final report

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Prepared by: L.M. Cafe, W.A. McKiernan, D.L. Robinson and B.J. Walmsley

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Meat & Livestock Australia Limited
Locked Bag 991
NORTH SYDNEY NSW 2059

Additional measurements on muscle line cattle

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Abstract

This project studied the effect of selection for divergent muscling in an Angus cow herd on the performance of the steer progeny and the maternal productivity of the cow herd. Twenty years of selection have resulted in the herd comprising a Low muscle line (D muscle score); a High muscle line (C muscle score); and a Myostatin line (B muscle score) with one copy of a mutation in the *myostatin* gene causing muscle hypertrophy. High steers had the same growth rates, but improved feed efficiency and retail meat yield than Low steers, with no difference in meat quality. High muscled cows had similar calving rates and maternal performance to Low cows on good and poor nutrition. Myostatin steers had similar growth rates, and improved feed efficiency and meat yield to High steers, with no significant differences in meat quality. Myostatin cows had the same calving rates and maternal performance as High cows on moderate to good nutrition but their performance appeared to be reduced after 18 months on poor nutrition. Industry can be confident that moderate increases in muscling in cows will not reduce maternal productivity, but caution should be taken if using a *myostatin* gene to further increase muscling.

Executive Summary

There is growing industry concern that market signals driving enhanced carcase yield of progeny (decreased fatness and/or increased muscling) may have adverse impacts on maternal productivity traits in the cow herd. The value of higher yielding carcases is recognised in the marketplace, with premiums of 14c/kg liveweight for an increase in muscle score class being paid across all market categories (McKiernan 2002). Excessively fat carcases are also discounted between 5-30c/kg carcase weight and in some cases up to 80c/kg. However, industry has shown reluctance to increase cow herd muscularity, and has also become concerned about the impacts of continued selection for increased growth and reduced fatness on maternal productivity traits.

Increased carcase yield offers producers the opportunity to increase the total amount of product from the same number of animals. Increasing the muscularity of the female component of a beef herd enables producers to achieve a rapid rate of improvement in the muscling and yield of resultant progeny. While such an improvement will provide economic returns from the sale of progeny with more meat, it is important to establish the impact that such a change will have on other traits such as feed efficiency, meat quality and maternal productivity.

This project was designed to address these issues using the NSW DPI Angus muscling selection line herd. Twenty years of selection for muscling have resulted in the cow herd comprising a Low muscle line (D muscle score average); a High muscle line (C muscle score average); and a Myostatin line (B muscle score average) with one copy of a mutation in the *myostatin* gene causing muscle hypertrophy. The results confirm the improvement in meat yield with selection for muscling in steers, and address the question of the effect of selection for muscling on feedlot feed efficiency and meat quality in steers. The effect of selection for muscling on maternal productivity is directly evaluated using results for heifer and cow fertility and performance under divergent nutritional conditions.

Major findings include:

- No difference in feedlot growth and finishing weight of steers from the three muscle lines
- Feed intake decreased with increased muscling, leading to an improvement in feed efficiency (Net Feed Intake)
- Dressing %, meat yield, and muscle to bone ratio increased with increased muscling
- Myostatin steers had reduced fatness, but there was little difference between Low and High muscle line steers
- No significant differences in meat quality between the lines
- Myostatin steers had lower muscle pH and lighter meat colour
- No differences in calving rates or female productivity in heifers or cows from the three lines on reasonable or better nutrition

- Calving ease worse in first calf Myostatin heifers than Low or High heifers, but no difference in calving ease between the lines for subsequent calving
- No significant differences in calving rates or weaning weights after 12 months on Low nutrition, but indications that the Myostatin cows on Low nutrition weaned slightly smaller calves
- Significant drop in calving rate in Myostatin cows after 18 months on Low nutrition, but no change for Low or High muscle cows, nor for Myostatin cows on Medium/High nutrition
- Sale value of cull cows and heifers increased with increased muscling

These results provide no evidence of any difference in performance between cows from the High (C muscle average) and Low muscle (D muscle average) lines, nor in the growth rates of their progeny under good, moderate or short term low nutritional conditions. This should put to rest the long held perceptions of poor performance due to higher muscling, at least for moderate increases in muscling. The advantages of the High muscle cows include: improved feed efficiency and increased meat yield in the progeny with no detriment in meat quality resulting in higher value output; the cows' increased value when cast for age; and no accompanying detriment to maternal productivity. This should encourage producers to select for increased muscling in their replacement females.

The High muscle bulls used in this herd were the highest muscled bulls without the *myostatin* deletion which could be sourced from Angus industry herds at the time, and had an average muscle score of B+ (range B to A-). Hence, within the Angus breed at least, producers can safely use the highest muscled bulls currently available to breed replacement heifers without fear of reducing the performance of the breeding herd.

The incorporation of the *myostatin* deletion into the cow herd, on the other hand, should to be treated with care. Whilst there is an advantage in using the gene to further increase the carcase value of the progeny, the heterozygous Myostatin cows (B muscle score average) have shown signs of reduced productivity after 18 months on a low plane of nutrition. Although further data is needed to confirm this result, it may be that the *myostatin* gene is best utilised through terminal sires. If heterozygous *myostatin* females are to be kept for breeding they should be run under more favourable nutritional conditions to maximise their advantage and limit their exposure to nutritional stress.

With the wide range of both muscling and fatness being driven by genotypic and environmental factors, the capture of the changes in cow body composition, resulting fertility and the calf performance on divergent nutrition, the data from this project will form a valuable component in the further development of the Beef CRC Maternal Productivity Model.

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1. Background

This project was set up to add new data and understanding to the current Beef CRC Maternal Productivity Research Project and to Angus BREEDPLAN. Data generated by examination of the three muscle lines will enable the partitioning of the effects of selection for muscling (as opposed to fat) on maternal productivity to achieve overall herd improvement in meat yield, and allow a better understanding of the impact of selection for muscling. More specifically this project assists in quantifying the effects of selection for muscling on cow reproductive performance (pregnancy rates, calving performance and ease plus inter calving interval) using data collected over the past two years in addition to data collected over the previous ten years. The effect of cow weight and condition changes on cow performance, and calf weaning weights as an indicator of cow milk production, have been studied. Heifer performance as a component of maternal productivity has been evaluated through comparisons of pregnancy rates after yearling mating, ease of first calving and rebreeding efficiency.

This project quantifies the extra value of product produced in the progeny from lines selected for increased muscling. Over the past two years, steers from divergent muscle lines (low, moderate and extreme) were studied in depth to determine the cost of production and output value. This included examining feed efficiency during finishing (NFI) and subsequent effects on the carcase, including meat yield and eating quality.

The outcome for industry will be greater confidence in using muscle selection processes to select for carcase composition in combination with female productivity and fertility.

The Beef CRC Maternal Productivity project is currently examining the effects of selection for increased carcase yield due to selection for subcutaneous fatness. Substantial improvement in carcase yield can be achieved by either decreased fatness or increased muscling, each of which has a different effect on body composition, and are likely to have different effects on the cow herd. Thus both of these components need to be examined to fully understand the effects. The current design of the Maternal Productivity project does not include cattle with divergent or extreme muscling, and thus an additional study was required.

This project will enhance the eventual description of breeding herd productivity by combining the outcomes of the current Maternal Productivity project with the addition of data generated by examination of lines divergent for muscling. It is essential to improve our understanding of the separate effects of the components of increased carcase yield on maternal productivity to achieve this goal.

2. Project Objectives

1. Commit and maintain the muscle line cattle for the purpose of collecting reproductive and production data until October 2011

2. Female productivity to be assessed by:
2.1. Inter-calving interval and calving ease (next 2 years data plus last 10 years recorded performance)
2.2. Cow weight change including body compositional changes (bi monthly over the next 2 years – 12 scans). Ultrasound estimates of body composition and stored energy profiles will be made at strategic intervals throughout the production cycle
2.3. Calf growth to weaning including scanning for their body composition assessment.
2.4. Ultrasound scanning of the ovaries of heifers to assess time of puberty followed by calving and rebreeding performance (also utilising last 10 years data).
2.5. Examination of the salvage value of cast for age cows and cull heifers

3. Productivity of the steer progeny to be assessed by:
3.1. Two years steer progeny (2008 and 2009 drop calves used in 2010 and 2011) will be grown to feedlot entry weight at Glen Innes and then sent to Tullimba feedlot for finishing and testing for feed efficiency.
3.2. Following finishing steers will be slaughtered and carcase data will be collected on the kill floor and in the chiller (MSA graded).
3.3. Meat yield will be assessed following commercial boning.

4. Investigate apparent differences in meat quality between the lines. In particular clarify the mechanisms by which the myostatin gene impacts on eating quality. This will be achieved by sampling muscles which vary in connective tissue and ageing rate. Over 2 years a resource of high muscling cattle comprising 40 steers carrying the myostatin gene and 40 without the myostatin gene will be slaughtered (or possibly split the total number of animals across the 3 different groups). Samples from low and high connective tissue muscles which differ in ageing rate will be collected at slaughter for sensory and objective meat quality assessment.

5. Results generated from this project analysed and published in a reputable scientific journal

6. This project and analysis of the data generated will form an integral component of the Beef CRC Maternal Productivity Project and as such the data and analysis will be freely available to the Beef CRC for inclusion and combined analysis if so desired. The data will also, for the relevant traits, be included in the Angus BREEDPLAN dataset.

3. Methodology

3.1 Herd description

The muscling herd was originally established by NSW DPI in 1992 at its Menangle Research Station near Sydney. The herd began with pure unselected Hereford cows and heifers being mated to high and low muscled Angus bulls. In 1997, the project was continued with females produced in the earlier matings being selected by visual muscle score into Low and High muscle lines. These lines have been mated to low and high muscled Angus bulls sourced from industry since. In 2005, following the segregation of a *myostatin* mutation (nt821 del11, Grobet et al. 1997) in the High line, a third selection line of females carrying one copy of the *myostatin* mutation was established (Myostatin line). High muscled progeny are allocated to either the High or Myostatin line based on their *myostatin* genotype.

The current design is for low muscle bulls (D muscle score average) to be mated to Low cows and heifers; high muscle bulls (B+ muscle score average) without the *myostatin* deletion mated to Myostatin cows and heifers, and High heifers; and Myostatin bulls (A muscle score average) carrying one copy of the *myostatin* mutation mated to High cows without the *myostatin* mutation. This strategy prevents the generation of animals homozygous for the mutation, which are less functional and are undesirable.

The herd was based at Menangle from its inception until March 2004, when due to severe drought conditions, it was transferred to Grafton Primary Industries Institute. In December 2004 the herd was further relocated to Glen Innes Research Station, where the temperate pastures provided the highest level of nutrition the herd had experienced. In May 2010 it was moved back to Grafton where divergent nutritional treatments can effectively be imposed. These moves have resulted in changes in management to suit the local conditions. For example, whilst located at Glen Innes, replacement heifers were well grown enough to mate as yearlings, which was not the case at Grafton or Menangle.

3.2 Data collection methodology

3.2.1 Breeding herd management

The cows were single-sire mated naturally in Spring/Summer, to calve in Spring the following year. Calves were weighed and tagged at birth, and their birth date, sex, dam, and need for birth assistance recorded. All calves were bled to determine *myostatin* genotype testing prior to weaning. Weaning was carried out in late April to early May, and the weaners were weighed, ultrasound scanned for body composition and muscle scored at this time. These measurements were repeated on any yearlings which remained a part of the herd at that age. Cows were permitted to remain in the herd if they didn't calve for one year, but were culled if they did not calve the following year. Heifers were mated as yearlings where postweaning growth permitted (Glen Innes), otherwise they were mated at two years of age (Grafton and

Menangle). Cows were culled for age at 10 to 11 years of age. The reason for all culling was recorded.

Bulls were used for 2-3 seasons, and were mated to small groups of cows (15-40) to ensure a reasonable number of sires were represented each year. The herd was run as a commercial beef herd in terms of the required treatments for parasites and disease to suit the location.

