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# Genetic and phenotypic aspects of live weight, body condition score and reproductive success of beef cows in New Zealand

A thesis presented in partial fulfilment of the  
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## Abstract

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The productivity of spring-calving beef cows under New Zealand hill country conditions is dictated by the seasonality of the system. With the calf being the primary production output, reproductive success of the cow, alongside growth and carcass merit of the calves, is essential. The objective of this thesis was to quantify live weight (LWT), body condition score (BCS) and reproductive performance of beef breeding cows in New Zealand's pastoral farming systems, both on a genetic and phenotypic level. This information was used to compare the profitability of cows that differ in their mature live weight (MWT) and other correlated traits exposed to variable feed availability.

The BCS of cows is a relevant indicator trait for productivity of the maternal herd on a phenotypic level. Cows in good body condition, particularly in the period leading up to mating, are more likely ( $P < 0.001$ ) to get pregnant. The curvilinear relationship indicates that most improvement may be obtained by reducing the percentage of low conditioned cows in the herd (75.7% pregnancy rate at BCS 4.5 versus 93.3% pregnancy rate at BCS 8). From a genetic perspective, the correlation between BCS and pregnancy rate was low ( $r_g = -0.10$ ). Pregnancy rate was considered as a separate trait for each of 15-month-old heifers, first-lactation 2-year-old cows and mature cows. Genetic variation and heritability were low for 15-month-old heifers and mature cows ( $h^2 \leq 0.06$ ), but greater for 2-year-old cows ( $h^2 = 0.12-0.14$ ), indicating that 2-year-old cows offered the greatest potential for selection on pregnancy rate. At all ages, heritabilities were greater for BCS ( $h^2 = 0.26$ ) and for MWT ( $h^2 = 0.48$ ) than for pregnancy rate. Placing downward pressure on MWT may decrease the ability of cows to reach BCS targets ( $r_g = 0.24$ ) which can impact on subsequent reproductive success.

Most growth and weight traits in finishing cattle had only limited genetic correlations with rebreeding ability of female herd replacements ( $r_g = 0.11-0.32$ ) or cow BCS ( $r_g = 0.12-0.36$ ) but high genetic correlations were observed with MWT ( $r_g = 0.45-0.92$ ) in the current study. Fat and muscle traits recorded on finishing animals were negatively genetically correlated with MWT ( $r_g = -0.40 - -0.19$ ) but were only weakly correlated with cow BCS ( $r_g = 0.02-0.25$ ).

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Comparison of simulated cows selected on the basis of MWT estimated breeding values (EBV) from within the current New Zealand Angus population indicated that there was little variation in profitability among different cow MWT types under conditions where supplementary feed in terms of increased pasture allowance was introduced to prevent excessive loss of condition. The cow MWT types in the simulation model differed in MWT EBV and correlated traits such as calf size, and adjustments in stocking rate were made to reflect changes in feed requirements per cow.

Overall, this thesis provided evidence that for cow-calf production systems where the primary focus is on enhancing the maternal performance of the cow, selection emphasis should be on improving rebreeding ability of 2-year-old cows as the most heritable reproduction trait, and on BCS of cows. Within the limitations of this study, cow types that differed in their MWT had only minor differences in profitability when simulated under a variable feed supply, such that selection strategies may lean towards prioritising the performance of finishing animals while taking advantage of those larger calves from bigger cows and accepting a correlated increase in MWT. This information can be used to develop guidelines for future genetic evaluation programs for beef cattle in New Zealand.

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*“All truly great thoughts are conceived while walking.”*

Friedrich Nietzsche, 1889

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## List of Abbreviations

**AI** = artificial insemination  
**ANOVA** = analysis of variance  
**BCS** = body condition score  
**BCS2** = body condition score of 2-year-old cows  
**BLUP** = Best Linear Unbiased Prediction  
**BPT** = beef progeny test  
**BWT** = birth weight  
**CEMA** = eye-muscle area (carcass)  
**CG** = contemporary group  
**CWT** = carcass weight  
**DfPC** = days from previous calving  
**DM** = dry matter  
**DNA** = deoxyribonucleic acid  
**DtCH** = days to conception of 15-month-old heifers  
**DtC2** = days to conception of 2-year-old cows  
**EBV** = estimated breeding value  
**EMA** = eye-muscle area (ultrasound)  
**FA** = front feet angle  
**FC** = fat colour (carcass)  
**FCS** = front feet claw set  
**FD<sub>P8</sub>** = fat depth at the P8 rump site (ultrasound)  
**FD<sub>RIB</sub>** = fat depth at the 12/13th rib site (ultrasound)  
**FF** = front legs front view  
**GL** = gestation length  
**HBCS** = body condition score of 15-month-old heifers  
**HBV** = herd mean breeding value  
**HHIP** = hip height of 15-month-old heifers  
**HIP** = hip height  
**HIP2** = hip height of 2-year-old cows  
**HP** = pregnancy rate of 15-month-old heifers

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**HWT** = live weight of 15-month-old heifers  
**h<sup>2</sup>** = heritability  
**IMF** = intramuscular fat percent (ultrasound)  
**lsmeans** = least-square means  
**LWG** = live weight gain  
**LWT** = live weight  
**LWT<sub>adj</sub>** = live weight adjusted for weight of the conceptus during pregnancy  
**LWT<sub>ref</sub>** = live weight at a reference BCS of 6  
**MB** = marbling (carcass)  
**MBCS** = body condition score of mature cows  
**MC** = meat colour (carcass)  
**MCP** = maternal cow project  
**ME** = metabolizable energy  
**MHIP** = hip height of mature cows  
**MWT** = mature live weight  
**MWT<sub>BCS</sub>** = mature live weight adjusted for body condition score  
**MWT<sub>HIP</sub>** = mature live weight adjusted for hip height  
**OA** = overall feet angle  
**OCS** = overall claw set  
**OSS** = ossification score (carcass)  
**PD** = pregnancy diagnosis  
**PPAI** = postpartum anoestrus interval  
**PR** = pregnancy rate of mature cows  
**PWG** = post-weaning gain  
**PYG** = post-yearling gain  
**RA** = rear feet angle  
**RB** = rebreeding performance of 2-year-old cows  
**RCS** = rear feet claw set  
**RF** = rib fat depth (carcass)  
**RH** = rear legs hind view  
**RS** = rear legs side view  
**SD** = standard deviation

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**SE** = standard error

**SNP** = single nucleotide polymorphism

**WT2** = live weight of 2-year-old cows

**WWR** = weaning weight ratio

**WWT** = weaning weight of calves

**WWT<sub>D</sub>** = direct genetic effect on calf weaning weight

**WWT<sub>M</sub>** = maternal genetic effect on calf weaning weight

**W18** = 18-months-weight

**YHIP** = yearling hip height

**YWT** = yearling live weight

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## General introduction

The role of beef breeding cows under New Zealand hill country cow-calf production systems is twofold: Their direct contribution to farm revenue is realised through production of calves (Charteris *et al.*, 1999, Morris & Smeaton, 2009) and their own value at culling; indirectly they contribute to farm performance through pasture management (Pleasants *et al.*, 1991) and increased productivity of other livestock classes farmed alongside cows such as sheep and deer (McCall, 1994, Morris, 2007). Cows are calved in spring in order to best align the nutritional requirements of the cows with pasture growth to optimise production (Pleasants *et al.*, 1991, McCall, 1994, Coleman *et al.*, 2018).

