits ranged from low to high
- Bulls with fewer than 50% morphologically-normal sperm at a pre-mating examination usually sired few calves
- 93% of the 73 bulls examined had “A” or “B” heparin-binding protein profiles
- There was no relationship between heparin-binding protein profile and calf output.

Behaviour
- Santa Gertrudis, Brahman and Brahman cross bulls can perform in a serving capacity test; however, expression of sexual behaviour in a test was less than that expressed by *Bos taurus* bulls
- Provision of sexual experience to virgin Santa Gertrudis bulls increased their performance in a serving capacity test
- Sexual behaviour in a serving capacity test was not consistently related to calf output, even when measures other than serves are used
- The serving capacity test should be used as a test of serving ability rather than as a predictor of calf output
- Use of restrained females enhances the ability to detect clinical problems.

10.2 Management of bulls to achieve high calf output

Mating percentages
- The paternity of 98% of calves was solved through DNA testing of progeny and bulls
- Calf output varied greatly between bulls and was moderately repeatable between years
- 58% of bulls sired <10% of calves, and 13% of bulls sired >30% of calves within mating groups; 7% of bulls sired no calves
- Physically-sound bulls with above-threshold, semen-quality values were able to impregnate at least 4 females per week
- 2% bulls sired a majority of the calves; a mating ratio of 2.5% bulls:females is likely to be adequate for most situations providing bulls pass a breeding soundness examination. Further information is needed to determine if this mating ratio is optimal where herd dispersion is very high or low.

Behaviour

- Our methods of assessing dominance were variably successful in establishing genuine hierarchy
- At 2 sites where dominance hierarchy was clearly established, dominant bulls sired more calves than subordinate bulls
- 5/8 Brahman bulls demonstrated distinct territorial behaviour as determined by bi-weekly observations.

11. RECOMMENDATIONS

Recommendation 1.

The final report to MLA should be widely distributed. This will be the responsibility of the project team and target groups are:

- Veterinarians. Copies of the Final Report can be distributed through the AACV upon request.

- Extension Officers and consultants throughout northern Australia (50 copies).

Recommendation 2.

The work in the Bull Power project should be subject to peer review. This has been partly done through presentations at the Buiatrics Congress in Sydney in July 1998 and at MLA 'Review of Reproduction and Genetics Projects across northern Australia' in Brisbane in December 1998. As well the group has given a commitment to publish the data in the international scientific literature.

Recommendation 3.

The results need to be explained, particularly the limitations to extrapolation, to veterinarians, producers and breed societies. The results were derived from *Bos indicus* or *Bos indicus* derived bulls adapted to the environment, mated in multiple-sire groups and extensively managed. The study does not relate to bulls prepared for sale, bulls whose semen was collected for processing for AI or for *Bos taurus* bulls.

To date the results have been presented to the technical groups of the Australian Brahman Breeders Association and the Santa Gertrudis Breeders Association (Australia) as well as at several field days for veterinarians and producers. However there is a need to take the results beyond this audience. This requires travel funds to take this work across northern Australia.

Recommendation 4. There are a number of strategies worthy of on-going research.

There is a need:-

(i) to obtain *more precise information on threshold values for physical and reproductive traits.* A threshold value is one above or below which there may be no improvement in fertility or no more risk of bulls being prone to injuries or breakdowns. For instance, the nominal cut-off value for percent normal recommended by the AACV is 70% but this may be reduced to 50% in multiple–sire matings; a certain sheath area is tolerable but selecting for even smaller sheaths may not improve functionality or make a bull less prone to injury.

(ii) for *more understanding in the area of bull behaviour and the underlying causes of sexual stimulation and motivation in bulls*. Future work should lead to fewer bulls working better and to do this there is a need to identify bulls with reliable siring potential and then be able to manage these bulls so that they can achieve this potential. Studies in behaviour in *Bos indicus* and *Bos indicus* cross bulls in northern Australia should focus on establishing mating potential under different situations and quantify the degree to which mating potential is restricted by herd dispersion (different topography, paddock size, herd size, location of waters, climate and weather).

(iii) for greater understanding of *the impact of the environment and relocation on bull management fertility.* There is anecdotal evidence that a significant percent of bulls that pass a breeding soundness examination produce very few progeny in their first year of use. This can be a function of obesity, adaptation to a new environment or use of unadapted bulls in crossbreeding programs.

(iv) to determine the *aetiology of high percentages of abnormal sperm in the ejaculates of bulls.* Is it genetic, environmental or infectious in origin? Also there is a need to *develop recommendations on the management of those bulls*. Should they be culled or should further examinations be conducted?