3.2.2 Cow body composition and nutritional treatments

In April 2010 the cow herd was moved to Grafton Primary Industries Institute and allocated to Low or Medium/High pasture-based nutrition. The nutritional treatments were driven by differences in soil type and fertility, and the amount of pasture improvement. The Low nutritional treatment was based on native and poor naturalised perennial grass species (ie capret grass, blady grass, and bahia grass), on unfertilised duplex soils. The yield and quality of these pastures is generally low, with digestibility generally less than 63% and protein less than 6%. The Medium/High nutritional treatment was composed of improved perennial species (ie kikyuyu, rhodes and setaria grasses, with some carpet and bahia grasses, and a small component of white clover) on heavy and red alluvial soils. The yield and quality of these pastures is generally moderate with digestibility of 60-70% and protein of 6-9%. High quality ryegrass pasture also formed part of the Medium/High treatment in late winter/early spring when conditions allowed. These treatments were located on opposite sides of the same research station, so that other environmental conditions were the same.

The 2010 Summer was challenging, with high buffalo fly numbers and many cows succumbing to three day sickness. Major flooding during this period also reduced pasture production and availability until Spring 2011. This resulted in the need to supplement 40 cows from Low nutrition in late Winter 2011 to prevent poor welfare due to low body condition. Supplementation consisted of cottonseed meal and molasses, and some hay and ryegrass pasture for several weeks until the cows gained sufficient condition to be returned to their Low nutritional treatments.

The cows were weighed, ultrasound scanned for body composition and muscle scored on nine occasions between March 2010 and October 2011. All ultrasound scans were conducted by an accredited scanner using a 3.5 MHz/180-mm linear array animal science probe (Esoate Pie Medical, Maastricht, Netherlands). Muscle scoring was conducted by one experienced assessor until May 2011, who then trained a new assessor to carry on from that point. The 15 point, E- to A+ muscle scoring system was used (McKiernan 2007).

3.2.3 Steers

The entire cohort of steers born in 2008 and 2009 were grown out on temperate pasture at Glen Innes Research station prior to entering ‘Tullimba’ feedlot for grain finishing at 16-18 months of age. Following a period of adaptation to the grain diet, the steers were allocated to individual intake pens in groups of 10-11. Individual intakes were measured for a period of 70-80 days to allow feed efficiency to be calculated (Arthur et al. 2001). Eleven steers from the 2008 cohort and nine from the 2009 cohort refused to eat in the individual feeders and were returned to the open bunks for finishing.

After 110-120 days on grain the steers were trucked to the Nothern Co-Operative Meat Company, Casino NSW (2010) or John Dee, Warwick Qld (2011) abattoirs for slaughter. Following commercial carcase preparation all carcases were MSA graded, and a commercial yield test was conducted on one side of each carcase during boneout.

Primals from 10 Low, 10 High and 20 Myostatin line steers were selected to be used for meat quality analysis in both years (80 steers in total). The striploin (STR045), oyster blade (OYS036) and topside (TOP073) were used for sensory testing, and the striploin and oyster blade for objective testing. Three ageing times were used overall: 7, 28 and 49 days in 2010 (all with objective and sensory measurements), and 7 (obj and sens) and 28 (obj) days in 2011.

Objective meat quality was conducted by the Meat Science Department of the University of New England following the methods described by Perry et al. (2001). Measurements included shear force, compression, colour, and pH in both years, and intramuscular fat and collagen in 2011.Sensory meat quality testing was conducted by Sensory Solutions following the protocols described by Watson et al. (2008) and Anon. (2008).

3.3 Statistical analyses

Statistical analyses were conducted by fitting Linear Mixed Models using the REML methodology (Robinson, 1987) in Genstat V11 (VSN International Ltd, Hemel Hempstead, UK). Models varied with data type, and included:

Calf and maternal performance models: Fixed effects of muscle line of dam or calf, (nutrition and muscle line x nutrition for 2010/2011 data); Random terms: calf sex, calf sire, year, dam previous lactation status; Covariate: calf or dam genotype.

Steer feedlot performance and carcase models: Fixed effect of steer muscle line, year, muscle line x year; Random terms: year x pen/kill replicate. Fixed effects of cut, ageing period and their interactions with each other and muscle line, and a random term of sample position were also included for the meat quality analyses.

Statistical significance was accepted at $P<0.05$, and a tendency at $P<0.1$. In the results tables, means followed by different letters denote significant differences ($P <0.05$).

4. Results and Discussion

4.1 Final progress report. Objective 1. Commit and maintain the muscle line cattle for the purpose of collecting reproductive and production data until October 2011

Final progress report (Objective 1) provided in Appendix 1.

4.2. Objective 2. Female productivity

4.2.1. Calving and weaning success

Calving data collected from 1998 to 2009 were analysed to assess the female productivity of the Low muscle, High muscle and Myostatin cows in reasonable to good nutritional circumstances. Heifers giving birth to their first calves were analysed separately to those giving birth to their second and subsequent calves. As expected, significant effects due to year and sire were observed for many productivity and fertility traits.

The differences in female productivity traits of the muscle lines are presented in Table 1. Myostatin cows produced calves which were 1.6-1.8 kg lighter than Low or High muscle cows, but they also had slightly higher calving ease values, denoting increased calving difficulty. The calving ease differences were small, but indicate that the Myostatin cows were assisted at birth slightly more often than the other lines, although this did not affect calf mortality (no difference in calf fate). The mature cows in the herd rarely required assistance at birth, as indicated by the low calving ease values.

Table 1. Predicted means for female productivity traits for cows giving birth to their second and subsequent calves.

	Low muscle	High muscle	Myostatin	sed	P
n records	844	852	183		
Birth weight	35.3b	35.5b	33.7a	0.77	0.027
Days to calving[1]	315	309	307	5.2	0.4
Calf wean weight	245	247	245	3.7	0.8
Calving ease[2]	1.03a	1.01a	1.06b	0.015	0.016
Calf fate[3]	1.01	1.01	1.02	0.009	0.5
Inter-calving interval (d)	450	449	451	5.6	0.9

1. Days from bull in to calf birth; 2. Angus calving ease (1= no assistance, 2 = easy pull, 3 = hard pull, 4 = surgical intervention, 5 = abnormal presentation); 3. Angus calf fate; 1= born alive, 2 = born dead

There were no differences due to muscle line in days to calving, or inter-calving interval, indicating that there was no difference in fertility of the lines when run on reasonable nutrition.

To maintain numbers, the cows in the herd were permitted to miss producing a calf for one year, but were culled if they didn't calve the following year. The calving interval includes these data, which is why it is around 3 months longer than the 12 month calving cycle. The absence of a difference due to muscle line indicates that a similar proportion of cows in each line have the occasional dry year.

Results for first calf heifers were analysed separately and are presented in Table 2. Data included eight years in which heifers were first mated as two year olds, and four years in which heifers were first mated as yearlings. The only female productivity trait which differed between heifers from the different muscle lines was calving ease. The Myostatin heifers had the worst calving ease, High heifers the best, and Low muscle heifers were intermediate. Across all muscle lines the heifers required more assistance at birth than the cows, as would be expected.

Table 2. Predicted means for female productivity traits for heifers giving birth to their first calf.

	Low muscle	High muscle	Myostatin	Sed	P
n	172	174	78		
Birth weight	33.8	33.2	32.6	0.87	0.7
Days to calving[1]	323	316	311	7.5	0.5
Calf weaning weight	214	220	221	6.7	0.4
Calving ease[2]	1.36ab	1.22a	1.55b	0.109	0.01
Calf fate[3]	1.02	1.05	1.03	0.032	0.6

1. Days from bull in to calf birth; 2. Angus calving ease (1= no assistance, 2 = easy pull, 3 = hard pull, 4 = surgical intervention, 5 = abnormal presentation); 3. Angus calf fate; 1= born alive, 2 = born dead

Although the differences didn't reach significance, it is interesting to note that in both heifers and mature cows the Low muscle cows tended to have the longest days to calving, the Myostatin cows the shortest, and the High muscle cows intermediate. With the differences of 8 to 12 days between the extremes, this will be a trait to observe as more data is collected into the future.

The age of first mating/calving had an effect on female productivity traits (Table 2), but data from both ages were pooled for first-calf heifer results because there were no interactions with muscle line. Conducting the first mating of the heifers as yearlings resulted in increased days to calving, and lower calf birth and weaning weights than first mating as two year olds. The increase in calving ease in the yearling-mated heifers did not quite reach significance, but there is an indication that the younger heifers required more assistance at calving. This did not result in increased calf mortality.

Table 3. Female productivity traits for heifers mated as yearlings or at two years of age for their first calving.

	Yearling	2 YO	sed	P
n	167	257		
Calf birth weight	32.3a	34.1b	0.91	0.026
Days to calving	327b	306a	5.6	<0.001
Calf weaning weight	207a	229b	7.7	<0.001
Calving ease	1.45	1.30	0.103	0.1
Calf fate	1.03	1.04	0.027	0.6

4.2.2. Cow weight and body compositional changes with divergent nutrition

The changes in cow liveweight and body composition were measured on nine occasions over 19 months as the cow herd treatments changed from grazing good nutrition, to a split across Medium/High or Low nutritional treatments. The changes in weight and composition throughout the first production cycle, from weaning of the 2009 calf to before the birth of the 2010 calf are shown in Figures 1 and 2 for cows which produced a calf in 2010.

The greatest change in weight and composition was from May to October 2010, when the cows calved and utilised their body reserves. The cows on Low nutrition utilised a greater proportion of their body reserves than those on Medium/High nutrition, but the muscling lines behaved remarkably similarly. The change in weight and body composition for the three muscling lines on Low nutrition during this period are shown in Table 4.

Table 4. Details of the liveweight loss and the composition of the loss for cows on Low nutrition from May to October 2010.

Trait and units	Low muscle	High muscle	Myostatin
Liveweight lost			
kg	128	133	128
%	23	23	22
kg/month	25.6	26.6	25.8
Rump fat lost			
mm	12.9	11.5	8.1
%	84	86	87
mm/month	2.6	2.7	1.6
EMA lost			
cm^2	24	27	36
%	44	43	51
cm^2/month	4.6	5.4	7.2
Muscle score lost			
units[1]	2.1	3.5	4.9
%	41	38	42
units/month	0.4	0.7	1.0

[1] Using 15 point muscle score scale

During this period of rapid change, the cows from the three muscle lines lost the same amount of weight (about 130 kg), and the same percentage of their liveweight. The three lines lost a similar proportion of their initial fat and muscle, but the composition of the loss was related to initial body composition. The Low muscle cows had the most fat and least muscle in May, and they had lost the greatest depth of fat and the smallest amount of muscle by October. The Myostatin cows were the opposite. It was apparent that the cows used the tissue that they had stored and available for use. The Myostatin cows were beginning to show a higher percentage of muscle loss than the other two lines by October, presumably because they had more muscle available to use by this stage.

