# Appendix 13 – Impact of improved reproduction in northern Australian cow herds

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***Summary***
Using expert opinion, Breedcow herd models representing ABARES statistical regions across north Australia were constructed and from this an estimated weaning rate of 67% was derived. Beef CRC outputs, especially variations in EBV for age at puberty and PPAI in both Brahmans and tropical composites, coupled with preliminary modelling of potential response rates to selection, suggest that reducing both by approximately 30 days in continuously-mated Brahmans and 14 days in seasonally-mated composites was feasible over a 10-year period. The expected change was a 5% increase in pregnancy rate, except in herds where pregnancy rates are already high. Effects on mortality rates or individual animal values were unpredictable. This change was modelled using Breedcow, along with an increase in replacement bull values of $500-1,000 and a one-third reduction in bull to female mating ratios.

In herds with base pregnancy rates of 80% or more, reliable responses could not be expected as genetic merit is adequate for current management and marketing systems. If the strategy is applied to herds with lower reproductive rates (half the cattle), the average estimated potential effects were to increase: weaning rate by ~4%; bull costs by ~$2/weaner; cattle sales by ~6%; average gross margins per cow and AE by ~$6 and ~$7, respectively. With a $500 bull premium, the gross margins were a further $1-2 higher; ie, overall bull costs did not increase on average. A 33% adoption rate in herds with weaning rates less than 70% is expected to increase annual beef business margins by ~$12-15M per year in north Australia; this extends to a predicted regional annual economic impact of ~$40M, depending on premiums paid for high-fertility bulls.

***Abbreviations and acronyms used***

| | | |
|---|---|---|
| **ABARES** | Australian Bureau of Agricultural and Resource Economics and Sciences | A research bureau within the federal government's Department of Agriculture, Fisheries and Forestry |
| **AE** | Adult equivalent | Unit of grazing capacity; one AE is equivalent to a 454 kg (1,000 pound) steer |
| **Breedcow** | Breedcow | A module within the Breedcow/Dynama beef cattle herd model (Holmes 2009a) |
| **CRC** | Cooperative Research Centre | Collective of scientists from multiple agencies working on a common problem with federal government funding |
| **EBV** | Estimated Breeding Value | Indicates genetic merit for a trait relative to the average at a previous start time |

| | | |
|---|---|---|
| **GM** | Gross margin | Income less variable costs; also referred to as marginal return. Used to show relative benefit. |
| **PPAI** | Post-partum anoestrus interval | Days between when a cow calves and when she next ovulates during lactation |
| **SC** | Scrotal circumference | Measured in cm using a standard procedure (Entwistle and Fordyce 2003) |
| **sd** | Standard deviation | Measure of biological variation; usually 2/3rds and 95% of a population is within 1 and 2 standard deviations of the average, respectively |

***Background***

Holmes (2009b) reported from industry-wide simulation studies that changes in weaning and female mortality rates of 1% resulted in changes in GM/AE of $0.75 and $1.41, respectively. Best (2006) reported that in central Queensland (ABARES zones 332 and northern 322; Figure 1) across a wide range of production systems, each percentage unit change in weaning and female mortality rates caused a change in GM/AE of approximately $2.50 and $5.00, respectively, which is over three times the impact predicted by Holmes (2009b). In a similar approach used by Holmes *et al*. (2011), an analysis prepared for the Beef CRC business case predicted an increase in GM/AE of $2.06 across north Australia for each one percentage unit change in weaning rate (G Fordyce, unpublished, Sep 2003). This estimate was based on no change in overall mortality rates, bull to female mating ratios being reduced by one-third, and cost per bull increasing by $2,000. The major reason for variance in results was the level of profitability attributed to base herds in each study.

Now that reliable information is available from the Beef CRC's Program 4, a new analysis was conducted to more accurately estimate the potential impact of beef producers selecting breeding cattle to increase genetic merit for reproduction.