12. MEDIA COVERAGE

12.1 Media articles

Date	Article	Source
April 1995	Serving capacity predicts bull fertility in northern trials	Beef Improvement News
March 1996	Bull performance and parentage determination	Top Paddock
October 1996	Bulls in multiple-sire mating systems	Talking point
October 1996	Progress in the bull performance and parentage determination trial	Top Paddock
December 1996	Bulls in multiple-sire systems	Northern Muster
March 1997	Unbelieveabull - but true	Country Courier
April 1997	Getting good service from *Bos indicus* bulls	Beef Improvement News
May 1997	Bull fertility analysis reveals startling findings	NAP News Issue 5
June 1997	Less bull for more power	North Qld Register
August 1997	Bull selection and use in northern Australia	Braford Annual
August 1997	Number of traits combine to affect fertility	Queensland Country Life
August 1997	Simple effective findings in bull fertility research	Queensland Country Life
October 1997	Bull fertility analysis reveals startling findings	Brahman News

12.2 Videos and television

October 1997	Bull Power	Cross Country

12.3 Field Days, workshops, schools

Date	Event
January 1996	Boolaroo Station, Clermont. Fertility and Genetic Improvement Workshop. Contribution by BM Burns and RG Miller on 'DNA fingerprinting – What use can it be to cattlemen.'
January 1996	Siemen's Summer School. Contribution by BM Burns on 'DNA fingerprinting – What does it mean?'
July 1996	Woodbine, Wowan. 'Selecting tropical breeds to meet market requirements' Field Day. Contributions by BM Burns, M D'Occhio and RG Miller on 'Are your bulls working' and 'Breeding soundness evaluation of *Bos indicus* infused breeds of cattle'.
July 1996	Rockhampton Showgrounds. 'Selecting Brahmans to improve returns' Field Day. Contributions by BM Burns, M D'Occhio and RG Miller on 'Are your bulls working' and 'Breeding soundness evaluation of *Bos indicus* infused breeds of cattle'.
August 1996	The Peaks, St Lawrence. 'Management and breeding strategies to optimise enterprise efficiency' Field day. Contributions by BM Burns, M D'Occhio and RG Miller on 'Breeding soundness evaluation of bulls' and 'Reproductive performance of individual *Bos indicus* and *Bos indicus* in multiple-sire mated beef herds.

Date	Event
November 1996	Booroondarra, Middlemount. Bull and female evaluation and genetic improvement strategies to optimise herd productivity. Contributions by BM Burns, RG Miller in sessions on 'Are your bulls working' and 'Breeding soundness evaluation of *Bos indicus* infused breeds of cattle'.
December 1996	Marlua, Calliope. Breeding and management strategies to optimise herd productivity. Contributions by BM Burns and RG Miller on bull percentages.
April 1997	Biloela AI Centre. Presentation by JD Bertram to bus tours as part of Beef 97 on 'Bull selection and use in northern Australia
September 1997	Toowoomba Showgrounds. Braford breeders bull selection day. Presentations by JD Bertram.
May 1997	Vet Farm, Pinjarra Hills. Bull examination workshop for veterinarians. Presentations by MR McGowan, JD Bertram and G Fordyce
August 1997	Hughenden Showgrounds. Market Analysis Workshop. Presentation by JD Bertram on bull soundness examination.
August 1997	Gowrie Station, Charleville. Market Analysis Workshop. Presentation by JD Bertram on bull soundness examination.
August 1997	Emerald Showgrounds. Market Analysis Workshop. Presentation by JD Bertram on bull soundness examination.
September 1997	Kamilaroi, Cloncurry. Field day on results from this property. Presentations by G Fordyce, LA Fitzpatrick, N Cooper and RG Holroyd on bull examination of bulls, bull:female ratios and mating practices.
September 1997	Brinard, Julia Creek. Presentation by G Fordyce on results from Kamilaroi.
October 1997	Sugar Bag Station, Mt Garnet. Contributions by RG Holroyd on bull examination of bulls, bull:female ratios and mating practices.
November 1997	Fletcherview Research Station, Charters Towers. Bull selection and management workshop for veterinarians (n = 11) and DPI extension staff (n =9). Presented by G Fordyce, LA Fitzpatrick and R Thompson.
March 1998	Valinor, Biloela. 'Tropical Beef Breeds Assessment' Field day. Contribution by BM Burns and RG Miller on 'Bull selection and use in northern Australia'.
April 1998	AACV Bull examination workshop, Wandoan. Presented by M McGowan, J Bertram and J Cooper.
April 1998	Warren Point Poll Hereford stud, Mitchell. Bull field day. Presented by G Fordyce and JD Bertram.
June 1998	Clermont showgrounds. 'Eating Quality Assurance Awareness' Day. Contribution by BM Burns on 'Reproductive performance of individual *Bos indicus* and *Bos indicus* infused bulls in multiple sire mated beef herds.
June 1998	AACV Bull examination workshop, Camden. Presented by M McGowan and J Bertram
July 1998	Belmont Research Station. BIA bull fertility field day. Presented by G Fordyce and R Miller.
August 1998	Stratford station, Mt Coolon. Bull field day. Presented by G Fordyce.
September 1998	Skye, Alpha. 'Bull management, evaluation and selection' field day. Contribution by RG Miller and BM Burns on 'Breeding Soundness Evaluation' and 'Reproductive performance of bulls in multiple-sire mated herds'.
November 1998	Upson Downs, Eidsvold. 'Bull selection and Brangus' field day. Contribution by BM Burns on 'Breeding Soundness Evaluation' and 'Reproductive performance of bulls in multiple-sire mated herds'.