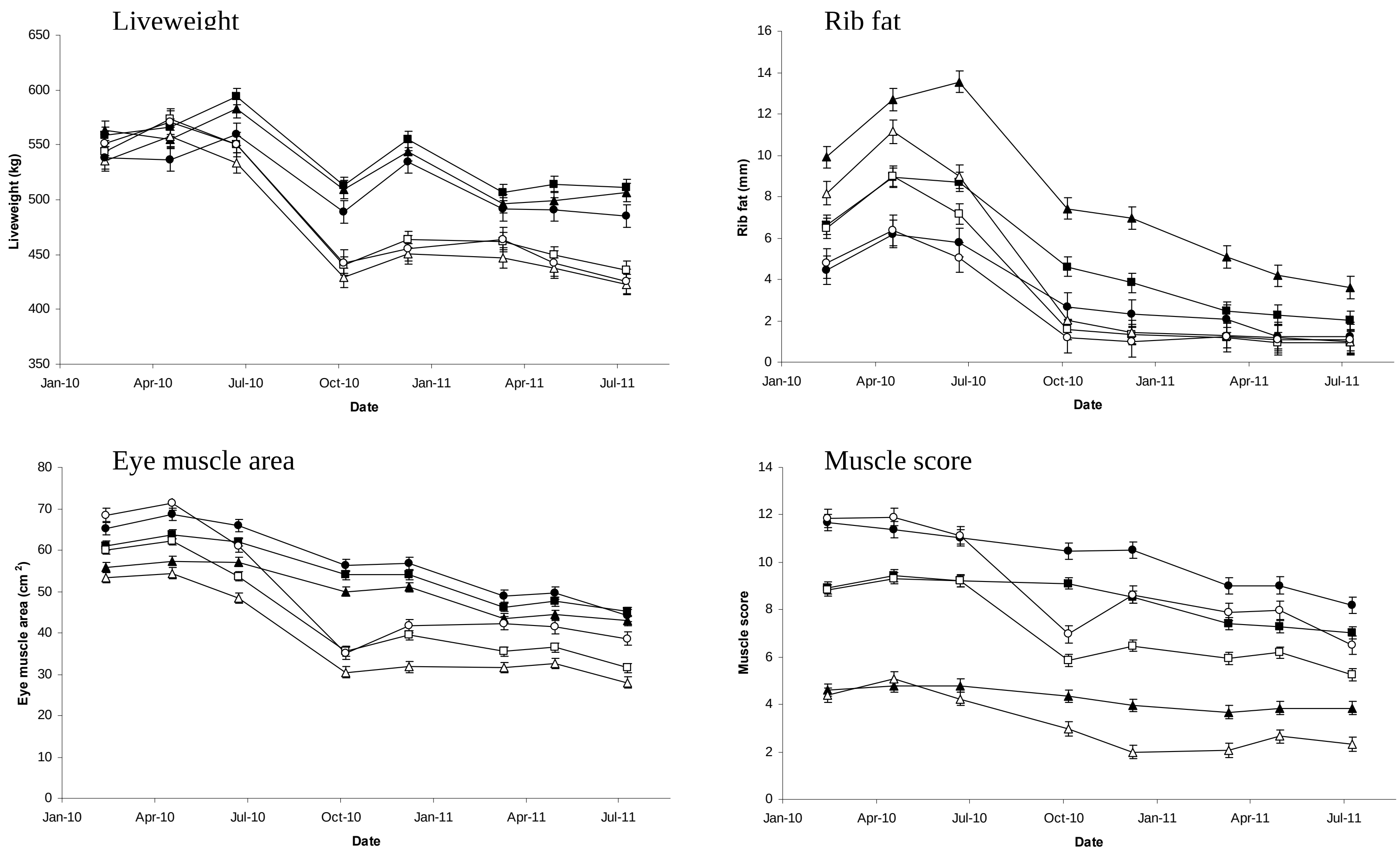

Figure 1. Change in liveweight, rib fat, eye muscle area and muscle score for cows from the High (■), Myostatin (●) and Low (▲) muscling lines on High (closed symbols) and Low (open symbols) nutrition over one production cycle. Error bars are se.

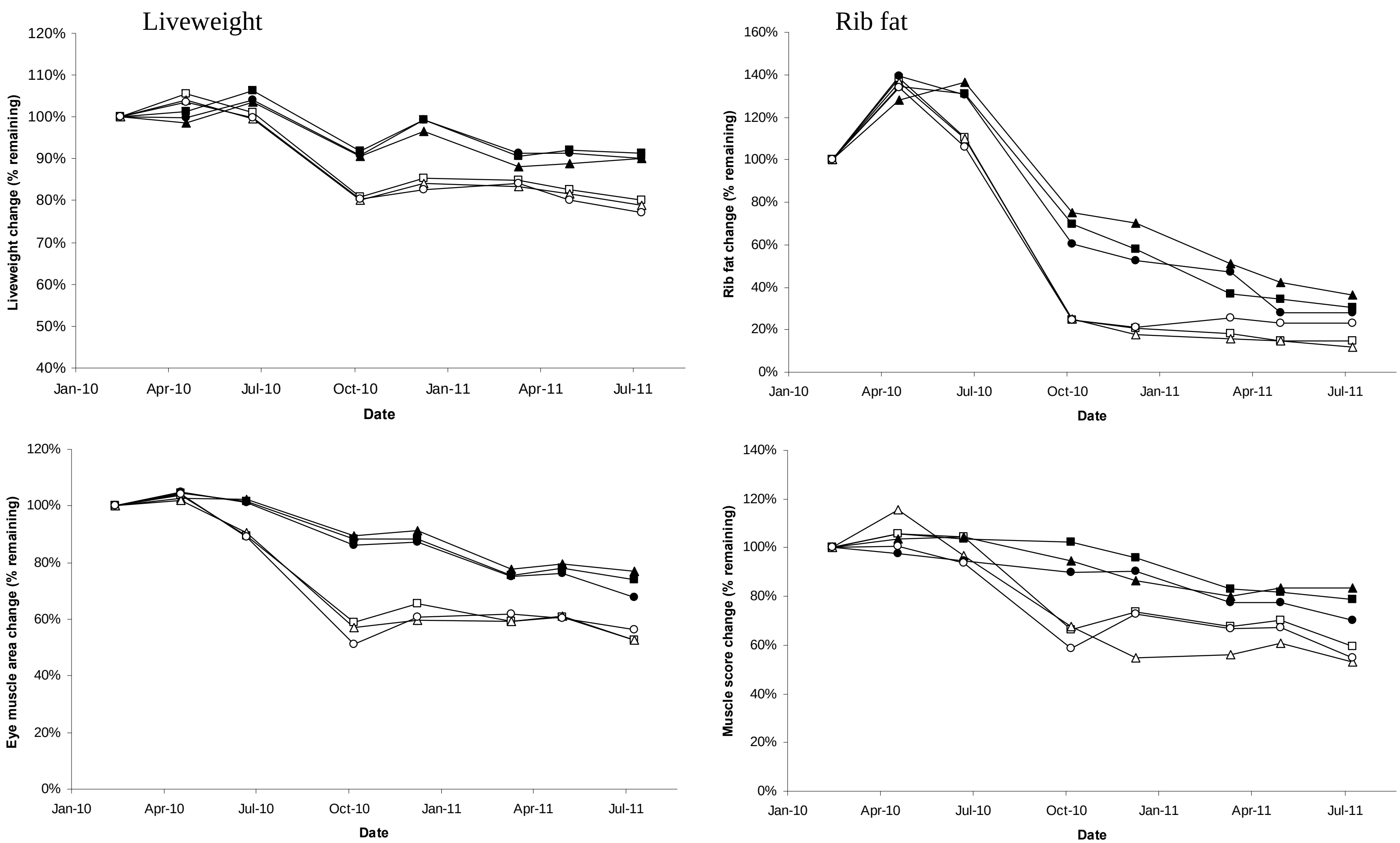

Figure 2. Change in liveweight, rib fat, eye muscle area and muscle score as a percentage remaining of original component for cows from the High (■), Myostatin (●) and Low (▲) muscling lines on High (closed symbols) and Low (open symbols) nutrition over one production cycle.

Table 5 provides a clear snapshot of the differences in weight and body composition of the lactating cow herd as influenced by both muscling line and nutritional treatment at weaning of the 2010 calf in May 2011. After 12 months on divergent nutrition, cow weight and body composition were all significantly (P<0.001) affected by nutritional treatment, and the muscling line effect was significant for all traits except for liveweight, where there was a weak trend (P=0.096) for the High muscle cows to be slightly heavier than the Low muscle or Myostatin cows. The only significant interactions (P<0.05) between muscle line and nutrition were for scanned rump and rib fat, where the usual reduction in fatness with increasing muscle was not obvious on the Low nutritional treatment as the cows had utilised all available fat stores.

Table 5. Weight and body composition of lactating cows at weaning of the 2010 calves in May 2011.

	n	Weight (kg)	P8 Fat (mm)	Rib Fat (mm)	EMA (cm^2)	MSc (1-15)
Low nutrition						
Low muscle	29	437	1.4a	1.2a	32.6	2.7
High muscle	42	455	1.5a	1.2a	37.7	6.3
Myostatin	25	443	2.0a	1.6ab	44.7	7.9
Medium/high nutrition						
Low muscle	34	499	5.0c	4.0c	44.2	3.9
High muscle	46	510	3.3b	2.4b	47.6	7.3
Myostatin	29	494	2.3ab	2.0ab	52.5	9.0
Muscle line P		0.097	0.028	0.004	<0.001	<0.001
Nutrition P		<0.001	<0.001	<0.001	<0.001	<0.001
Muscle x Nutrition P		0.8	0.002	<0.001	0.3	0.9

abc Letters denote means which are significantly different for the interaction between muscle line and nutrition

The stored body energy components for the three lines of cows were modelled at three time points when the foetal component of the cows' liveweight was expected to be small, and as the nutritional treatments drove major changes in liveweight and body composition. Average liveweight, ultrasound scanned rib fat, and hip height (frame score) were used to estimate body energy reserves using the Meat Animal Research Centre (MARC) body composition model that is used to drive BeefSpecs. Low muscled cows had larger total energy stores when they were able to lay down fat on better nutrition (Figure 3). The differences in muscling drove small differences in stored body energy when most fat had been utilised. When these results are presented as a proportion of the initial body stores remaining (Figure 4), it is clear that fat was the major body component being used during this period of liveweight loss, and that the muscle lines were behaving similarly. The significant utilisation of muscle observed in the cows (around 60% for both visual muscling and scanned EMA) is not transferring into such a large loss in total body protein as only approximately 50% of the body's protein is muscle (Haecker 1920, Moulton et al. 1922), with the remainder being tied up in less mobile depots such as the skeleton and body organs.

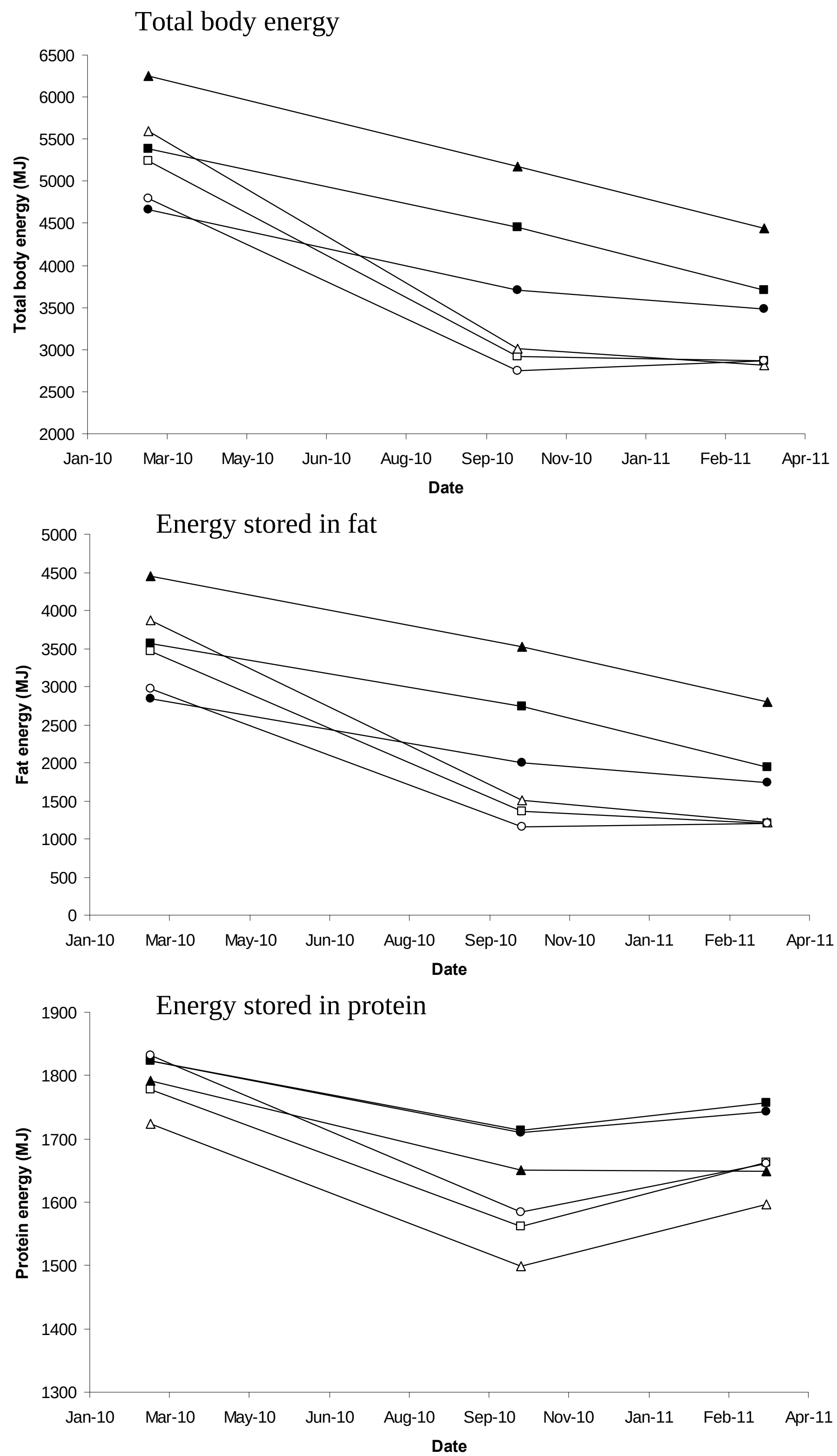

Figure 3. The changes in total stored body energy, and energy stored as fat and protein in cows from the High (■), Myostatin (●) and Low (▲) muscling lines on High (closed symbols) and Low (open symbols) nutrition with changes in body composition during weight loss.