With the calf being the primary production output from beef breeding cows, high reproductive performance is crucial to ensure profitability of the cow herd (Diskin & Kenny, 2016). Knowledge of key performance parameters throughout the annual production cycle such as live weight (LWT) and body condition score (BCS) with potential implications on the reproductive performance of the herd is essential to reach production targets (Morris *et al.*, 2010) and to optimise the role of beef breeding cows on extensive hill country pasture (Hickson *et al.*, 2017). Limited information exists on the phenotypic and genetic performance of beef breeding cows under seasonal grazing systems in New Zealand hill country. Thus, it is useful to understand to what extent maternal performance can be improved under those variable environments, and how this might influence other correlated traits.

Historically, selection for improved performance in beef herds was primarily focused on the finishing performance of the progeny (Arango & Van Vleck, 2002, Pardo *et al.*, 2020). Selection criteria for finishing progeny may be considerably different to those relevant for the maternal herd where the focus is generally on reproductive efficiency (Diskin & Kenny, 2016) rather than growth and carcass characteristics (Wilson *et al.*, 1976, Wolcott *et al.*, 2013). Both production systems need to complement each other (Fitzhugh, 1978) to prevent potential conflicting developments in correlated traits and to, ultimately, optimise the profitability of the entire beef herd.

In commercial cow-calf production systems, feed allocation to cows is driven primarily by availability due to seasonal fluctuations in pasture growth as a response to climatic conditions and management strategies rather than by the nutritional requirements of

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the animals (Morris & Hickson, 2016). The flexibility and buffering capacity of beef breeding cows in terms of storing body energy reserves in times of ample feed and mobilising body condition as a response to nutritional restrictions (Pleasants *et al.*, 1991, Pleasants *et al.*, 1994) is often used as a tool to adjust the feed demand of the herd to better suit the pasture growth curve (Adams *et al.*, 1996, Morris, 2007). Accounting for the variability in feed allocated to the cow herd can have implications for the profitability of the cow-calf production system. The profitability of the farming systems is dependent on management strategies and environmental conditions that dictate variability in feed supply and may vary for cows that differ in their mature live weight (MWT).

The aim of this thesis was to quantify the LWT and BCS of beef breeding cows, and their reproductive success, both on a genetic and on a phenotypic level, and to evaluate how cows that differed in MWT estimated breeding values (EBV) respond to seasonal variation in feed availability. More specifically, the objectives were:

- 1) to quantify LWT and BCS profiles of beef cows on extensive hill country pasture (Chapter 2),
- 2) to evaluate the relationship between BCS with reproductive success (Chapter 3),
- 3) to define key maternal performance traits and examine their genetic and phenotypic correlations among each other (Chapter 4),
- 4) to determine the correlations of key maternal traits with finishing performance of heifer and steer progeny (Chapter 5),
- 5) to develop a bio-economic model to quantify the performance of a cow herd in response to a consistent annual or variable feed supply (Chapters 6) and
- 6) to evaluate the performance and profitability of cows that differ in their MWT and other correlated traits under a variable feed supply (Chapter 7).

Data for this research originated from a central beef progeny test study on five commercial New Zealand hill country farms. The project was initiated in 2014 and funded by Beef + Lamb New Zealand Genetics. Records were obtained as part of the project for a variety of maternal and finishing traits for a total of 4,473 Angus and Hereford cows and their progeny, either retained as herd replacements or finished for slaughter, and these provided the basis for analysis in this research.

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This study will provide evidence relating to the genetic parameters of key maternal and finishing traits, which can be used to inform subsequent selection strategies. Outcomes from this thesis will also provide a basis for future research in cow-calf production systems and can be used by farmers to evaluate performance and productivity of their herd and enhance overall profitability through management of seasonal LWT and BCS targets with potential implications on the reproductive performance of the herd. Furthermore, the development of a bio-economic simulation model will provide a foundation to examine the flexibility and buffering capacity cows provide to the farming system in terms of the impact of cows of different MWT EBV on the profitability of the cow-calf production system in response to variable feed availability.

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## **Chapter 1 – Review of Literature**

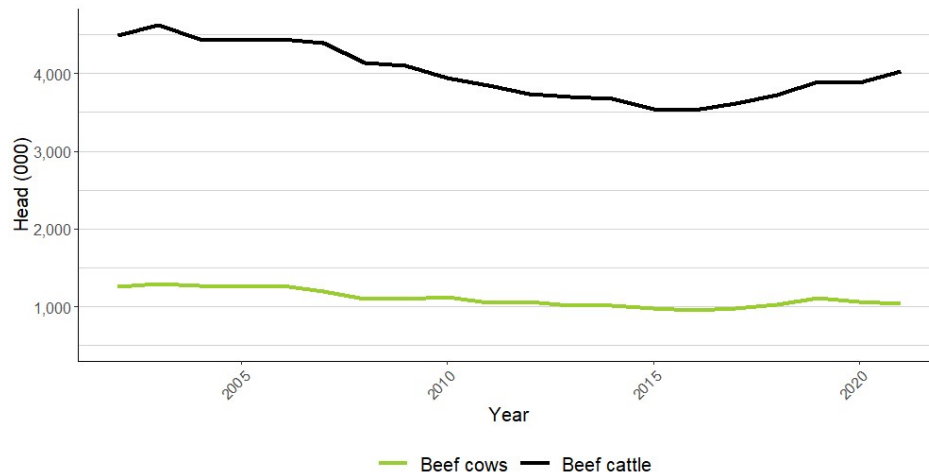


## 1.1 The New Zealand beef industry

The New Zealand beef industry is based on an extensive, year-round grazing system (Carter, 1975, Morris, 2013b). The pasture-based feeding system makes New Zealand highly competitive in the international market (Beef + Lamb New Zealand, 2017b) due to pasture being a sustainable, low-cost feed (Morris & Kenyon, 2014). Pasture makes up about 95% of the diet of sheep and cattle (Morris, 2013b, Morris & Kenyon, 2014, Valentine & Kemp, 2017), allowing most of New Zealand's beef cattle exports to be classified as grass-fed beef (Beef + Lamb New Zealand, 2017b).