***Method***

The north Australian breeding herd was described to provide a base for estimating potential for improvement. The primary outputs from Program 4 were collated and from this, the key changes that drive herd and business change were identified. The impact on the main elements of beef production were then described and quantified as required. From this, input change parameters for Breedcow were derived and applied to the Beef CRC templates to calculate potential impacts on northern beef herd gross margins.

***North Australian breeding herds***

It is very difficult to accurately gauge overall breeding herd productivity and efficiency within a region. ABARES data can provide some general indications, but specific levels of many traits are not known. An attempt has been made to develop a broad understanding of north Australia's beef herd structure and productivity using modelling. Holmes *et al*. (2011), as experienced beef business advisers, produced best estimates of typical herd numbers, management and performance within ABARES statistical zones (Figure 1) across north Australia. The data was used within Breedcow (Holmes 2009a) to produce representative models of herd structure and performance (Beef CRC templates), which collectively provide an indication of current north Australian breeder herd performance (Table 1). Best estimates of the national ratio of female to total slaughter and live export numbers (which infers mortality rates) is 46% (Geoffrey Niethe, pers. comm.). It is presumed that the ratio is significantly lower in northern than in southern Australia. As the templates estimate the north Australian ratio at 46% (Table 1), this suggests some inaccuracies. Despite the limitation of inaccurate prediction of absolute values, the templates are considered valid for assessing the impact of change.

The template outputs (Table 1) show the opportunity for genetic change to improve northern beef herd efficiency. There appears to be an opportunity to increase weaning rates by ~10% and halve mortality rates through changes in both genetics and management. The effects of management changes are potentiated by genetic change as breeding females more likely to cycle will respond to better management.

***Beef CRC outputs***

The Beef CRC's Program 4 (and its forerunner CRCII Program 2.3) has used detailed lifetime records from more than 2,000 Brahman and tropical composite (any stabilised cross derived from two or more parent breeds, with tropically-adapted breeds typically constituting 50% of the cross) cows, a similar number of steer siblings, and approximately 4,000 bull progeny to investigate the genetics all major production traits. The focus has been on an earlier start to oestrus cycling, both in heifers reaching puberty and cows after calving. The ability of cows to cycle during lactation and of heifers to reach puberty are seen as major limitations to herd efficiency in north Australia.

The outcome of this work is primarily quantitative genetic parameters (heritabilities and genetic correlations) and gene marker panels (genomics) that can be used to increase the accuracy of breeding values in young animals, especially pre-breeding. Vast amounts of technical information have been and will be published. Some of the key information in relation to cow herd efficiency is:

**Figure 1. North Australia ABARES statistical zones: the area represented comprises all of Queensland and the Northern Territory, plus Western Australia north of 26° latitude (the level of the NT/SA border).**

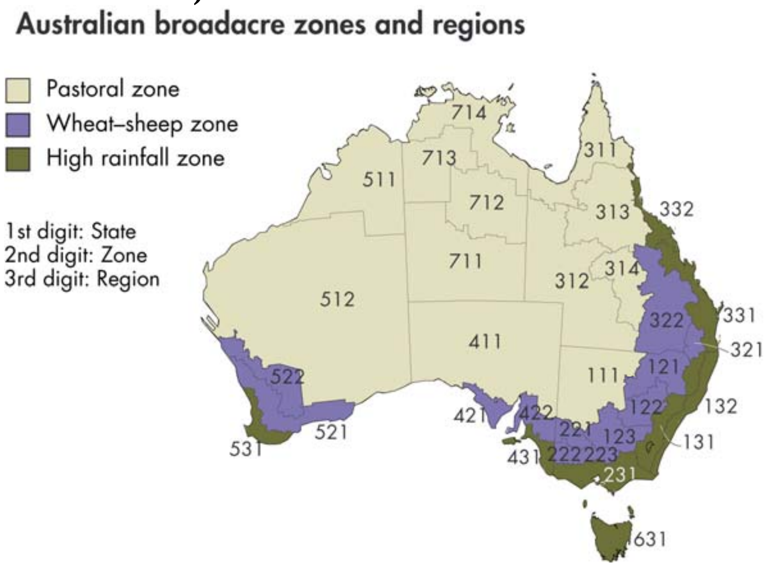

**Table 1. Estimated north Australian herd size and gross margins (Holmes *et al*. 2011) - this data excludes lot-fed cattle**