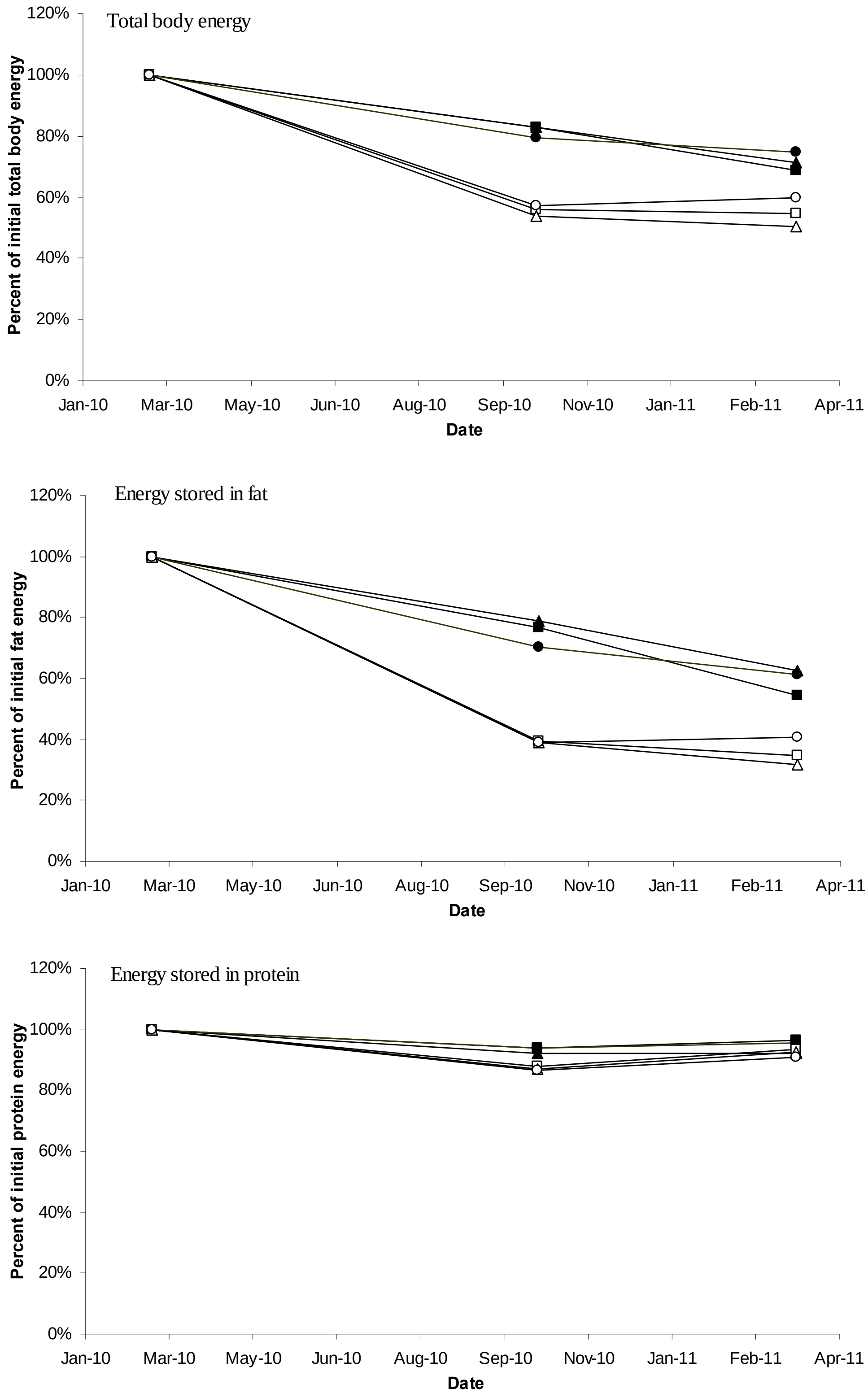

Figure 4. The changes in the proportion of initial body energy stores remaining in cows from the High (■), Myostatin (●) and Low (▲) muscling lines on High (closed symbols) and Low (open symbols) nutrition with changes in body composition during weight loss.

4.2.3. Calving success under divergent nutrition

Calving in 2011 represented the first opportunity to assess the effect of a chronic period of Low nutrition and large changes in body composition (as detailed in section 4.2.2 above) on calving success in the herd. At calving in 2011 the mature cows had been under the Low and Medium/High nutritional treatments for 18 months, and the cows on Low nutrition had lower body reserves than those on Medium/High nutrition from the time of joining in November 2010 throughout pregnancy.

With the modest numbers of cows per cell per year, the only significant difference in calving rate for 2011 was for the Myostatin cows on Low nutrition. This group had a live calving rate of only 52%, compared to 84-96% in the other mature cow groups. In the calculation of days to calving a penalty of 21 d longer than the latest calving cow was applied to cows which did not calve. This is the driver of the longer days to calving for the Myostatin cows on Low nutrition (Table 6). This is the first time that the Myostatin cows in the herd have shown reduced calving rates to the other lines. It is not possible to entirely rule out a sire effect, since a single sire was mated to this group, but it is possible that the prolonged period of low nutrition had reduced the fertility of the myostatin cows at this mating.

Table 6. Predicted means for calving traits for cows after 18 months of divergent nutrition (2011-born calves).

	n	Birth weight (kg)	Days to calving[1]	Calving ease[2]
Low nutrition				
Low muscle	37	33.7	311	1.0
High muscle	42	32.9	306	1.0
Myostatin	21	30.9	330	1.0
Medium/High nutrition				
Low muscle	39	36.9	311	1.0
High muscle	40	36.8	302	1.0
Myostatin	22	35.1	296	1.0
Muscle line P		0.5	0.7	0.2
Nutrition P		0.013	0.3	0.9
Muscle x nutrition P		0.9	0.4	0.4

1. Days from bull in to calf birth; 2. Angus calving ease (1= no assistance, 2 = easy pull, 3 = hard pull, 4 = surgical intervention, 5 = abnormal presentation);

The cows on Low nutrition gave birth to calves which were 3.8 kg lighter than those on Medium/High nutrition (32.5 vs 36.3 kg, P = 0.006), but there were no significant effects of muscle line and no interaction between nutrition and muscle line on calf birth weight, days to calving or calving ease (Table 6).

These results are consistent with those reported for the herd prior to the imposition of the nutritional treatments (Section 4.2.1), with the exception of the Myostatin cows on Low nutrition showing the reduced calving rate. It is important to validate these results over further reproductive cycles to determine whether the longer term effects of chronically reduced nutrition differ with muscling line. It is planned to continue the nutritional treatments for an additional two reproductive cycles to ensure that meaningful and statistically robust results are obtained.

4.2.4. Calf growth to weaning and body composition

Data from calves born from 2003 to 2009 were analysed to assess the effects of selection for muscling on calf growth and body composition at weaning under reasonable nutrition. Data prior to 2003 were not included in this analysis as this was when the *myostatin* gene segregated in the herd and the *myostatin* test became available.

Table 7. Liveweight and body composition of Low muscle, High muscle and Myostatin calves.

	Low muscle	High muscle	Myostatin	sed	P
n	483	460	221		
Birth weight (kg)	35a	35a	37b	0.8	<0.001
Prewean ADG (kg/d)	0.91	0.92	0.93	0.013	0.4
Wean weight (kg)	241	244	246	3.3	0.3
Wean P8 fat (mm)	4.3b	4.3b	3.7a	0.22	<0.001
Wean rib fat (mm)	3.5b	3.3b	2.8a	0.12	<0.001
Wean EMA (cm^2)	40.9a	45.4b	49.8c	0.72	<0.001
Wean muscle score (1-15)	4.7a	8.4b	10.0c	0.24	<0.001

Myostatin calves were 2kg heavier than Low or High muscle calves at birth, but there was no difference in growth to weaning, and no difference in weaning weight (Table 7). There were significant differences in body composition between the three lines. The Myostatin calves had less rib and rump fat than the Low or High muscling calves, whereas the Low muscling calves had a smaller EMA and lower muscle score than the High muscling calves, which were in turn less muscled than the Myostatin calves (all P<0.001).

Calf weights and growth rates, and their body composition at weaning were all significantly (P<0.05) affected by the year of birth, calf sire and calf sex. First calf heifers produced smaller calves which were 25 kg lighter at weaning, but there was no significant effect of the previous lactation status of mature dams on calf traits. The lack of an effect of previous lactation status on the dams' subsequent performance indicates that the productivity and fertility of the herd were not being reduced by low body condition for the years studied.

The dam's *myostatin* genotype was included as a covariate in the calf performance model in order to account for variation in calf performance due to dam genotype. Myostatin dams had calves which were 2.1 kg lighter at birth than High muscle dams (P<0.001), but there was no effect of dam genotype on the calf weight at weaning. There were also tendencies (P<0.10) for Myostatin dams to wean calves with reduced fatness and increased muscle score, so that a Myostatin calf from a Myostatin dam would tend to be slightly leaner and more muscled than a Myostatin calf from a High muscle dam. This may indicate a slight imprinting effect, with an increase in the effect of the Myostatin gene when inherited from the dam as opposed to the sire, or a maternal effect of the Myostatin dams. This will be investigated further.

The question remaining is whether the muscling lines will behave similarly under adverse nutritional conditions. To date only one cohort of calves have been weaned since the start of the divergent nutritional treatments on the herd. The calves on Low nutrition grew more slowly and were smaller at weaning than those on Medium/High nutrition, but the weaning results were similar across muscling line for this cohort (Table 8) as those reported for the 2003 to 2009 calves. There were no muscle line differences in weaning weight or pre-weaning growth rate for the calves, and the differences in body composition showed increases in muscle and decreases in fat from Low muscle to High muscle and Myostatin calves as in the 2003-2009 calves.

Table 8. Weaning weight and body composition of Low muscle, High muscle and Myostatin calves born in 2010 and grown under divergent nutritional treatments.

	n	Weight (kg)	Pre-wean ADG (g/d)	P8 fat (mm)	Rib fat (mm)	EMA (cm^2)	MSc (1-15)
Low nutrition							
Low muscle	28	181a	598a	1.54a	1.47a	28.8a	4.03a
High muscle	29	178a	574a	1.57a	1.30a	30.0a	5.52b
Myostatin	28	187a	604a	1.56a	1.32a	36.6b	7.43c
Medium/High nutrition							
Low muscle	36	214b	718b	2.99d	2.39c	34.5b	4.98ab
High muscle	31	212b	724b	2.44c	1.92b	37.4b	7.02c
Myostatin	32	216b	727b	2.06b	1.68b	41.4c	8.53d
Muscle line P		0.3	0.4	0.005	<0.001	<0.001	<0.001
Nutrition P		<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Muscle x Nutrition P		0.9	0.7	0.035	0.11	0.6	0.7
Dam genotype covariate							
Estimate		-6.0	-26.0	-0.27	-0.09	-4.3	-0.70
P		0.3	0.18	0.3	0.6	0.033	0.15

abc Letters denote means which are significantly different for the interaction between muscle line and nutrition

The only significant interaction between muscle line and nutrition was for P8 fat, as the typical differences in fatness due to muscle line were not expressed in calves on the Low nutritional treatment. A similar result was observed in the dams at weaning (section 4.2.2).

The dam's *myostatin* genotype was again included as a covariate in the calf performance model in order to account for variation in calf performance due to dam genotype. Although it reached significance only for EMA, where the calves of Myostatin dams had 4.3 cm smaller EMA at weaning, across all traits there was a trend for the Myostatin dams to be poorer performers (covariate estimates in Table 8). This is possibly due to chronic Low nutrition having a higher impact on the Myostatin cows, and continuation of the nutritional treatments for another two reproduction cycles should provide sufficient data to confirm whether this is the case.

4.2.5. Heifer fertility and time of puberty

As reported in section 4.2.1., no differences were observed in calving rates of heifers mated as yearlings (approx 14 months of age) in the herd, where the Low and High muscle heifers showed 90% calving, and the Myostatin heifers 100%. This indicates that there is no practical difference between the three muscling lines in age at puberty or heifer fertility, as this would be the earliest that they would be mated. This result is consistent with some earlier work on ovarian parameters in heifers from the herd, where there was no effect of selection for muscling on ovarian activity in heifers from 13 to 24 months of age (McKiernan et al. 2004).