Most New Zealand beef cattle are farmed in mixed livestock systems, with the majority of beef cattle farmed in conjunction with sheep (Beef + Lamb New Zealand, 2017a). Only a few farms concentrate solely on beef production. Due to their pasture and health requirements, beef cattle and sheep can be managed complementary to each other (McCall, 1994, Beef + Lamb New Zealand, 2017a), especially under hill country conditions (Morris, 2013a). For farmers it is relatively easy to modify their composition of sheep and cattle numbers on farm in response to current economic demands (Charteris *et al.*, 1999).

The total number of beef cattle in New Zealand was approximately 4.02 million in 2021, of which about 70% were located in the North Island (Beef + Lamb New Zealand, 2022). The percentage of beef breeding cows and heifers in the beef cattle population has declined from 36% in 1973 to 26% in 2021 (Morris & Smeaton, 2009, Stats NZ, 2021). Current trends, however, indicate a relatively stable number of heifers and cows (Figure 1.1), whereas the numbers of other beef cattle, including weaner calves, has increased (Beef + Lamb New Zealand, 2022).



**Figure 1.1** Total number of beef cattle and beef breeding cows and heifers in New Zealand from 2002 until 2021 (Stats NZ, 2021).

Due to the extent of the country's land, stretching across 13 degrees of latitude (Beef + Lamb New Zealand, 2021), farming systems can vary greatly among farm types and are largely dependent on the climate and topography. Weather conditions can differ significantly throughout the country and within regions (NIWA, 2022), from subtropical regions in the north to the colder southern parts of the country (Charteris *et al.*, 1999). Sheep and beef farms are mainly situated in steeper hill country regions (Carter, 1975, Morris, 2013b). On those properties, soil can be of lower fertility (Beef + Lamb New Zealand, 2017b) and environmental conditions vary largely across regions and within and among years. As a result, farming operations can be rather complex, having to manage variable feed resources throughout the annual production cycle (Charteris *et al.*, 1999, Machado *et al.*, 2005, Beef + Lamb New Zealand, 2017a).

The beef breeding cow herd is dominated by the two maternal breeds Angus and Hereford (Morris, 2013a). Maternal sires are used within the breeding herd to sire herd replacements. Heavier European breeds such as Simmental, Charolais, South Devon and Limousin (Bass *et al.*, 1975, Carter, 1975, Baker *et al.*, 1990) were imported into New Zealand from the late 1960's (Morris, 2008) and also contribute to the beef industry, although to a considerably lesser extent. Those breeds are generally used for crossbreeding to improve productivity of the herd by making use of hybrid vigour, also known as heterosis (Cartwright, 1970, Hickson *et al.*, 2014). They mainly contribute to the beef sector as terminal sires, with their progeny being predominantly finished and slaughtered (Morris, 2008, Beef + Lamb New Zealand, 2017a) and not used to generate

replacements for the maternal herd. Cattle born in the dairy industry also contribute to the beef industry as part of finishing operations. The dairy herd directly contributes to the beef sector through slaughter of cull cows and 4-day old bobby calves and indirectly through the supply of Friesian and crossbred bull calves as well as beef-cross dairy calves. In 2018/19 Angus made up the largest percentage of beef cattle with approximately 34%, whereas 10% were Hereford and 10% Angus-Hereford crosses. A further 18% were referred to as unclassified 'mixed' beef cattle, 16% Friesian, 4% Hereford-Friesian crosses and 7% were classified as 'other' breeds (Beef + Lamb New Zealand, 2021).

## **1.2 Production systems for beef breeding cows**

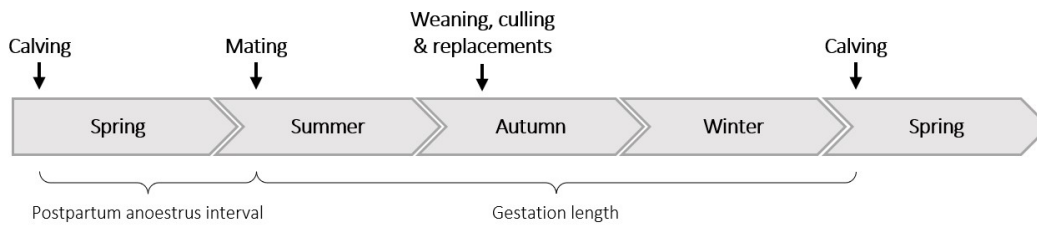
New Zealand's beef cattle systems can generally be divided into two sectors; the cow-calf production system which produces weaned calves versus the finishing sector in which cattle are raised post weaning for processing (Charteris *et al.*, 1999, Morris, 2007, Morris, 2013b).

Beef breeding cows play a key role within New Zealand cow-calf production systems and their primary contribution to the productivity of the entire farming systems is realised through production of calves for the next generation (Morris & Smeaton, 2009). Generally, male beef breed calves are castrated and raised as steers for slaughter as part of the finishing operation on higher fertility lowland country (Charteris *et al.*, 1999, Morris, 2013b). Female calves are primarily retained as replacements for old and cull cows within the cow-calf production system with the remainder raised alongside steers for slaughter as part of the finishing operation (Beef + Lamb New Zealand, 2017a).

### **1.2.1 The annual production cycle of beef breeding cows**

The cow-calf production system in New Zealand is based on seasonal calvings where the reproductive cycle of the cow is typically aligned with the annual pasture growth curve. Thus, maintaining a 365-day calving interval is essential (Grosshans *et al.*, 1997, Diskin & Kenny, 2016, Coleman *et al.*, 2018) and is realised through a restricted calving season. Calving generally occurs in spring (Figure 1.2) to ensure that the timing of rapid pasture growth in spring provides sufficient feed supply to meet the nutritional requirements of cows during late pregnancy and early lactation (Montgomery, 1985, McFadden *et al.*, 2005, Diskin & Kenny, 2016). Reproductive performance of the herd can be improved by cows calving later in spring with higher pregnancy rates and

reduced postpartum anoestrus intervals (PPAI) (Montgomery, 1985, Smeaton *et al.*, 1986). From a management perspective, a compact calving season is desirable to allow suitable feed allocation to meet the nutritional demands of the dam, ensure easier management and animal handling procedures and higher average calf weaning weights (WWT) (Morris *et al.*, 2006, Hickson *et al.*, 2011, Diskin & Kenny, 2016, Beef + Lamb New Zealand, 2017g) while allowing the cow more time to get back in calf the following mating season with sufficient time for the PPAI (Lesmeister *et al.*, 1973). Calving early within the first calving period has the potential to increase cow lifetime productivity (Hickson *et al.*, 2011).