| *ABARES region* | *Herd AE* | *Cow number* | *Cow AE* | *Female deaths* | *Weaners /Cows mated* | *Female /Total sales* | *Herd GM/AE* | *Cow GM/AE* |
|---|---|---|---|---|---|---|---|---|
| 311a | 43,000 | 31,652 | 34,731 | 8% | 43% | 37% | $52 | $24 |
| 311b | 396,000 | 253,513 | 320,520 | 4% | 59% | 46% | $154 | $98 |
| 312 | 827,000 | 474,479 | 754,371 | 3% | 69% | 48% | $141 | $129 |
| 313a | 80,000 | 58,888 | 64,616 | 8% | 43% | 37% | $60 | $33 |
| 313b | 384,000 | 202,376 | 311,901 | 4% | 58% | 45% | $106 | $77 |
| 313c | 336,000 | 143,989 | 212,749 | 4% | 61% | 48% | $152 | $134 |
| 313d | 206,000 | 96,375 | 128,806 | 5% | 55% | 46% | $116 | $99 |
| 313e | 824,000 | 340,033 | 508,550 | 3% | 69% | 48% | $189 | $173 |
| 314 | 806,000 | 382,526 | 603,911 | 5% | 70% | 47% | $169 | $131 |
| 321 | 448,000 | 225,374 | 347,447 | 6% | 75% | 46% | $285 | $274 |
| 322 | 3,043,000 | 1,330,145 | 2,012,915 | 3% | 77% | 49% | $240 | $213 |
| 331 | 1,065,000 | 603,299 | 960,875 | 3% | 71% | 47% | $132 | $119 |
| 332a | 132,000 | 61,329 | 101,154 | 2% | 73% | 49% | $220 | $219 |
| 332b | 504,000 | 258,139 | 383,427 | 3% | 67% | 48% | $150 | $129 |
| 511a | 140,000 | 103,639 | 119,143 | 11% | 42% | 31% | $73 | $37 |
| 511b | 117,000 | 74,225 | 106,443 | 8% | 58% | 42% | $100 | $74 |
| 512 | 330,000 | 208,559 | 279,452 | 11% | 62% | 38% | $118 | $82 |
| 711 | 208,000 | 115,452 | 166,846 | 3% | 57% | 47% | $92 | $71 |
| 712 | 544,000 | 335,322 | 499,035 | 5% | 58% | 43% | $115 | $90 |
| 713 | 494000 | 304,351 | 451425 | 5% | 56% | 45% | $114 | $81 |
| 714 | 90,000 | 65,425 | 80,991 | 10% | 50% | 35% | $92 | $59 |
| **Total** | **11,017,000** | **5,669,090** | **8,449,308** | **4%** | **67%** | **46%** | **$173** | **$143** |