4.2.6. Salvage value of cull-for-age cows

Due to the short duration of this experiment, it was not feasible or informative to collect data on the small number of cull females sold from the herd over this time. Therefore to approximate the differences in value between the lines, data was requested from MLA's NLRS for the last 12 months for females sold at Casino and Inverell saleyards, the most likely location and method of sale for the cast for age cows and cull heifers from the herd. Not only are these reports based on traits measured within this project, but they also afford an insight into differences generated by a much larger representation of animals of variable muscle score.

Supporting previous reports by McKiernan (2002), average differences in value were 15.5, 21.6 and 15.0 c/kg live weight for vealer heifers, heifers and cows respectively in favour of the higher muscle score animals (Table 9). During this period no cows with a muscle score above C were sold through either saleyard, but previous reports indicate that the price improvement from C to B is at least equal to that from D to C (McKiernan 2002).

Table 9. Average cents per kg liveweight and total numbers within each category sold (in brackets) for female classes at the Inverell and Casino saleyards during the period 30 January 2011 to 30 January 2012.

Class	Weight Range (kg)	Muscle Score	Casino	Inverell
			Fat Score 2	*Fat Score 2*
Vealer heifers	200 – 280	C	229.1 (16016)	221.3 (102)
		D	216.7 (1934)	203.3 (70)
			Fat Score 2	*Fat Score 2*
Heifers	0 - 330	C	201.4 (1104)	203.2 (4248)
		D	189.0 (515)	180.5 (385)
	330 - 400	C		195.8 (3420)
		D		166.5 (159)
			Fat Score 3	*Fat Score 4*
Cows	400 - 520	C	162.9 (27)	161.2 (6)
		D	139.1 (3230)	151.6 (697)
	>520	C		166.8 (43)
		D		155.4 (1974)

4.3. Objective 3. Productivity of the steer progeny

4.3.1. Feedlot growth and efficiency

Two hundred and twenty eight steers from the 2008 and 2009-born cohorts were finished at Tullimba in 2010 and 2011 respectively. The 2009-born steers were approximately 10kg lighter at feedlot entry, grew 0.28 kg/d slower and were 20kg lighter at feedlot exit than the 2008-born steers (all $P<0.001$).
Twenty steers refused to eat from the individual intake feeders, resulting in 208 steers with successful intake data collected. There were no significant differences in liveweight or feedlot growth rates in steers from the three muscling lines (Table 10). There were significant differences in intake and NFI, with the Low muscle steers having the greatest intake and the highest NFI, whilst the Myostatin steers were the most efficient, and the High muscle steers were intermediate.

Table 10. Predicted means for feedlot performance and feed efficiency of two cohorts of muscle line steers.

	Low muscle	High muscle	Myostatin	sed	P-value
n	91 (76)*	76 (73)	61 (58)		
Muscle score at entry	3.9a	8.8b	11.4c	0.24	<0.001
Start Wt (kg)	443	434	441	5.5	0.13
End Wt (kg)	544	536	541	6.5	0.2
ADG (kg/d)	1.39	1.38	1.37	0.045	0.9
Intake (kg DM/d)	12.2b	11.8ab	11.5a	0.22	0.004
FCE (kg gain/kg DM)	0.116	0.119	0.120	0.003	0.3
NFI	0.34c	-0.06b	-0.40a	0.16	<0.001

*n in parentheses is the number of steers with complete individual intake data

4.3.2 Carcase and yield traits

Carcase and yield traits were collected for the 228 steers following slaughter immediately after grain finishing, and there were significant differences due to muscle line (Table 11). Dressing % increased with muscling, with Myostatin steers showing a 1.7% increase in dressing over High steers, and a 2.2% increase over Low steers. This resulted in the myostatin steers yielding heavier carcases than the other two muscling lines despite there being no difference in liveweight at slaughter. Hot P8 fat measurements and cold MSA rib fat measurements both showed the steers from the Myostatin line to be leaner than those from the Low and High muscling lines. The myostatin steers also had a lower level of eye muscle marbling than the High line, which was in turn lower than the Low line. The myostatin steers had a slightly lower ultimate pH and meat colour than the other lines. This is consistent with previously reported results (McGilchrist 2011) that more highly muscled steers had a lower muscle response to adrenaline, resulting in higher glycogen storage in the carcase after the slaughter process to fuel pH decline.

Table 11. Carcase traits of muscling line steers killed in 2010 and 2011.

	Low muscle	High muscle	Myostatin	sed	P-value
n	94	76	61		
HSCW	295.2a	293.8a	304.8b	3.95	0.009
Dressing %	54.3a	54.8b	56.5c	0.2	<0.001
Hot P8 fat	19.0b	19.1b	17.3a	0.82	0.057
MSA* Rib fat	11.0b	11.9b	9.3a	0.53	<0.001
MSA EMA	68.1a	70.3b	80.3c	1.06	<0.001
MSA Mb	374.3c	354.7b	315.1a	8.65	<0.001
MSA MC	2.96b	2.84b	2.52a	0.119	<0.001
MSA pH	5.54b	5.55b	5.52a	0.009	0.036

* Rib fat, eye muscle area (EMA), marbling (Mb), meat colour (MC) and pH conducted during MSA grading. MC converted to a numeric scale from 1- 9 for analysis

Significant differences in carcase yield traits following commercial boneout were also observed between the three muscle lines (Table 12). The Low muscle steers had the lowest yield of saleable meat, the highest proportion of bone and the lowest muscle:bone ratio. The Myostatin steers were the highest for these three traits, and the High steers were intermediate. The High muscled steers showed an increase in saleable meat yield of 0.7 % above the Low muscle line, and the Myostatin steers and increase of 3.8% above the Low line. There was no difference in fat yield between the Low and High muscle lines, but the Myostatin steers had significantly less fat. These results are consistent with those previously reported on a small number of steers from this herd (Cafe et al. 2006). They also align with results reported by others for steers of different breed types with variation in muscling (Perry et al. 1993, Conroy et al. 2009).

Table 12. Carcase yield traits of muscling line steers killed in 2010 and 2011.

	Low muscle	High muscle	Myostatin	sed	P-value
n	87	66	56		
Meat Yield%	67.5a	68.2b	71.3c	0.33	<0.001
Fat%	12.9b	12.8b	10.2a	0.35	<0.001
Bone %	20.0c	19.3b	18.8a	0.18	<0.001
Muscle:Bone	3.39:1a	3.54:1b	3.83:1c	0.04	<0.001

There was variation in muscle score within the three selection lines, and the full muscle score range (with the exception of A+) was represented across the 228 steers at feedlot entry. When the carcase yield results were analysed with a muscle score covariate instead of the fixed effect of muscle line, an increase in muscling of one full muscle score led to 1.2% increase in retail meat yield, 0.75% decrease in fat yield and 0.48% decrease in bone yield (all $P < 0.001$). The magnitude of the increase in retail beef yield with an increase of one full muscle score in the live animal is slightly less than the 1.7% improvement reported by Perry et al. (1993). The cattle used by Perry et al. were a mixture of breeds including British, European and Bos Indicus and their crosses, which differ not only in muscling but in other aspects of body shape, which could be expected to influence the relationship between visual muscling and meat yield.

4.4. Objective 4. Meat quality of the steer progeny

Striploin, oyster blade and topside primals of 40 Myostatin, 20 Low muscle and 20 High muscle steers across the experiment were used to assess the effects of selection for muscling and the *myostatin* deletion on meat quality. These muscles vary in ageing rates, which in combination with a range of ageing times was designed to allow the mechanisms driving any differences in meat tenderness due to muscling or the *myostatin* gene to be studied.

Table 13. Objective meat quality traits for muscle line steers - shear force (SF), meat colour (L*, a*, and b*), pH and cooking loss.

	Low muscle	High muscle	Myostatin	sed	P-value
n	60	60	120		
SF (N)	32.6	31.5	32.2	1.5	0.9
SF (kg)	3.3	3.2	3.3	0.15	0.9
Colour L*	40.9	40.4	41.2	0.54	0.4
Colour a*	23.1	23.6	23.0	0.32	0.1
Colour b*	11.2	11.3	11.0	0.23	0.4
pH	5.60	5.62	5.58	0.023	0.3
Cooking loss (%)	23.5	24.4	24.4	0.61	0.2

Striploin and oyster blade samples aged for 7, 28, and 49 days used for analysis.

No significant differences were observed between the three muscling lines for any of the objective meat quality traits (Table 13). Differences in objective meat quality traits were observed between year, muscle and ageing, but no interactions were observed with muscle line, hence pooled means are presented. The objective meat quality traits predicted for 7 day ageing are presented in Table 14. Seven day shear force is a little higher without the effect of the longer ageing times, but there are no differences between muscle lines.

Table 14. Objective meat quality traits for muscle line steers at 7 days ageing - shear force (SF), meat colour (L*, a*, and b*), pH and cooking loss.

	Low muscle	High muscle	Myostatin	sed	P-value
n	60	60	120		
SF (N)	35.0	34.0	34.7	1.82	0.3
SF (kg)	3.6	3.5	3.5	0.19	0.3
Colour L*	40.5	40.0	40.4	0.62	0.8
Colour a*	23.1	23.5	22.9	0.37	0.8
Colour b*	11.0	11.1	10.8	0.27	0.8
pH	5.58	5.61	5.58	0.022	0.6
Cooking loss (%)	23.3	24.0	24.4	0.58	0.6

Striploin and oyster blade samples aged for 7 days used for analysis.

Similarly, no significant differences were observed between the three muscling lines for any of the sensory meat quality traits (Table 15). As reported above, the Myostatin steers had lower MSA marbling and lower intramuscular fat was measured in the striploin of the Myostatin steers from the 2011 cohort (Low muscle 6.2%, High muscle 7.1%, Myostatin 4.4%, sed = 0.7, P<0.001), but differences were not enough to drive significant differences in consumer rating of the meat. As with the objective analyses, there were significant effects due to year and muscle, but no significant interactions with muscle line.

Table 15. MSA sensory attributes of 7-day aged muscle* from steers from the three muscle lines.

	Low muscle	High muscle	Myostatin	sed	P-value
n	60	60	120		
Tender (0-100)	61.0	60.6	59.5	1.76	0.6
Juicy (0-100)	62.6	62.5	59.8	1.81	0.14
Flavour (0-100)	63.4	63.9	61.2	1.62	0.16
Satisfaction (1-5)	3.44	3.50	3.42	0.071	0.5
Overall like (0-100)	61.8	63.1	60.6	1.84	0.4
MQ4 (0-100)	62.1	62.5	60.3	1.67	0.3

* Striploin, oyster blade and topside data used for analysis.

The 2011 striploin and oyster blade samples were also analysed for collagen content. There were differences between muscles, with the oyster blade containing significantly higher levels of soluble and total collagen than the striploin. But as there were no differences in collagen content between the muscle lines, no interactions between muscle line and cut, and no differences in tenderness to explain, these results are not presented.

4.5 Objective 5. Publications and extension activities

Three major scientific publications will be prepared using the results presented in this report:

1. Selection for increased muscling is not detrimental to maternal productivity traits in Angus cows. L Cafe, W McKiernan, D Robinson. Submit to Journal of Animal Science approximately December 2012.
2. Selection for increased muscling improves feed efficiency and carcase characteristics in Angus steers. L Cafe, W McKiernan, D Robinson. Submit to Animal Production Science approximately June 2012.
3. Selection for increased muscling improves carcase yield without reducing meat quality in Angus steers. L Cafe, W McKiernan, D Robinson. Submit to Animal Production Science approximately July 2012.

Additional research has been conducted by Peter McGilchrist on steers from the muscling herd. He studied the effect of selection for muscling on carbohydrate and fatty acid metabolism in beef cattle as part of his PhD research program through the Beef CRC. The results of this research can be found in McGilchrist 2011.

Results emerging from the project have been reported at a number of field days and workshops over the past 12 months. Examples of these include a major field day held at Grafton in March 2011 which attracted 120 participants; a Beef CRC Breeder Management Workshop held at Glen Innes in March 2011 with 30 participants; a Cross Breeding Field Day held at Wollomombi in August 2011 with 40 participants; and a Blonde d'Aquitaine Field Day held in Perth in December 2011 with 70 participants.