**Figure 1.2** Reproductive cycle of beef breeding cows on New Zealand hill country farms.

A short calving spread may be realised through a confined mating season. On commercial farms beef breeding cows are generally mated via natural mating with the bull remaining with the breeding herd for approximately 63 days (McFadden *et al.*, 2005, Morris & Smeaton, 2009). This allows cows to cycle up to three times based on a 21-day oestrus interval. The industry target is to achieve 60% of cows conceiving within the first cycle (Morris, 2007, Beef + Lamb New Zealand, 2017g). From a management perspective and to achieve high reproductive performance, a high percentage of cows conceiving early in the breeding season is desirable, resulting in earlier calving dates which may subsequently lead to increased WWT (Lesmeister *et al.*, 1973) and higher fertility (Beef + Lamb New Zealand, 2017c). McFadden *et al.* (2005) reported a mean pregnancy rate of 91% based on data from 1,005 beef cow herds in New Zealand. Within a 63-day mating season (equivalent to three 21-day cycles), a pregnancy rate of at least 95% is desired for mature cows to ensure a high proportion of calves weaned per cow mated (Beef + Lamb New Zealand, 2017g). Systems under natural mating conditions and seasonal calvings often use pregnancy

rate as a measure of reproductive success to determine number of cows conceiving within a certain time frame from the start of the mating season (Grosshans *et al.*, 1997, Berry *et al.*, 2003). Researchers are often differentiating between pregnancy rates in heifers and mature cows but rarely make further distinctions at other ages. According to Hickson *et al.* (2008) farmers are often concerned with the rebreeding ability of first-calving 2-year-old cows due to high energetic demands during first lactation and to meet nutritional requirements for growth. The single most important factor for cows leaving the breeding herd is due to failure to conceive (Beef + Lamb New Zealand, 2017a) and is therefore of economic relevance for the farmer.

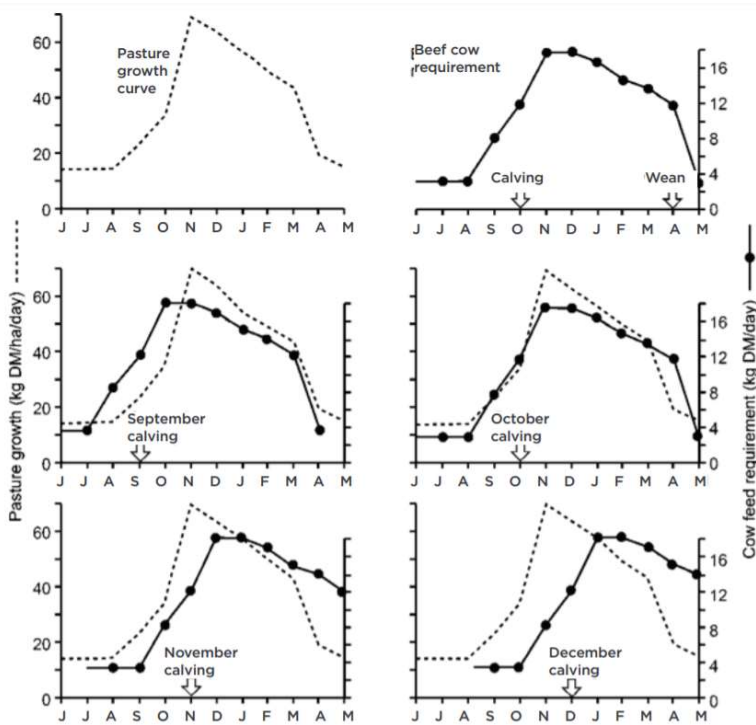
Beef breeding cows in New Zealand were traditionally first mated at 27 months of age (Hickson *et al.*, 2008), resulting in first calves being born to three-year-old cows (Morris & Smeaton, 2009). Nowadays, about 55% of heifers are mated at 15 months of age to achieve an age at first calving of two years (Beef + Lamb New Zealand, 2017g). Calving heifers for the first time at two rather than three years of age has the potential to improve reproductive efficiency (Lowe, 1994, Hickson *et al.*, 2011) and cow lifetime production (Morris & Smeaton, 2009, Hickson *et al.*, 2010) and may lead to shorter generation intervals and subsequently increased rates of genetic improvement. Reproductive performance, however, tends to be lower in younger cows with pregnancy rates likely to increase with the age of the cow (Beef + Lamb New Zealand, 2017g).

The gestation length (GL) of cows is a contributor for maintaining a 365-day calving interval (Coleman *et al.*, 2018) and can differ due to several factors, such as breed of sire and dam, age of the dam (Bourdon & Brinks, 1982) and sex of the calf (Reynolds *et al.*, 1990). With an average GL in beef cows of 282 days, cows have approximately 83 days to get back in calf for the following production cycle (Morris & Smeaton, 2009) if they are to maintain a 365-day calving interval.

### ***1.2.2 The role of the beef breeding cow in pasture management***

Besides their contribution to the next generation of calves, beef breeding cows play a major role in pasture management. Pasture growth, supply and quality is highly dependent on the season (Clark & Woodward, 2007, Litherland & Lambert, 2007) and can vary considerably over the year and among years due to climatic variation, such as rainfall and temperature variations. From a commercial perspective, it is challenging to match seasonal feed supply with nutritional demands of the cows. Producing silage by

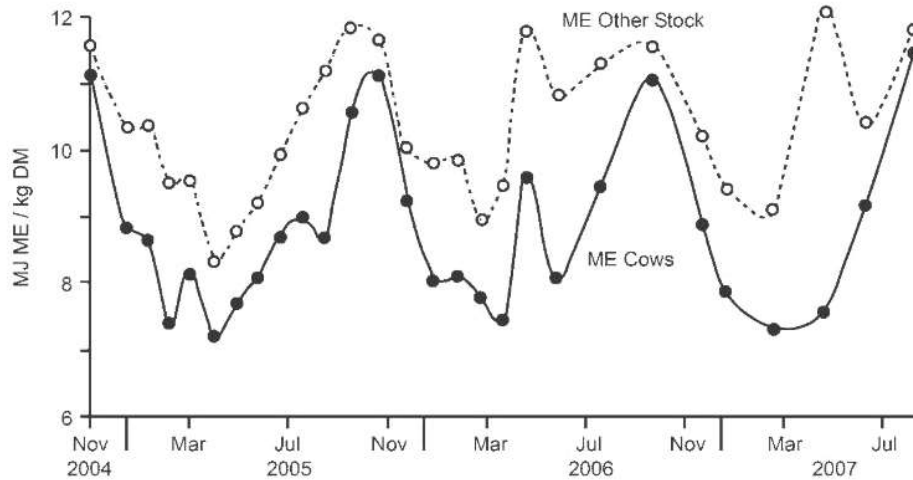
mowing pasture that has accumulated due to a mismatch of supply of pasture relative to demand during spring, is often not feasible on hill country farms. Instead, flexible feed demand that suits the seasonal variability are required (Machado *et al.*, 2005) to enable sufficient feed intake when there is enough feed available, but lower intake in times of feed shortage. Beef breeding cows are used on hill country farms to provide this flexibility and annual feed demand of cows can be aligned with the seasonal pasture growth curve (Adams *et al.*, 1996, Morris, 2007). Calving date is a management tool often used to match average feed demands with average pasture availability (Figure 1.3) (Adams *et al.*, 1996, Morris & Smeaton, 2009, Diskin & Kenny, 2016).