- Parameters derived from Brahmans and composites are often quite different in magnitude and or sign, especially in relation to reproductive traits where composites have much lower genetic variance.
- Balanced selection for meat quality traits will not result in less efficient breeding cattle, and vice versa.
- Age at puberty was more than 50% heritable with EBVs (Johnston *et al*. 2009) ranging between -100 and +100 days for most bulls; sd was 45 days.
- Faster growing heifers reached puberty earlier; only in Brahmans was earlier puberty related to higher fatness (Johnston *et al*. 2009), and in this breed, there was an indication that unbalanced selection for better temperament may increase age at puberty (Prayaga *et al*. 2009).
- Selection for adaptation traits such as body temperature (moderate heritability) usually has either no adverse or positive effects on production traits (Prayaga *et al*. 2009).
- SC and several sperm traits (motility and normality assessments) are heritable (Corbet *et al*. 2011); selection for any will reduce age at puberty and increase the chances of lactation cyclicity (ability of a cow to commence cycling during lactation), though the relationship may be stronger for sperm traits than it is for SC (unpublished).
- The target of explaining 15% or more of existing genetic variation for most traits using genomics should be reached by early 2012; genomics are breed-specific.
- Heritability of cows rearing a calf after their first mating and re-conceiving during their first lactation is high (unpublished).
- Calving rate (calves/opportunities to calve) has a heritability of 5% and 15% in tropical composites and Brahmans, respectively. In Brahmans, EBVs for most bulls range from -0.1 to +0.1 (unpublished).

- Heavier maiden heifers in better condition (but not with more subcutaneous fat) have higher calving rate (unpublished).
- Low-moderate heritability of into-mating body condition score (unpublished).
- Analyses of calf wastage data, and factors related to calf wastage (eg, teat and udder scores) are pending.

***Potential herd performance impacts of Beef CRC outcomes***

Understanding how earlier cycling in both heifers and rebreeding cows affects herd performance and business requires an understanding of cycling effects on pregnancies, and the effect of pregnancies on a range of other outcomes.

Genetic merit for both age at puberty and PPAI vary by approximately 200 days for a majority of animals within Brahman populations (Unpublished). To reduce herd averages for both age at puberty and PPAI by 30 days is the equivalent of shifting by ~0.6 sd, which is achievable in a practical system if these traits are targeted in bull selection.

Basic modelling shows that in a continuously-mated herd or a herd with mating extending beyond the first major annual weaning, with a weaning rate of 67% (possibly close to the north Australian average – Table 1), ~50% of mature cows and ~25% of first-lactation cows are estimated to cycle during lactation. Without altering mortality rates, if both age at puberty and PPAI are reduced by one month, with this in turn increasing the proportion of mature and first-lactation cows cycling before weaning to 75% and 50%, respectively, then weaning rate is increased by 7% to 74%.

Nutrition is generally higher in areas that are typically populated by tropical composite cattle rather than Brahmans. The variation, and this includes genetic variation, in both age at puberty and PPAI are therefore lower than in areas of poorer nutrition populated mainly by Brahman cattle. Further, the opportunity to improve genetically is lower in composite cattle as they are inherently more fertile; eg, inheritance of lactation cyclicity is lower is composite cattle. Thirdly, the effect of genetic change advancing the time of first oestrus, thus on percentage cycling during mating, is expected to be directly transferred to overall annual pregnancy rates where mating is completed before weaning, eg, with 3–month mating. Finally, lactating cows represent 70% of mated females in typical tropical composite herds. Therefore, applying similar strategies in seasonally-mated tropical composite cattle as in extended-mating Brahmans (as discussed above) to advance cyclicity could increase pregnancy rates due to improved genetics by as much as 4% (25% base change in lactating cow pregnancy rates achievable in continuously-mated Brahmans x 0.5 less variation x 0.5 less opportunity to change x 0.7 cows lactating).

Therefore, the typical impacts on pregnancy rates in tropical composite and Brahman cattle are likely to be similar, ie, reducing time of cyclicity by 0.6 sd can change annual pregnancy rates by 4-7%. It is a fair assumption that changes in pregnancy rates are directly reflected on average changes in weaning rates as there is no evidence yet that pregnancy rate change is correlated with calf wastage change. Because 10% of established pregnancies do not typically result in weaned calves, a 5% change in pregnancy rates will be reflected in a 4.5% change in weaning rates.