The results from the muscling herd have been incorporated into the Beef CRC Champions network, and factsheets describing the effects of selection for muscling on cow fertility and steer carcase traits have been prepared. Copies of drafts of these factsheets are attached (Appendices 2 and 3). These have been prepared in conjunction with the project team, ensuring that accurate extension material from the project will be available for use by extension programs nationally.

4.6. Objective 6. Maternal Productivity and BREEDPLAN

4.6.1. Beef CRC Maternal Productivity Analysis

The muscling herd maternal performance data were collected largely to fill a gap in the information collected within the Beef CRC Maternal Productivity Program, and to allow the development of an accurate maternal model which can account for variability in muscling. With the wide range of both muscling and fatness in the herd being driven by genotypic and environmental factors, the capture of the changes in cow body composition, resulting fertility and calf performance on divergent nutrition, these data will be a valuable component of the model development. Initially the muscling herd data are being analysed separately to the other Maternal Productivity program herds, for presentation in this report. When the researchers and statisticians within the Maternal Productivity Program have analysed the remaining research and industry herds separately, all data from both sources will be used for a combined analysis. The exact nature of the combined analysis will depend upon the results from each herd, and it is planned to be conducted from July 2012.

4.6.2. Angus BREEDPLAN

Changes in EBVs for some traits with the generation of selection for muscling and birth year in the Low and High muscle progeny have been described by Walmsley et al. (2011). Updated examples of these results with the Myostatin line added are presented in Figure 5 for 400 day weight, eye muscle area and rib fat EBVs. The 400 day weight EBV is representative of the trends observed in 200 day weight, 600 day weight and mature cow weight EBVs. These results indicate that the EBVs for 400 day weight are similar between progeny from the three muscle lines, which is consistent with weight and growth data presented throughout this report. Selection for increased muscling has led to an increase in eye muscle area EBV and a decrease in rib fat EBV in the High muscled progeny which is consistent with the phenotypic results reported. The visible annual variation in EMA and rib fat EBVs can be attributed to individual

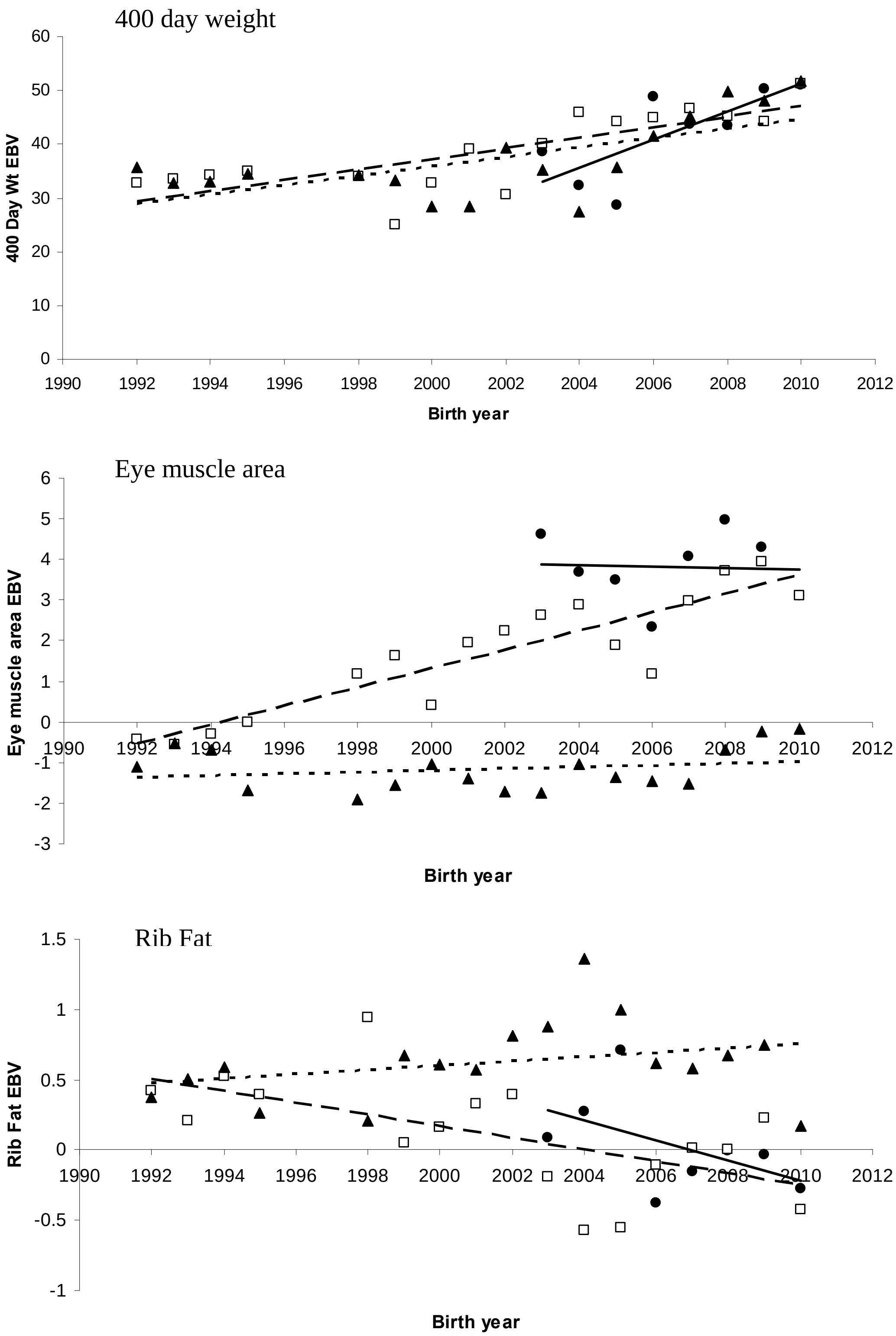

Figure 5. The change in Angus BREEDPLAN EBV for 400 day weight, eye muscle area and rib fat for Low (▲, dotted trend line), High (□, dashed trend line) and Myostatin (●, solid trend line) progeny with year of birth.

sire effects as only 2-5 sires were used across each line per year, and selection was not based on these EBVs.

Throughout the development of the herd, an attempt has been made to select sires of similar growth potential across the muscle lines, so that the lines remain of comparable size. In recent years this has included using the 600d weight EBV to select bulls with breed average or slightly greater growth potential to follow the industry trend of increasing cow size. This has been achievable for the High and Low muscle bulls, which have been selected from many studs, and for which the average growth figures for the bulls used ranked just above breed average (Table 16). The Myostatin bulls are more difficult to source, and the EBVs for those bulls are generated only by the small numbers of progeny generated within the muscling herd. However, the combination of High and Myostatin bull genetics in both the High and Myostatin progeny has ensured the three lines have remained similar in genetic growth potential (Figure 5).

Table 16. The average BREEDPLAN EBVs for sires used in the muscling herd from 2006 to 2011. Traits presented are those for which at least four of the muscling herd bulls in each line have figures[1].

	Low muscle	High muscle	Myostatin	sed	P-value
Calving Ease Dir (%)	-0.35	-0.59	-0.95	1.046	0.9
Birth Wt (kg)	4.9	4.8	3.6	0.57	0.06
200 Day Wt (kg)	39.3	40.9	22.8	4.36	0.001
400 Day Wt (kg)	71.3	75.2	46.7	6.25	<0.001
600 Day Wt (kg)	91.1	95.4	57.2	7.98	<0.001
Mat. Cow Wt (kg)	84.7	87.7	53.0	9.97	0.012
Carcase Wt. (kg)	49.4	52.2	31.8	5.95	0.16
Eye Muscle Area (cm^2)	2.7	3.2	8.1	1.44	0.007
Rib Fat (mm)	-0.01	-0.81	0.35	0.414	0.025
Rump Fat (mm)	0.23	-1.06	-1.00	0.530	0.019

1. Twelve Low muscle, 11 High muscle and 9 Myostatin bulls included in analysis.

The individual EBVs for all traits for these bulls are presented in Appendix 4.

5. General Discussion and Industry Implications

It is important for cattle producers to supply the optimum type of cattle to processors to maximise returns, but obtaining feedback on what constitutes the optimum is not an easy process. Beef industry research and development organisations have been working at addressing this over the last 30 – 40 years and the important points of profitability and acceptability along the marketing chain have been recognised. Producers are starting to react to the messages they are now receiving, specifically in the areas of meat yield, growth and meat quality.

Feedback from processors has identified a lack of reliable carcase measurements as an impediment to improving the payment system to better reflect the value of carcases. Weight and fat measures are adequate but further measures of muscle are not suitable. Butt profile has little usefulness and is poorly related to overall carcase muscle and meat yield (Johnson 1980), as opposed to the totally different live animal muscle appraisal of muscle score, which is closely related to meat yield percentage (Perry et al. 1993). Eye muscle area is a useful predictor of yield, but in the current system it is measured 12 hours after payment for the carcase is made.

On the live animal, however, the characteristics of assessment are all closely related to value and hence the industry is recognising this by paying premiums and discounts. The characteristics affecting price (within market category) are liveweight, fat score and muscle score. The price paid for animals within various market categories varies little due to differences in weight or fat score (approximately 5¢/kg lwt/change in fat score). In contrast, the major influence or price variation within category is muscle score – approximately 14¢/kg lwt/change in muscle score across all market categories (McKiernan 2002). More recent analysis indicates this difference has increased to 25 c/kg lwt /muscle score (Littler pers. com.).

When these market conditions were applied to a whole herd economic model using Beef-N-Omics, an increase of one muscle score in the sale progeny, combined with the final salvage value of the cow, generated a 24% increase in gross margin per breeder (unpublished). However this analysis assumed there were no detrimental effects on meat eating quality, feed efficiency or maternal productivity traits. There is a growing industry concern that if market signals for enhanced carcase yield result in selection pressure being applied for that trait (decreased fatness and/or increased muscling) this will have an adverse impact on meat quality and especially maternal productivity traits.

At an individual animal level, increased carcase yield offers producers the opportunity to increase total product output from the same number of animals. Increasing the muscularity of the female component of a beef herd will enable producers to achieve a rapid rate of improvement in the muscling capacity of their resultant progeny (McKiernan 2011). While such an improvement will provide large economic returns from the sale of progeny with more meat, it is important to establish the impact that such a change will have on other traits such as feed efficiency, meat quality and maternal productivity. It is important to determine the feed efficiency of cattle that differ in their muscling phenotype at a young age (post-weaning) since feed efficiency at that stage will impact directly on the cost of finishing animals.

In reality beef producers have been avoiding selecting for increased muscle in their herds under the belief that increased muscling in their females will result in poor conception, poor fertility, poor calving and poor growth of calves. This situation has been evident for some time and only about 5%-10% of the cattle population is classified as high muscling (McKiernan 2001, McKiernan 2002).

If market premiums for increased muscling in progeny (and cull cows) are pursued, the consequences for body composition and efficiency in the breeding females must be evaluated. It is predicted that future commercial cow-calf operations will be managed in more marginal and variable environments, and thus the effect of this on herd productivity needs evaluation in cattle selected for muscularity. In particular, many cattle breeding operations may be restricted to grazing of low quality pasture and/or crop residues in mixed farming enterprises.

In contrast to the above, it is anticipated that there will be a trend for greater intensification of growing /finishing systems (e.g. lot feeding, high-performance pasture systems) in order to meet demanding market requirements for end-product yield and quality. Under this scenario the industry requires resilient maternal genotypes and production systems that can efficiently utilise variable feed resources (e.g. via efficient energy storage & mobilisation of body tissue reserves) whilst also having the potential to produce progeny that meet high quality market targets when finished in appropriate environments. The industry currently lacks the knowledge to effectively balance these potentially conflicting requirements of different sectors of the supply chain.

This project was designed to address the role that selection for improved muscling may play in resolution of these issues. Firstly these results address the issues of steer efficiency in the feedlot and meat quality, and confirm the advantage of selection for muscle on improved meat yield. Secondly they directly address the issues of maternal productivity, reporting on heifer and cow performance under good and adverse nutritional conditions.

5.1. Steer performance

These results confirm the advantage that selecting for increased muscling has on meat yield, as reported previously by Cafe et al. (2006). The combination of these results and those previously reported gives substantial confidence in the result that it is possible to select for increased muscling using a visual muscle score, and that doing so will result in increased meat yield via increased muscle to bone ratios. Steers carrying one copy of the *myostatin* mutation were higher yielding and had less fat (at all depots) than High muscle steers, which were higher yielding with similar fat to the low muscle line steers.