**Figure 1.3** Pasture growth curve (kg DM/ha/day; dashed line) and feed requirements (kg DM/day; solid line) for cows varying in calving dates (adapted from Morris & Smeaton (2009)).

In times of increased pasture growth in early spring, beef breeding cows generally consume pasture in excess of their requirements and utilise the surplus feed to rapidly gain live weight (LWT) up to 1kg/day (Morris, 2007) and store surplus feed as body energy reserves (Pleasant *et al.*, 1991). At this time pasture quality typically reaches its highest point (Litherland & Lambert, 2007). Having adequate body energy reserves,

cows can then be fed below their maintenance and production requirements when feed is in short supply which will result in them mobilising body energy reserves as a nutritional buffer to support themselves throughout months of feed shortage (Law *et al.*, 2013). The cows ability to consume large volumes of forage relative to their requirements (McCall & Scott, 1988) allows them to eat low quality pasture while maintaining their own productivity (Law *et al.*, 2013) which results in cows often being offered the lower quality feed on farm. This provides a method for removing grass that has become senescent during periods of excessive pasture growth, allowing fresh, high-quality pasture to grow back subsequent to grazing of the cows (Pleasants *et al.*, 1991, McCall, 1994). While the cow provides flexibility in being able to adjust daily intake to match pasture supply by gaining and mobilising body energy reserves, cows also consume poor quality feed on farm to refresh pasture for other livestock classes (Morris, 2007) which is why management strategies on farm often utilise complementary grazing. Beef breeding cows are primarily farmed alongside other, more profitable livestock enterprises such as sheep or finishing beef cattle (Beef + Lamb New Zealand, 2017f) to maximise their performance by improving pasture cover and/or quality (McCall, 1994). A report by Morris & Smeaton (2009) outlined a difference in average metabolisable energy (ME) consumption of cows of 8.8 MJ ME/kg dry matter (DM) as opposed to other stock classes which consumed approximately 10.3 MJ ME/kg DM throughout the year (Figure 1.4). Beef breeding cows tend to be more profitable on low quality pasture compared with other livestock classes (Morris & Smeaton, 2009). The ability of cows to cope with variability in nutritional levels (Pleasants *et al.*, 1994) can be used to buffer other livestock classes that are less adaptable to seasonal fluctuations (Pleasants *et al.*, 1991).



**Figure 1.4** Average metabolisable energy content of pasture (MJ ME/kg DM) available to beef breeding cows (solid line) and other livestock classes on farm (dashed line; adapted from Morris & Smeaton (2009)).

Supplementation is the primary management strategy to overcome feed deficits over winter and dry summer months (De Ruiter *et al.*, 2007, Morris, 2013b) and is predominantly provided through conserved pasture such as hay or silage (Morris, 2007). Efficiency of supplementation is, however, often limited on extensive hill country farms due to high cost and challenges in harvesting excess pasture and/or providing supplementation on steep terrain on a regular basis (McCall & Scott, 1988). As a result, supplementation is used more often for finishing cattle but is rare for beef cows within the breeding herd. Compared to those farming systems internationally where finishing stock is often grown on grain supplements (Robinson & Oddy, 2004, Greenwood *et al.*, 2018) and/or cows receive supplementation in form of crop residues (Males, 1987, Russell *et al.*, 1993) in times of feed shortage to maintain performance, New Zealand's farming systems rely on utilising the buffering capacity of cows in terms of their ability to adjust body energy reserves and to renew pasture cover.

### **1.2.3 Performance parameters of beef breeding cows**

The contribution of beef breeding cows to the farming system is twofold: while cows are required to produce a live and healthy calf each year to either contribute to the next generation of herd replacements or finishing animals for slaughter, cows need to be able to adjust their individual requirements to a variable, seasonal environment determined by climatic conditions and/or management strategies (Beef + Lamb New

Zealand, 2017a). Optimising the role of beef breeding cows on extensive hill country pasture requires knowledge of the performance of animals under those variable farming conditions to best align reproductive efficiency with nutritional demands. Cows are required to provide flexibility to the farming system (Pleasants *et al.*, 1994) while maintaining a high level of production (Law *et al.*, 2013). Monitoring and managing LWT and body energy reserves of cows throughout the annual production cycle may be an efficient tool to determine herd feed demand (Morris & Smeaton, 2009) and to optimise the reproductive performance of cows (Hickson *et al.*, 2017). Under commercial environments, traits such as LWT and body condition score (BCS) are relatively easy traits to measure (Morris *et al.*, 2010) and may be used as performance indicators to reach production targets.

While LWT generally is a good indicator of the feed requirements of the animals, it is dependent on several parameters such as breed, nutritional status, stage of the reproductive cycle and size of the cows (Morris *et al.*, 2002). Cows continue to grow in size and increase body weight until they reach their mature live weight (MWT) at approximately five to six years of age (Northcutt *et al.*, 1992, Tennant *et al.*, 2002).

The BCS of cows is a proxy for the stored body energy reserves of cows in terms of body fat and muscle reserves (Wagner *et al.*, 1988, Bishop *et al.*, 1994) and reflects the relative amount of metabolisable fat and muscle that is available as an energy source. In times when energy requirements of cows exceed the amount of feed available, cows lose weight by burning fat and protein tissue. If feed is in ample supply, however, cows gain primarily fat and only a minimal proportion of protein tissue such that the proportion of body fat is getting progressively higher at greater BCS (Lalman *et al.*, 2021). Body condition score is generally a more accurate predictor for body energy reserves of the animals (Wagner *et al.*, 1988, Bishop *et al.*, 1994, Morris *et al.*, 2002) and is independent from the LWT and frame size of the animals (Hickson *et al.*, 2017) and not influenced by factors such as gut-fill and weight of the conceptus during pregnancy (Morris *et al.*, 2002, Diskin & Kenny, 2016).

Typically, BCS of beef breeding cows in New Zealand is evaluated through visual assessment and assessed on a 1-10 (Smeaton *et al.*, 2000, Hickson *et al.*, 2017) or a 0-5 (Morris *et al.*, 2002) scale. Measures of BCS can be used to evaluate body energy reserves at certain critical time points throughout the year to improve feed planning and may be used to enhance reproductive performance of the breeding herd (Morris *et*

*al.*, 2002, Morris *et al.*, 2006, Tait *et al.*, 2017). Determining the level of body energy reserves cows are in at different stages of the reproduction cycle may provide a useful tool to align stocking rate with pasture feed supply under extensive farming conditions (Beef + Lamb New Zealand, 2017d).