A preliminary analysis of the impact of selection based on females rearing a calf after their first mating and re-conceiving during their first lactation showed an achievable annual increase in weaning rate of 0.5% (Stephen Barwick, pers. comm.). Selection on bull semen parameters alone or genomic selection alone can also achieve this rate of change. Combinations of these methods will increase the achievable rate of change. However, including emphasis on other traits will reduce potential rate of change.

Given all the above, we postulate that genetic merit for PPAI and age at puberty could be reduced in typical north Australian herds by 0.5 sd (~1 month in continuously-mated herds and ~2 weeks in controlled-mated herds) over 10 years, with a resultant 5% increase in pregnancy rates.

For the purposes of modelling, this principle was applied to each age group in modelled herds where the opportunity for improvement exists. The guideline used was that no age group (yearlings through to aged cows) within region should be modelled to increase weaning rates (of heifers or cows mated) higher than 80%; if estimated current weaning rates exceeded 80%, those rates remained static. The upper limit of 80% was used as this is considered a high weaning rate.

Increasing weaning rates can achieve other flow-on benefits, which may include:

- Heavier average weaner weight. The overall effect is not expected to be substantial.
- Reduced cow mortalities and lower dry season management costs. This is not only dependent on genetics, but more on changes in management that become more viable with better genetics in herds mated past the first annual weaning round. The management changes include shorter mating periods, and reduced dry season lactations.
- Lower handling costs. This is not expected to be achieved until a business can reduce the number of weaning musters conducted annually. Genetic improvement alone is unlikely to achieve this.
- Increasing sales. This will be the major benefit across all herds, especially an increase in steer sales which is usually the profit centre of northern beef businesses. The potential effect can be calculated using herd models.
- Accelerated genetic improvement with a smaller percentage of available heifers needed as replacements. However the expected effect of this is much lower than that due to using genetically-superior bulls.

***The cost of genetic change***

The method of achieving the change postulated in commercial northern beef herds is through:

- Using bulls with high genetic merit for early age at puberty and low PPAI (days to calving at present).
- Reducing bull to female mating ratios by one third to achieve much more efficient use of bull power.

Bulls of known high genetic merit for early pubertal and post-partum cyclicity and with high mating capacity are very likely to cost more. This is because they are likely to attract premiums and that sellers may impose higher reserves to compensate for their higher production cost. The higher cost will be due to more data and sample collection and analyses, and greater use of artificial breeding. We postulate that the bulls will attract an extra $500-1,000 on average.

One of the principle strategies in implementing the targeted change is selection of bulls that have high values at breeding soundness evaluation. It is now well established that sound bulls can be mated to an average of at least 40 females (Fordyce *et al*. 2002), thus providing producers with the opportunity to do this where prevailing mating ratios were higher.

***Calculation of the potential effect of reducing age at puberty and PPAI***

To calculate the potential impact of Program 4 outputs using Beef CRC Breedcow templates:

- All pregnancy rates inputs for were incremented by 5%, with upper limits of 90% on retained cow weaning rates, and 80% for true weaning rates when incremented. After weaning rates were set, some after-mating sales required some adjustment.
- Bull costs were increased by either $500 or $1,000.
- Mating ratios, thus annual bull replacements were reduced by one third, but not below 2.5% bulls to females unless the level was already lower.
- All other selling and husbandry practices remained the same.
- Though there are other potential production benefits, these are not reliable, and were therefore not included as model input changes.

***Results***

The response in gross margins to improving the genetic merit for reproduction leading to a 5% increase in pregnancy rate in northern herds was highly variable between statistical regions (Table 2). When base weaning rates were 70% (south-east sector of Queensland), reliable responses could not be expected. In regions with lower base weaning rates (5.5M of the 11M AE = 50% of the cattle) and if a $1,000 premium is paid for high-fertility bulls, the median response in marginal returns was ~$7/AE for the herd and ~$6/AE within the breeding herd (Table 2). The response was $1-2/AE higher when the premium for high-fertility bulls was $500. In these regions, the overall benefit of improving reproduction genetics is expected to be $37M annually ($45M if lower bull premiums) with full adoption.