Although the steers carrying the *myostatin* mutation had less subcutaneous and intramuscular fat they were not significantly lower in eating quality. High muscle steers had eating quality similar to the Low muscle steers and there were no differences in either objective or subjective meat quality traits.

There is a concern that although the relationship between meat yield and fat is relatively high and that response in increasing lean by selection against fat can be achieved, too much decrease in fat will have an adverse effect on the eating quality of the carcass. Kempster (1989) alludes to the problems of too little fat reducing meat quality, but also includes too much muscle which effectively reduces fatness and in turn affects eating quality. Similar conclusions are drawn from the Clay Centre breed evaluation trials (Koch et al. 1983) which note the opposite relationship between high yielding breeds and marbling. Koch et al. (1982) reported a correlation between fat depth and marbling of 0.16. It is apparent that reasonable levels of fatness/marbling are required to maintain meat eating quality. The current results indicate that selection for muscling (particularly independent of the *myostatin* gene) is a superior alternative to selecting for reduced fatness, as meat yield increased while quality was maintained.

Nutrient partitioning and functionality at the tissue level is likely to be altered in association with an increase in muscling. Such metabolic changes can impact on the efficiency of the animal in utilising feed as well as the meat quality of the ensuing carcass. Assessing these relationships is critical in determining the profitability of selection to increase muscling within a beef production system. Feed efficiency is an important issue when feed costs are high, as in feedlot finishing or supplementation programs. During feedlot finishing these results clearly show a significant difference between the muscle lines in feed intake and yet all lines perform the same for growth rate. There was a consistent improvement in Net Feed Intake (NFI), the preferred method of assessing efficiency, with increasing muscling. The Myostatin line was more efficient than the High muscle line which in turn was more efficient than the Low muscle line.

The implications to producers is that they can select for muscling with confidence knowing that these higher muscled animals will not only grow as fast as lower muscled cattle in the feedlot but will be more efficient at feed conversion, produce more meat from any given live weight (higher dressing % and meat yield) with equal meat eating qualities.

5.2. Maternal efficiency

It is widely known and well documented (Arthur 1995) that double muscling can cause serious harm to a productive cattle enterprise. Double muscling can lead to poor growth, poor calf survival, dystocia and numerous other detrimental traits. However, these findings are based on data collected before it was possible to distinguish between animals carrying one or two copies of a *myostatin* mutation. Since the discovery of the mutation responsible (Grobet et al. 1997), few results have been reported for heterozygous animals, or those with a single copy of the mutation. The results presented here suggest that the heterozygous animals fall somewhere between normal performance and the full effects of double muscling, although numbers at this stage are still relatively small. It is evident from these results that the effects are not fully deleterious and are in fact advantageous in some areas (increased yield, some fat, and little effect on growth or maternal productivity under reasonable nutritional conditions).

The arrival of the European breeds into the Australian cattle population added to the negative perceptions derived from earlier experiences with double muscling. These breeds bought with them the advantage of high muscling, but also had high calving difficulties, low levels of fatness and large frame size which limited their application to harder pastoral conditions. These traits unfortunately were attributed to high muscling rather than breed traits. Some of these breeds exhibited traits which didn't fit the mould, for example high levels of milking ability in Simmentals, and high marbling ability in Braunviehs, indicating the existence of breed effects rather than muscling affects (reviewed by McKiernan 1995). However, these previous experiences and perceptions have prevented Australian cattle breeders from selecting for increased muscle in their herds under the belief that increased muscling in their females will result in poor conception, poor fertility, poor calving, poor growth of calves and lower ability to survive the "tough" times of the variable Australian pastoral conditions.

This experiment looks at variation in muscling within one breed so we can attribute the results directly to the effects of muscling. The aim is to test the performance of the muscling lines under considerable nutritional stress. At the time of the preparation of this report, data from only one and a half production cycles on divergent nutrition had been collected, so results are tentative. However, the change in liveweight and body composition of the cows during the nutritional treatments are providing indications of likely effects. There is no evidence that the Low and High muscle lines are behaving differently to each other on Low nutrition at this stage. However, there are indications that the Myostatin cows on Low nutrition are beginning to show decreased performance. There was some suggestion of this at weaning of the 2010 calves, but the telling result is the low calving rate for this group in 2011. With the continuation of the nutritional treatments for a further two production cycles, we should obtain sufficient data to determine whether this is a real effect.

6. Conclusions

These results provide convincing evidence that there was no difference in performance between cows from the High (C muscle average) and Low muscle (D muscle average) lines, nor in the growth rates of their progeny under good, moderate or low nutritional conditions. This should put the long held perceptions of poor performance due to higher muscling to rest, at least for moderate increases in muscling. The advantages of improved feed efficiency and increased meat yield of progeny resulting in higher value output from the High muscle cows; no detriment to meat quality; the cows' increased value when cast for age; and no accompanying detriment to maternal productivity should encourage producers to select for increased muscling in their replacement females.

The incorporation of the *myostatin* deletion into the cow herd, on the other hand should to be treated with care. Whilst there is an advantage in using the gene to further increase the carcase value of the progeny, the heterozygous Myostatin cows (B muscle score average) have shown signs of reduced productivity after 18 months on a low plane of nutrition. Although further data is needed to confirm this result, it may be that the Myostatin gene is best utilised through terminal sires. If heterozygous *myostatin* females are to be kept for breeding they should be run under more favourable nutritional conditions to maximise their advantage and limit their exposure to nutritional stresses.

7. Acknowledgements

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Appendix 1. Final progress report. Objective 1. Commit and maintain the muscle line cattle for the purpose of collecting reproductive and production data until October 2011

This has been achieved. The muscling herd has been maintained, with all reproductive and productivity data collected as intended.

October 2011 marked the end of calving and the starting point of the second full production cycle on the divergent nutritional treatments. The number of cows and heifers mated for the 2011 calving are presented in Table A1.

Table A1. Numbers of cows mated for the 2011 calving.

	High nutrition	Low nutrition	3YO Heifers	2YO Heifers
Low muscle	37	40	10	10
High muscle	39	42	9	10
Myostatin	22	21	20	18

This was the first mating for the two year old heifers, and the second for the three year old heifers. Results for each of these age groups are presented separately to the older cows because their nutritional treatments differ. The yearling-mated first calf heifers were kept on good nutrition during their first lactation to allow them to continue to grow. Their nutritional treatments began after weaning of their first calf ie after their second mating. Consequently, for the three year old heifers, the nutritional treatments began approximately six months into gestation. In contrast, at this time the older cows had been on their nutritional treatments for 18 months.

Table A2. Percentage of females mated which produced a calf in 2011, and in parentheses, the percentage which produced a live calf.

	High nutrition	Low nutrition	3YO Heifers	2YO Heifers
Low muscle	89.6 (84.3)	86.5 (83.8)	90 (90)	90 (90)
High muscle	92.1 (84.7)	92.7 (92.7)	100 (100)	90 *(70)*
Myostatin	95.5 (95.5)	*57.1 (52.4)*	95 (90)	100 *(72.2)*

With the modest numbers of cows per cell per year, the only significant difference in calving rate for 2011 was for the Myostatin cows on Low nutrition (Table A2). This group had a live calving rate of only 52%, compared to 84-96% in the other mature cow groups. This is the first time that the Myostatin cows have shown reduced calving rates to the other lines (see Section 4.2). It is not possible to entirely rule out a sire effect, since a single sire was mated to this group, but it is likely that the prolonged period of low nutrition had reduced the fertility of the myostatin cows at this mating. This will be an important result to validate if the nutritional treatments can be continued for further production cycles.

There were few calving problems in the mature cows and three year old heifers, with only one cow assisted at birth. Overall, seven calves were born dead across the mature cow groups, and none in the three year old heifer groups. Calving problems were a significant issue for the two year old heifers, where 20 and 28% of calves died at birth in the High and Myostatin groups respectively. These levels of dystocia were higher than usually seen in first calf heifers in the herd, and are likely to be due to the sire mated to these two groups on this occasion. The bull had Angus BREEDPLAN EBV figures of -5.3 for calving ease (worst 1% of breed) and +6.3 for birth weight (worst 15% of breed), and would not be considered a suitable heifer sire.

The cows were weighed and scanned for body composition in October 2011, when there were less than ten cows left to calve. The difference in liveweight and body composition with nutritional treatment was reduced at this point, due to a difficult winter. Thirty of the cows on Low nutrition required supplementation in winter to avoid poor welfare, and the feed available to those on Medium/High nutrition was of a reduced quality and quantity due to flooding during the previous summer. It appears that the Myostatin cows are beginning to show a reduced ability to cope with the prolonged Low nutrition, as evidenced by their reduced calving rates discussed above, and they were approximately 20 kg lighter than the other lines within both nutritional treatment groups at this stage. The body composition of the herd as affected by muscle line and nutrition are presented and discussed in section 4.2.2.

The BREEDPLAN recording of the herd has been kept up to date. The only outstanding data is the 2011 calving data and the steer slaughter data, which will be prepared and sent soon after the submission of this report.

Appendix 2. DRAFT BEEF CRC CHAMPION FACT SHEET: MUSCULARITY AND A PRODUCTIVE BREEDING HERD - ACHIEVING BOTH

FAST FACTS

- Selection for increased muscularity led to cows that were the same weight, slightly smaller in frame score and with more muscle and less fat
- An increase in muscularity of one muscle score unit (D to C) did not affect calving rate
- There was no difference in calving difficulty between muscling lines
- There was no effect of muscularity on weaning rate or calf growth

Research conducted by the Beef CRC has demonstrated that selection for increased muscle is not associated with negative effects on the breeding herd.

Addressing industry concerns

There are potential gains to be made within the beef industry through selection for increased muscularity due to the associated increase in carcase value through increases retail beef yield. To date, there has been limited selection for increased muscling due to the perception it may have a negative effect on cow performance traits including fertility, calving ease, calf survival, cow milk production, cow longevity and progeny growth rate.

NSW DPI has been developing an Angus cow herd divergent in muscling since the 1990s. Careful selection based on visual muscle score has resulted in the formation of Low and High muscling lines. The cows in the Low muscling line currently have an average muscle score of D, and the cows in the high muscling line an average muscle score of C. This factsheet reports on the relationships between this level of increased muscling and maternal productivity traits. Complementary information on how selection for muscling changes the carcase can be found in a separate factsheet.

Figure 1: Yearling heifers from the Low (left) and High (right) muscling lines

Muscle and the breeding herd

Cows in the High muscling line were similar in weight, slightly smaller in frame score and had more muscle and less subcutaneous fat than cows in the Low muscling line (Table 1). These differences in body composition have not led to any differences in reproductive performance in mature cows (Table 2). The High muscling cows display the same levels of calving ease, days from joining to calving, birth and weaning rates as the Low muscling cows. Calf weaning weight is also similar between the two lines indicating that milk production and growth rate have not been affected by selection for increased muscling.

Table 1: Body composition of mature cows selected for High and Low muscling on good nutrition.

Line	Low	High
Weight (kg)	551	553
P8 fat (mm)*	13.5	9.6
Rib fat (mm)*	9.2	6.6
Eye muscle (cm^2)*	54.7	60.5
Muscle Score*	D	C+
Hip Height§	128.2	126.4

Significant difference (P<0.001) § Significant difference (P<0.05)

Table 2: Reproductive performance of cows selected for High or Low muscling giving birth to their second or subsequent calf from 1998 to 2009.

Line (number of records)	Low (844)	High (852)
Calving ease[1]	1.03	1.01
Birth weight (kg)	35.3	35.5
Wean weight (kg)	245	247
Days to calving	315	309
Live calf %	88.2	89.2
Wean%	85.0	87.2

[1.] Calving ease scale of 1-4.

Results were similar for heifers giving birth to their first calf at either two or three years of age. The heifers from both lines required more calving assistance than the mature cows, particularly when giving birth to their first calf at two years of age. However, there was no difference between Low and High muscled heifers in calving ease or any of the other female productivity traits measured.

The divergence in muscling between these lines appears to have stabilised, indicating that the muscling in the High line is likely to be as high as can be achieved without the use of specific extreme muscling genes or crossing with extremely muscled breeds. The difference in muscling has been achieved by using B muscled Angus bulls over the High muscling cows.

Summary

Selection for increased muscling resulted in cows of similar live weight but with more muscle and less fat. Importantly, selection for increased muscling, from D to C muscle score, had no impact on calving rates, calving ease or calf growth rates to weaning.