#### ***1.2.4 Aligning nutritional requirements of the cows with seasonal pasture availability***

The nutritional level of cows as reflected by LWT and/or BCS may impact on the productivity of the herd at various stages of the production cycle. According to Morris (2007) nutritional requirements of spring-calving beef cows across the season can be divided into four periods which need to align with the annual pasture growth curve in a way to optimise profitability of the farming system:

1. Post-weaning period: weaning until 4 to 6 weeks prior to calving
2. Pre-calving period: 4 to 6 weeks prior to calving
3. Post-calving period: calving until start of the mating season
4. Post-mating period: following the mating season until weaning

##### *1) Post-weaning period*

Calves are generally weaned in New Zealand between five and seven months of age (Morris *et al.*, 2006). Weaning weights are thereby dependent on weaning dates which often align with regional market dates but may also vary due to feed supply. Following weaning of their calves and until approximately one to two months prior to the subsequent calving season, cows are of low priority on farm and primarily take on the role of improving pasture quality and utilisation to the benefit of other livestock classes (Morris, 2007). During this time, cows may utilise surplus body energy reserves without suffering in performance, provided sufficient pasture resources are allocated to the cow in the period prior to calving. Especially during the first half of pregnancy energy requirements for the conceptus are low and no additional energy is required for production following weaning (non-lactating period) (Freer *et al.*, 2007). Utilising the cow during this time to remove senescent pasture can significantly benefit overall profitability on sheep and beef farms.

##### *2) Pre-calving period*

This is a critical time for cows to regain or at least maintain BCS in order to prepare for the upcoming calving season to avoid calf loss and metabolic issues during parturition.

This may, however, not always be feasible under extensive pasture-based farming systems. Generally, this time should align with the onset of increased pasture growth in early spring to provide sufficient nutrients over this period and to support the increasing energy requirements of the cows during late pregnancy due to the fast-growing fetus in utero. Research has shown that poor nutrition prior to calving may have a negative impact on subsequent reproductive performance (Bellows & Short, 1978, Hess *et al.*, 2005).

### *3) Post-calving period*

The BCS cows are in at the start of calving is directly related to BCS at the subsequent mating (Hess *et al.*, 2005) and is therefore vital for subsequent reproductive performance of beef breeding cows (Osoro & Wright, 1992). Cows that are at a higher nutritional level pre-calving are likely to also exhibit above average energy reserves at mating (carry-over effect of BCS) and may be more likely to show reproductive success. Generally, the post-calving period is the most critical in relation to all aspects of cow-calf production and survival. This is the time when it is critical to manage the calving season to align with the peak in pasture growth in spring and to provide sufficient nutrients for the peak in milk production (Adams *et al.*, 1996). The level of feed will affect live weight gain (LWG) and reproductive ability of the cow and growth potential of the calf in the weeks leading up to mating (Smeaton *et al.*, 1983). The feed allowance level during gestation and following calving has an important effect on postpartum reproductive performance in first-calving heifers (Bellows *et al.*, 1982) and may impact on the PPAI (Wright *et al.*, 1992, Diskin & Kenny, 2016) and re-breeding performance in cows (Morris & Smeaton, 2009). With increasing body energy reserves, the PPAI is likely to decrease (Wright *et al.*, 1992) which may have a positive impact on early conception due to an increased number of opportunities for cows to conceive.

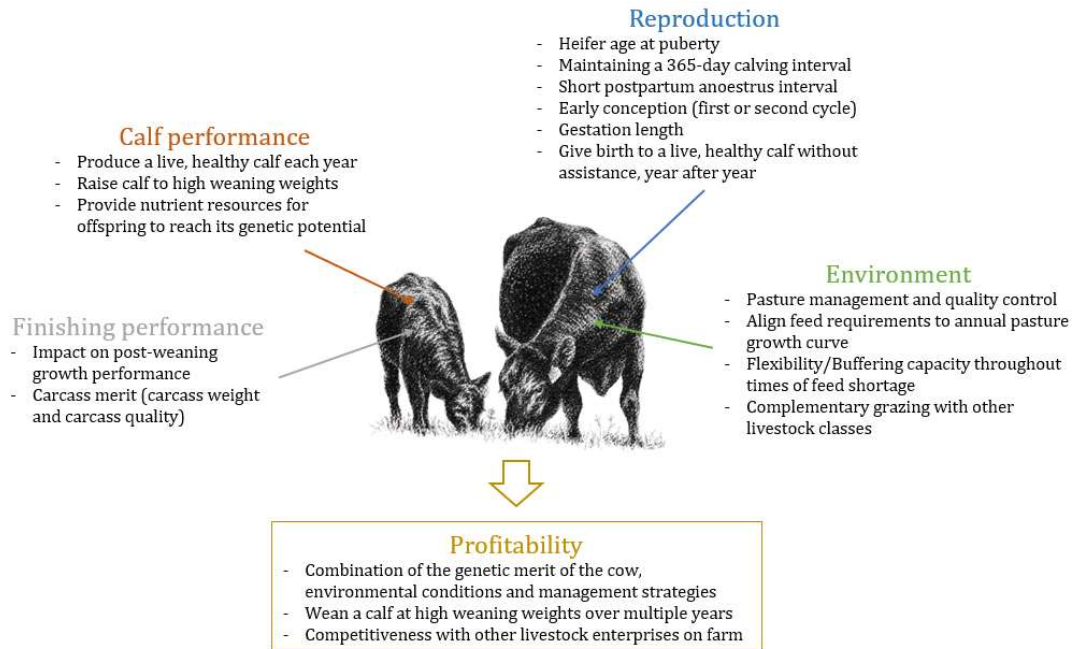
Usually, pasture allowance at that time is high enough for milk production to not be negatively affected (Morris, 2007). An increase in LWT and BCS during this time occurs when the energy intake exceeds the requirements for maintenance and milk production. Consequently, cows with higher overall milk production generally show a lower increase in LWT during this period compared to low-milking cows. Similarly, WWT are only marginally affected by pasture allowance of the cow due to milk production generally being maintained by the cow (Morris, 2007).

4) *Post-mating period*

In the period following mating and up until weaning, feed supply is usually high enough for cows to gain LWT and BCS. However, dry conditions and in extreme situations droughts are possible in which case loss in body energy reserves can occur (Morris *et al.*, 2006, Hickson *et al.*, 2017). As long as LWT loss is not severe, growth rates of calves generally do not suffer, and WWT is only marginally affected. However, at this time it is particularly challenging to separate the effects of milk and pasture on WWT with calves starting to compete for pasture at this time. During this period, it is critical to ensure that cows have sufficient body energy reserves going into the next winter (Charteris *et al.*, 1999).