**Table 2. Estimated potential impact of full adoption of the Beef CRC's Program 4 recommendations on north Australian herds - this data excludes lot-fed cattle**

| *ABARES region* | *Impact* | *Bull costs/weaner* | | *Female sales* | | *Male sales* | | *Impact* | *Impact* |
|---|---|---|---|---|---|---|---|---|---|
| | *Wnrs /Cows mated* | *2011* | *Impact* | *2011* | *Impact* | *2011* | *Impact* | *Herd GM/AE* | *Cow GM/AE* |
| 311a | 4.2% | $13.06 | $6.33 | 3,375 | 13.8% | 5,687 | 6.6% | $4.91 | $3.90 |
| 311b | 4.4% | $32.25 | -$3.52 | 60,921 | 6.1% | 70,596 | 4.8% | $11.17 | $10.63 |
| 312 | 4.6% | $34.18 | -$4.51 | 146,137 | 2.2% | 160,543 | 1.8% | $6.69 | $7.09 |
| 313a | 4.2% | $12.62 | $6.50 | 6,280 | 13.7% | 10,581 | 6.6% | $5.33 | $4.45 |
| 313b | 4.5% | $24.26 | -$0.38 | 46,345 | 6.4% | 55,960 | 5.1% | $7.53 | $7.52 |
| 313c | 4.4% | $25.09 | $3.97 | 37,658 | 2.3% | 41,436 | 1.7% | $1.81 | $2.40 |
| 313d | 3.7% | $24.61 | $5.19 | 20,862 | 2.9% | 24,370 | 1.8% | $1.92 | $2.58 |
| 313e | 3.3% | $19.91 | $4.62 | 103,688 | 0.5% | 111,257 | 0.2% | -$0.29 | -$0.53 |
| 314 | 3.7% | $32.17 | -$2.43 | 109,941 | 2.7% | 124,035 | 2.0% | $4.62 | $5.23 |
| 321 | 0.4% | $13.09 | -$0.07 | 70,035 | -0.1% | 81,503 | -0.1% | -$0.43 | -$0.53 |
| 322 | 3.5% | $33.06 | -$1.45 | 468,602 | -0.1% | 490,886 | -0.2% | -$2.93 | -$4.34 |
| 331 | 3.5% | $36.66 | -$0.81 | 187,813 | 4.2% | 208,780 | 3.6% | $5.44 | $5.54 |
| 332a | 3.8% | $17.17 | -$0.84 | 20,501 | 1.6% | 21,764 | 1.4% | $3.60 | $4.70 |
| 332b | 3.7% | $42.16 | -$5.67 | 75,218 | 2.5% | 82,080 | 2.0% | $8.09 | $10.14 |
| 511a | 4.5% | $19.26 | $6.01 | 9,299 | 19.8% | 21,074 | 6.7% | $8.26 | $6.93 |
| 511b | 4.5% | $24.91 | $2.32 | 15,331 | 8.3% | 21,208 | 5.5% | $7.20 | $6.36 |
| 512 | 3.8% | $33.45 | -$3.93 | 38,356 | 8.0% | 61,819 | 4.5% | $9.39 | $9.24 |
| 711 | 0.8% | $37.82 | -$2.63 | 27,836 | 2.4% | 31,544 | 2.3% | $3.38 | $3.63 |
| 712 | 4.5% | $19.17 | $1.44 | 73,665 | 8.5% | 93,901 | 6.5% | $6.45 | $5.28 |
| 713 | 4.3% | $26.01 | -$1.66 | 67,585 | 7.8% | 82,749 | 6.3% | $8.14 | $6.69 |
| 714 | 4.0% | $17.24 | $2.55 | 8,541 | 11.1% | 15,295 | 5.6% | $6.62 | $5.32 |
| **Total** | 3.7% | $29.89 | -$1.03 | 1,597,989 | 2.8% | 1,817,068 | 2.2% | $3.01 | $2.68 |