12.4 Presentations to Producer Discussion Groups and Technical Committees

Date	Event
January 1997	Gyranda, Theodore. MR McGowan and B Joyce to the Santa Gertrudis Association on current findings from the project.
May 1997	Swan's Lagoon G Fordyce to producers from Charters Towers area.
June 1997	Flora Valley, Kimberley region by G Fordyce on current findings from the project
June 1997	Narayan, Munduberra. JD Bertram to the Belmont Red Association on progress with bull selection at Narayan.
July 1997	JD Bertram to the Australian Braford Society on the role of DNAfp in bull selection.
November 1997	RG Holroyd to AACoy Managers at Tropical Beef Centre, Rockhampton on major results of project.
August 1998	RG Holroyd, G Fordyce, R Miller and B Burns to Australian Brahman Breeders Association Technical Committee on project results and conclusions.
August 1998	RG Holroyd to the Santa Gertrudis Association on project results and conclusions.
October 1998	QBII technology exchange workshop, Bowen. Presentation of results by G Fordyce and RG Holroyd.
December 1998	University of Queensland, Spermatology workshop. Presented by M McGowan and S Johnston.
December 1998	NAP3 Review on Reproduction and Genetics. Results presented by project team.

12.5 Presentations to North Queensland Regional Beef Research Committee

August 1996 and November 1996 at Townsville by G Fordyce

13. PUBLICATIONS

13.1 Publications in journals or conference proceedings

Bertram J, Holroyd R, McGowan M and Doogan V. (1996). Modifications to the *Bos taurus* serving capacity test to improve the expression of sexual behaviour in Santa Gertrudis bulls. In 'Feeding and Breeding' Proceedings of 1996 AACV conference, 23-27 September, Toowoomba, pp. 93-96.

Fordyce G and Holroyd RG (1996) Case report: Mating outcome of 2-year old (250 kg) and 3-year old (350 kg) Bos indicus cross bulls following a drought. In 'Feeding and Breeding' Proceedings of 1996 AACV conference, 23-27 September, Toowoomba.

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McGowan M, Holroyd R, Bertram J, Fitzpatrick L, Fordyce G and Miller R (1997). Selection and management of bulls in multiple-sire herds. Proceedings of 10th Federation of Australasian Veterinary Association's Congress. Multifaceted Veterinarian CD ROM, Cairns, August 1997

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Bertram JD, Fordyce G, McGowan MR, Jayawardhana GA, Holroyd RG, Fitzpatrick LA, Doogan VJ and De Faveri J (1998). Bull selection and use in northern Australia. 3. Serving capacity tests. *XX^th World Assoc. Buiatrics Cong* , Sydney 1998, pp 401-5.

Fitzpatrick LA, Fordyce G, McGowan MR, Holroyd RG, Bertram JD, Miller RG, Jayawardhana GA, Doogan VJ and De Faveri J (1998). Bull selection and use in northern Australia 4. Semen traits. *XX^th World Assoc. Buiatrics Cong* , Sydney 1998, pp 407-12.

Fordyce G, Fitzpatrick LA, O'Kane J, Merrin N, Armstrong J and De Faveri J (1998). 5. Bull : female ratios. *XX^th World Assoc. Buiatrics Cong,* Sydney 1998, pp 413-15.

Holroyd RG, Doogan VJ, De Faveri J, Fordyce G, McGowan MR, Bertram JD, Vankan DM, Fitzpatrick LA, Jayahardhana GA and Miller RG. Bull selection and use in northern Australia 6. Calf output and predictors of fertility of bulls in multiple-sire herds. *XX^th World Assoc. Buiatrics Cong* , Sydney 1998, pp 417-22.

13.2 Technical publications

Efficiency of bull reproductive performance. BIAA Technical Report Number 4, November 1995. Summary and recommendations of the Technical Advisory Group Review Committee, pp 12 - 13.

Examination of serving behaviour. In 'The Veterinary Examination of Bulls', (1995), pp. 57 - 59.

Assessment and libido and serving capacity. In 'Bull Selection' by John Bertram and colleagues, (1995), pp. 24-26.

Optimising bull performance, BIAA Technote No.96/1, April 1996.

Fordyce G, Fitzpatrick L, Cooper N and Holroyd R. Bull selection and use in northern Australia (Bull Power). Calf-getting ability in Brahman cross bulls. Swan's Lagoon Beef Cattle Research Station, Research Report 1995, pp. 72 - 75.

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