**1.2.5 Productivity measures and profitability of the cow-calf system**

Defining maternal productivity is challenging, due to females contributing in various ways to the value of the entire production system. Generally, to evaluate the profitability of the beef breeding cow, her whole life cycle needs to be taken into account, and both inputs and outputs need to be considered (Figure 1.5; Archer *et al.*, 1999, Morris, 2008). Reproduction and nutrition are thereby the two most influential factors (Hess *et al.*, 2005) such that, from a commercial perspective, the aim is to maximise reproductive performance of the beef cow while maintaining feed intake and, ultimately, minimising feed costs (Archer *et al.*, 1999).



**Figure 1.5** The role of beef breeding cows on New Zealand extensive hill country pasture.

The cost of rearing a replacement heifer to birth of her first calf generally marks the start point at which maternal productivity is measured and ends with that calf either successfully rearing its own progeny (Walmsley *et al.*, 2018) or being finished for beef production. To achieve an overall high lifetime productivity, cows are expected to get in calf early in the breeding season, give birth without assistance, rear a live, healthy calf until weaning while at the same time ensuring high WWT and getting back in calf the following mating season to repeat the same cycle while maintaining a 365-day calving interval (Walmsley *et al.*, 2018).

In cow-calf production systems where the calf is often the sole production output of the beef breeding cow profitability is highly dependent on the reproductive performance of the breeding herd (Diskin & Kenny, 2016), especially under New Zealand's extensive, seasonal calving conditions with a confined mating period (Berry *et al.*, 2014). The primary measure of profitability of the breeding herd is generally determined by the calving percentage (number of calves weaned divided by the number of cows mated) or WWT as a proportion of the LWT of the cows or energy intake per cow and calf unit (Walmsley *et al.*, 2018) or numbers of calves reared regarding a cow's lifetime production (Hickson *et al.*, 2011, Morris & Hickson, 2016). While there may be potential

to enhance reproductive performance in beef breeding cows achieving this goal has been proven challenging, with the national calving percentage being relatively static over the last 30 years ranging from 80 to 84% (Morris & Smeaton, 2009, Morris & Hickson, 2016). The target LWG to achieve high WWT is 1 kg per day (Morris, 2013a) although this target is rarely achieved under extensive hill country conditions, where cows are used to maintain pasture quality. The amount of calf LWG up until weaning is a good indication of the milk supply of the dam (Arthur *et al.*, 1997) with approximately 70% of variation in WWT explained by the milk supply of the dam (Morris & Smeaton, 2009) and, therefore, her feeding level as a reflection of pasture availability (Morris, 2007, Beef + Lamb New Zealand, 2017a). The majority of energy intake of the calf prior to 12 weeks of age is from milk production of the dam whereas approximately 50% of the total energy intake of the calf may be substituted by pasture past this point (Greenwood & Cafe, 2007, Roca Fraga, 2013).

The single largest expense in the cow-calf production system is the feed supply necessary for maintenance and productivity of cows (Law *et al.*, 2013). Increasing feed efficiency (Archer *et al.*, 1999) by improving the feed conversion ratio (amount of feed consumed as a proportion of LWG; Arthur *et al.*, 2001, Morris *et al.*, 2014) may be used as a tool to enhance overall farm profit. Most feed intake is utilised for maintenance rather than production (lactation and/or gestation) (Morris *et al.*, 2014). Larger cows with greater LWT generally have higher energy requirements for maintenance and tend to consume more feed compared to lighter cows (Smeaton *et al.*, 2000, Arthur *et al.*, 2004, Morris, 2008). Although this generally results in lower maintenance costs of lighter cows, they also generate less revenue from the carcass at culling and wean lighter calves. Cows can be considered efficient if a greater proportion of feed intake is converted into WWT through milk production rather than improving their own condition, i.e., weaning a calf heavier than 50% of the dams LWT at weaning (Morris & Hickson, 2016). Beef + Lamb New Zealand (2017a) suggested the most suitable cow type for extensive New Zealand hill country production systems to be an animal of moderate frame size with approximately 500 to 530 kg LWT and a weaning BCS of 7, whereas her calf should achieve a WWT of 240 kg at about 200 days of age. The optimal frame size of cows, however, has been discussed for many years (Law *et al.*, 2013) and may vary largely across production systems throughout New Zealand and more so in a global context (Arango & Van Vleck, 2002).

Compared with other livestock classes on farm beef breeding cows are considered to be of poorer profitability on a gross margin/kg DM eaten basis (Beef + Lamb New Zealand, 2017a). This is primarily due to low reproductive rates (Arango & Van Vleck, 2002, Law *et al.*, 2013, Morris & Hickson, 2016) and their energy inefficiency with the highest proportion of energy (65–75%) required in a beef production system (from conception to slaughter) being utilised by the breeding herd (Gregory, 1972, Montaño-Bermudez *et al.*, 1990), where most of the feed consumed (approximately 70%) is used for maintenance rather than production (Ferrell & Jenkins, 1984, Archer *et al.*, 1999). This highlights the importance of body size to profitability with the two most relevant components being MWT and milk production (Arango & Van Vleck, 2002). Current evaluations of beef cow profitability, however, often do not account for their role in pasture management where beef cows are generally able to utilise low quality feed much more profitably compared to sheep or deer while allowing for higher quality pasture to be offered to those other livestock classes (Beef + Lamb New Zealand, 2017a).

### **1.3 Genetic improvement of maternal performance**

The majority of beef cattle in New Zealand are farmed within commercial herds, and only a small number of animals are recorded individually, despite all cattle being tagged with an electronic identification tag as part of the national animal identification and tracing scheme (Ministry for Primary Industries, 2020). Animals with performance records are generally based in seedstock herds. Most performance recording herds are registered with breed societies and pedigree recording is compulsory within a breed society. Most bulls used for mating on commercial beef farms originate from those registered herds (Beef + Lamb New Zealand, 2017e). To achieve genetic gain within a commercial herd the genetic merit of the breeder's herd must be above that of the commercial herd and selecting the most suitable bull should be focused on traits that follow the breeding objective of the commercial herd. Genetic gain may be primarily realised through bull selection but ideally replacement heifers should be genetically superior compared to their predecessors for economically relevant traits within the commercial farming system for sustained genetic improvement of the breeding herd (Diskin & Kenny, 2016, Beef + Lamb New Zealand, 2017e).