### *Discussion*

When herd weaning rates are 70% or higher, which is equivalent to pregnancy rates of ~80% or more, genetic merit appears adequate and management has a far greater impact on the ability to improve herd profitability than changing genetic merit for reproduction. In regions with weaning rates lower than 70%, reducing age at puberty and PPAI by 0.5 sd through genetic change is expected to increase business profitability by ~$7-8/AE

The estimate of impact on all north Australian beef business made by assuming application of the target strategy in low-weaning rate herds (50% of cattle) and a 33% rate of adoption is ~$12-15M annually. Total benefits including producer benefit may be of the order of three times the producer benefit (Zhao *et al*. 2000), which suggests that at the nominated adoption rates, the regional economic benefit of Beef CRC Program 4 outputs may be in the order of $40M annually.

### *References*


Best, M. (2006). The economics of beef in central Queensland. Gross margins and production notes. Department of Primary Industries and Fisheries, Queensland.

Corbet, N.J., Burns, B.M, Corbet, D.H., Crisp, J.M., Johnston, D.J., McGowan, M.R., Venus, B.K. and Holroyd, R.G. (2011) Bull traits measured early in life as indicators of herd fertility. *Proceedings of the Association for the Advancement of Animal Breeding and Genetics* **19**:55-58.

Entwistle, K.W. and Fordyce, G. (2003) Evaluating and reporting bull fertility. Australian Association of Cattle Veterinarians, Brisbane.

Fordyce, G., Fitzpatrick, L.A., Cooper, N.J., Doogan, V.J., De Faveri, J., and Holroyd, R.G. (2002). Bull selection and use in northern Australia. 5. Social behaviour and management. *Animal Reproduction Science* **71**, 81-99.

Holmes, W.E. (2009a). Breedcow and Dynama Herd Budgeting Software Package, Version 5.05 for Windows 95, 98, Me, NT, 2000 and XP. Training Series QE99002, Queensland Department of Employment, Economic Development and Innovation, Townsville.

Holmes, W.E. (2009b). Sensitivity calculations on beef CRC representative herds templates, Queensland Department of Employment, Economic Development and Innovation, Townsville.

Holmes,W.E, Bertram, J.D, Best, M, English, B.E, Hamlyn-Hill, F.J, Jackson, D.C, Laing, A.R, Rolfe, J.W, Stirton, A, Sullivan, M.T, Telford, P.B, Leigo, S, MacDonald, N, Oxley, T, Schatz, T, Huey, A.M, Jeffery, M, and Smith, P.C. (2011), *Representative Herds Templates for Northern Australia V2.0 – data files for Breedcow and Dynama herd budgeting software*, Beef CRC, DEEDI (Qld), DAFWA and DoR (NT). http://www.dpi.qld.gov.au/16_6886.htm

Johnston D.J., Barwick, S.A., Corbet, N.J., Fordyce G., Holroyd, R.G., Williams, P.J. and Burrow H.M. (2009). Genetics of heifer puberty in two tropical beef genotypes in northern Australia and associations with heifer- and steer-production traits. *Animal Production Science*, **49**:399-412.

Prayaga, K.C., Corbet, N.J., Johnston D.J., Wolcott, M.L., Fordyce G. and Burrow H.M. (2009). Genetics of adaptive traits in heifers and their relationship to growth, pubertal and carcass traits in two tropical beef cattle genotypes. *Animal Production Science*, **49**:413-425.

Zhao. X., Mullen, J.D., Griffith, G.R., Griffiths, W.E. and Piggott, R.R. (2000). An Equilibrium Displacement Model of the Australian Beef Industry. Economic Research Report No. 4, NSW Agriculture, Armidale.