Further reading

Muscle Scoring Beef Cattle:
www.dpi.nsw.gov.au/__data/assets/.../**muscle-scoring-beef-cattle**.pdf

Contact Details
Jeisane Accioly
Department of Agriculture and food of Western Australia
jeisane.accioly@agric.wa.gov.au
Ph: (08) 9780 6186

Fact Sheet Prepared: ***30 September 2011***

Appendix 3. DRAFT BEEF CRC CHAMPION FACTSHEET: SELECTION FOR MUSCLING AND ITS EFFECTS ON CARCASE

Selection for muscling is associated with increased saleable beef, higher sale yard value (c/kg) and potentially higher profit. There has been industry reluctance to pursue selection for increased muscling because of perceived negative relationships with other important traits for beef production, in particular on-farm productivity. Research conducted by the Beef CRC has separated fact from fiction.

FAST FACTS

- It is possible to use visual selection for muscling to increase muscularity in cattle
- Selection for divergent muscularity has led to a difference in muscle score of one full unit (D vs C) between Low and High muscling lines
- To achieve substantial progress in muscularity, selection pressure should be applied to both sires and dams
- Selection for muscularity has not resulted in negative effects on other production traits.

Addressing industry concerns

Under current Australian beef pricing systems, approximately 80% of carcase profit is related to meat yield and 20% to quality. Despite this, the beef industry has not embraced selection for muscularity due to concerns that it would result in negative associations with growth; feed efficiency; reproduction rate and meat quality. Work carried out by NSW DPI defining ("Muscle Scoring Beef Cattle") demonstrated that selecting for muscling is repeatable and heritable and particularly valuable for those breeds lacking accurate Eye Muscle Area (EMA) EBV. When performed by proficient individuals visual muscle score is closely related to retail beef yield and dressing percentage. This has also been validated for *Bos indicus* cattle.

A separate factsheet, 'Muscularity and a productive breeding herd – achieving both' addresses the fact that selection for increased muscling has no negative effects on the breeding herd.

Establishing divergent selection for muscle score

NSW DPI has been developing an Angus cow herd divergent in muscling via selection based on visual muscle score. This has resulted in the formation of Low and High muscling lines. The cows have been joined to Angus bulls that were selected for divergent muscling, based on visual muscle score and more recently, also on 600 day weight EBV. This factsheet reports on relationships between selection for muscularity and various production traits after 13 years of selection for divergent muscling.

Growth, body composition and feed efficiency

Results from the muscling selection lines (Table 1) indicate that progeny from the High muscling line are around one full muscle score higher in muscling than those in the Low muscling line. Progeny from the high muscling line had larger EMA as measured by ultrasound with no difference in weight, height or fatness. Steers from High and Low muscling lines had similar feedlot performance for growth and feed conversion rate. However the High muscling line had more favourable Net Feed Intake, which is a measure of feed efficiency (Table 2). These findings demonstrate that selection for increased muscularity had no impact on progeny growth rates, and resulted in improved feed efficiency in the feedlot.

Table 1: Weaner (W) and Yearling (Y) measurements for progeny born between 1998 and 2009 in a research herd visually selected for High and Low muscularity.

Line	Low line (n = 357)	High line (n = 348)
Muscle Score*	D	C
W EMA (cm^2)*	42.3	47.7
W Weight (kg)	253	261
Y Weight (kg)	346	359
Y P8 fat (mm)	5.6	5.7
Y Rib fat (mm)	4.3	4.3
Y Height (cm)	122	121

* Significant difference (P<0.001)

Table 2: Results for Net Feed Intake (NFI) for 2008- and 2009-born steers from a herd visually selected for High and Low muscularity.

Line	Low line (n = 76)	High line (n = 73)
Muscle Score*	D-	C+
Start weight (kg)	443	434
End weight (kg)	544	535
Feed Conversion Ratio	9.2	8.6
NFI*	0.35	-0.06

* Significant difference (P<0.001)

Carcase and meat quality

Research revealed a 0.5% increase in dressing percentage as well as a 0.7% improvement in meat yield in steers from the High muscling line.

Objective (tenderness, cooking loss, meat colour, pH, IMF) and sensory (tenderness, flavour, juiciness and overall like) meat quality measurements showed no difference between samples from High and Low muscling animals.

Visual selection and Estimated Breeding Values (EBVs)

Recently, researchers have analysed the relationships between BREEDPLAN EBV trends and selection for muscle score in the research herd over 11 years. Visual selection for High muscling was associated with an increase in the EBV for Eye Muscle Area (EMA), a decrease in the EBV for rump fat depth, and consequently an increase in the EBV for retail beef yield (RBY). There was no apparent relationship between visual selection for muscularity and weight EBVs. This demonstrates the independence between growth and muscling. Therefore producers can select for increased yield without negatively impacting growth.

Summary

Carcase value can be increased by selecting for increased muscularity. Beef CRC research has shown that selection for muscularity does not negatively affect other important traits including growth, reproduction, feed efficiency and meat quality. As with any trait, selection for muscling should be used as part of a multiple trait selection program. In order to ensure progress in the selection for muscularity, both cows and sires should be selected for the trait.

Further reading

Muscle Scoring Beef Cattle:
www.dpi.nsw.gov.au/__data/assets/.../**muscle-scoring-beef-cattle**.pdf

Contact Details

Jeisane Accioly
Department of Agriculture and food of Western Australia
jeisane.accioly@agric.wa.gov.au
Ph: (08) 9780 6186

Fact Sheet Prepared: ***30 September 2011***

Appendix 4. Angus Group BREEDPLAN EBV (December 2011) for sires used in the muscling herd from 2005 until 2011.

Bull ID	Bull Muscle Line	Cow Muscle Line	Mating years	Calving Ease Dir (%)	Calving Ease Dtrs (%)	Gest. Length (days)	Birth Wt (kg)	200 Day Wt (kg)	400 Day Wt (kg)	600 Day Wt (kg)	Mat. Cow Wt (kg)	Milk (kg)	Scrotal Size (cm)	Days to Calving (days)	Carcase Wt. (kg)	Eye Muscle Area (sq.cm)	Rib Fat (mm)	Rump Fat (mm)	Retail Beef Yield (%)	IMF (%)
Y136	L	L	2005 2006	0.1	-3.9	-1.2	5.0	18	48	67	86	-7	2.0	-3.9	26	-1.8	0.3	1.6	-1.0	1.1
Y110	H	Myo	2005 2006 2007	-2.0	-3.4	-2.2	5.3	32	68	83	96	5	0.5	-3.1	51	-1.9	-1.6	-1.8	0.1	0.5
Y112	H	H, Myo	2005 2006 2007	0.3	-2	-4.9	3.0	34	62	66	48	6	0.9	-4.0	34	2.7	0.3	0.2	0.2	0.2
X239	H	H	2004 2005	3.6	4.9	0.5	2.6	24	42	57	49	7	1.6	-2.4	31	1.3	-0.5	-0.8	0.7	0.5
Z61	Myo	H	2006 2007	-2.4	0.6	1.2	4.3	24	51	65	56	-1	-	-	35	13.7	-0.2	-1	3.3	-0.2
A24	L	L	2007 2008	-0.4	2.5	-2.2	4.6	36	65	85	70	16	2.1	-3.7	41	0.8	1.3	1.5	-1.3	1.5
A7	L	L	2007 2008 2009 2010	2.9	-0.2	-4.5	3.2	39	71	84	69	11	2.4	-4.9	43	1	-0.6	0.1	-0.3	1.4
B102	H	H, Myo	2008 2009 2010	1.2	-2.9	-4.6	4.4	42	74	96	79	17	0.3	-2.5	54	3.8	-0.3	-0.5	0.6	0.8
B50	H	H, Myo	2008 2009 2010	-5.3	-2.5	-1.4	6.3	46	86	110	110	12	0.2	-3.0	61	2.1	-0.9	-1.8	0.5	1.2
B34	H	Myo	2008 2010	1.4	0.4	-7.0	2.7	38	80	98	85	18	1.6	-5.5	47	6.4	-0.4	-0.3	1.1	1.8
Z33	L	L	2006 2007	-1.1	-1.5	-3.4	5.5	46	71	99	100	12	1.2	-1.4	51	-1	0.2	-0.1	-0.7	1.2
A149	Myo	H	2007 2008	-1.0	-1.4	0.7	3.1	18	38	44	37	-1	-	-	23	5.9	1.1	1	1.6	-
A28	Myo	H	2007 2008	0.9	-0.7	-0.3	3.4	20	45	61	68	6	-	-1.4	34	6.4	0.3	-0.3	1.9	-
B10	Myo	H	2008 2009	1.3	0.1	-	2.9	24	50	60	51	-	-	-	35	6.2	0.2	-0.1	1.6	-
A53	L	L	2007 2008	0.7	-2	-1.7	2.6	27	52	68	57	11	0.1	-2.7	36	1.4	1.5	2.5	-1.2	1.5

Bull ID	Bull Muscle Line	Cow Muscle Line	Mating years	Calving Ease Dir (%)	Calving Ease Dtrs (%)	Gest. Length (days)	Birth Wt (kg)	200 Day Wt (kg)	400 Day Wt (kg)	600 Day Wt (kg)	Mat. Cow Wt (kg)	Milk (kg)	Scrotal Size (cm)	Days to Calving (days)	Carcase Wt. (kg)	Eye Muscle Area (sq.cm)	Rib Fat (mm)	Rump Fat (mm)	Retail Beef Yield (%)	IMF (%)
B357	L	L	2009	-1	-1.5	-1.9	5.3	30	60	77	76	13	2.0	-2.1	44	5.1	-0.6	-1	0.8	1.5
39	H	Myo	2010 2011	-0.9	0.1	-3.7	5.7	40	70	100	102	12	0.8	-2.7	52	4.5	-0.8	-1.6	1.4	0.5
38	L	L	2010 2011	-3.5	-4.8	-2.8	7.0	46	81	107	109	15	0.8	-4.6	63	5.2	-1.1	-1.2	1.2	1.1
C182	Myo	H	2009 2010	-0.4	-	-	3.9	26	48	56	-	-	-	-	-	-	-	-	-	-
C188	Myo	H	2009	-4.1	-	-	5.6	25	48	57	-	-	-	-	-	-	-	-	-	-
D72	Myo	H	2010 2011	-	-	-	2.8	-	-	-	-	-	-	-	-	-	-	-	-	-
37	L	L	2010 2011	0.8	-0.6	-2.1	5.1	53	94	113	94	18	1.0	-3.9	66	5.7	-1.3	-0.8	1.1	1.8
17	L	L	2009 2010	3.1	1.2	-4.5	3.3	37	67	86	72	11	0.9	-2.6	50	2.4	0.1	-0.4	0.1	0.9
E108	H	Myo	2011	-2.5	-0.3	-6.0	6.0	53	89	118	113	14	1.3	-3.6	63	2.8	-1.3	-1.1	0.7	1.0
F60	H	H, Myo	2011	0.5	-	-	4.5	37	78	97	-	10	-	-	55	-	-	-	-	-
N43	L	L	2011	-1.2	1.1	-3.7	5.0	42	73	89	86	15	2.3	-6.0	49	4.8	1.1	1.1	0.8	1.1
E8	H	Myo	2011	0	3.5	-4.9	5.4	45	81	98	95	8	0.6	-3.4	58	5.3	-1.4	-1.5	1.5	1.6
E76	H	Myo	2011	-2.8	0.5	-3.9	7.0	59	97	126	100	17	2.1	-4.6	68	4.9	-1.2	-1.4	0.9	1.8
E205	L	L	2011	-3.0	2.3	-1.6	6.9	50	85	106	94	14	2.0	-3.8	59	3.0	-1.0	-1.0	0.7	1.0
D87	Myo	H	2010 2011	-	-	-	3.2	-	-	-	-	-	-	-	-	-	-	-	-	-
E109	Myo	H	2011	-	-	-	3.1	-	-	-	-	-	-	-	-	-	-	-	-	-
N18	L	L	2011	-1.6	-1.4	-4.2	5.5	48	88	112	103	8	2.4	-3.3	65	5.2	0	0.4	0.3	2.2
Breed average 2009 born calves				**0**	**0.3**	**-2.6**	**4.5**	**37**	**69**	**88**	**81**	**12**	**1.3**	**-2.7**	**49**	**3.0**	**-0.1**	**-0.1**	**0.2**	**0.9**