According to Morris (2008) breeding objectives for beef breeding cows on commercial New Zealand hill country farms generally align with management objectives and focus on:

- Achieving high calf weaning rates (95 calves per 100 cows mated each year)
- WWT in excess of 50% of cow's LWT at weaning
- Reducing calf death rate (2–3% per year)
- Enhancing role of cows in pasture management

### **1.3.1 Genetic parameter estimation**

Traits of interest should be economically important, heritable, measurable and variable within the population in order to achieve genetic gain and to be incorporated into a breeding program (Morris & Smeaton, 2009). Estimation of genetic parameters of key performance traits are essential in animal breeding and used to estimate breeding values and to predict genetic gain (Lush, 1949). The heritability of a trait is a key indicator as to whether certain traits can be genetically influenced and is based on the assumption that both genetic and environmental components describe the phenotypic variance of a quantitative trait (Bochud, 2012). Heritability is defined as the proportion of the phenotypic variance due to additive genetic differences (Lush, 1949, Berry *et al.*, 2014) and estimates provide information on the strength (consistency, reliability) of the relationship between genotype and phenotype for a trait in a population (Bourdon, 1999b). Thus, higher heritability implies a higher percentage of parental performance being inherited by their progeny and a stronger correlation between genotype and phenotype (Visscher *et al.*, 2008) and this can vary between trait groups. While finishing traits, such as growth performance, carcass and meat characteristics usually have moderate to high heritability (20–60%) (Bourdon & Brinks, 1982), many fitness, health and fertility traits are only lowly heritable (<10%) (Morris *et al.*, 1987, Meyer *et al.*, 1990, Cammack *et al.*, 2009, Berry *et al.*, 2014). Heritability estimates for key maternal and finishing traits within New Zealand genetic evaluations are displayed in Table 1.1.

**Table 1.1** Heritability estimates of selected maternal and finishing (growth and carcass) traits for beef cattle in New Zealand (Baker *et al.*, 1990, Morris *et al.*, 1993, Morris *et al.*, 1999, Morris *et al.*, 2000, Beef + Lamb New Zealand, 2017e, Angus New Zealand, 2020).

Trait	Heritability
<b>Maternal traits</b>	
Days to calving	0.00–0.10
Calving date	0.09
Calving ease	0.14–0.50
Interval calving to conception	0.11
Heifer puberty (Age at first oestrus)	0.27–0.31
Pregnancy rate heifers	0.12
Pregnancy rate cows	0.00–0.12
Gestation length	0.15–0.65
n of calvings	0.11
n of mating years	0.13
n of calves weaned	0.15–0.28
Mature live weight	0.40–0.70
Milk	0.10–0.25
<b>Growth traits</b>	
Birth weight	0.31–0.60
Weaning weight/200-day weight	0.12–0.30
400-day weight	0.23–0.25
600-day weight	0.31–0.35
<b>Carcass traits</b>	
Carcass weight	0.25–0.49
Eye-muscle area	0.20–0.42
Rib fat	0.27–0.45
Rump fat	0.29–0.32
Marbling	0.15–0.32
Dressing out %	0.15–0.31
Retail beef yield	0.29–0.60

Traits with a greater genetic variation are more likely to cause genetic change such that even selecting for lowly heritable traits may result in significant changes provided there is sufficient genetic variation. When selecting for traits of interest, genetic correlations with other traits also need to be considered. That is especially relevant for selection decisions, where selecting for one trait is likely to cause genetic change in a correlated trait (Bourdon, 1999c). Knowledge of such correlations are required to optimise selection decisions and for breeding program design. Correlations are thereby considered a measure of strength (consistency and reliability) of the relationship between traits and can be either negative or positive. While selection for some traits may positively affect other desired traits, it can also result in detrimental effects of

other favourable characteristics that are considered important to enhance performance of the animal and efficiency of the production system (Bourdon, 1999a).

### **1.3.2 Genetic evaluation systems in New Zealand**

Genetic evaluation systems are constantly evolving to adapt to changes in production systems and consumer needs by incorporating genetic improvements in animal breeding, data recording as well as novel computing methods (Graser *et al.*, 2005). Currently genetic evaluations within the New Zealand beef industry are primarily based on performance and pedigree recording.

Estimated breeding values (EBV) have been developed to quantify the genetic merit of breeding animals. They are essentially predictions of the relative genetic merit of an animal for a certain trait, half of which is passed on to its progeny. The amount of information available for a particular trait will determine the reliability and accuracy of the EBV. While the true breeding value of an animal is not known, a high accuracy indicates a good fit of the EBV for the animal's true breeding value and a lower likelihood of change of the animals EBV over time. Breeding values are estimated from the measured deviation of an animal within a contemporary group (CG; generally consisting of animals of the same breed, sex and age that are managed within the same environment, season and year) from the average performance of all animals within the same CG, information of the performance of all known relatives of the animal (Nicol *et al.*, 1985), the heritability of the trait and correlations with related traits (Beef + Lamb New Zealand, 2017c, BREEDPLAN, 2019). The EBV can be used to compare the genetic merit of an individual to a set base, which represents the breed mean for a specific date. Estimates are reported as positive or negative deviations from that base (Beef + Lamb New Zealand, 2017e) and displayed in units of the original measurement (e.g. LWT in kilograms and GL in days; Nicol *et al.*, 1985).

For certain New Zealand beef cattle breeds, EBV are produced for a range of economically relevant traits using Best Linear Unbiased Prediction (BLUP) by BREEDPLAN (Nicol *et al.*, 1985). Most beef sires registered with breed societies in New Zealand have EBV calculated by BREEDPLAN for a range of maternal and finishing traits. These traits include reproductive traits such as days to calving, calving ease and GL as well as traits related to growth (e.g. birth weight (BWT), 200-day weight or MWT) and carcass performance (e.g. carcass weight (CWT), fat depth, eye-muscle area or marbling).

## 1.4 Maternal performance traits

Genetic evaluation of cow fertility and production can be challenging under extensive pastoral farming conditions (Pardo *et al.*, 2020) as data recordings may not always be feasible and only a limited number of traits is recorded on a regular basis on commercial farms. Genetic improvement of the cow herd for economically relevant traits relating to reproductive performance of the herd should, however, be a target to enhance the productivity of the breeding herd (Diskin & Kenny, 2016). For breeding herds different traits are of importance compared to finishing operations. The relevance of traits can vary with market requirements and may change over time. Several traits that define cow maternal performance and are essential for high lifetime productivity are shown in Table 1.2.

**Table 1.2** Definitions of maternal performance traits recorded in beef cows.

<b>Trait</b>	<b>Definition and description</b>	<b>Reference</b>
Longevity	Length of a productive life Traits such as survival, number of calves born, and number of calves weaned are measures for lifetime productivity	Arthur & Makarechian (1992), Morris <i>et al.</i> (1993), Arthur <i>et al.</i> (1993), Arthur & Makarechian (1992), Morris <i>et al.</i> (1993), Szabó & Dákay (2009)
Stayability	Probability of cows remaining in the herd (survival) Inconsistent definitions throughout the literature Directly related to overall profitability of the system	Hudson & Van Vleck (1981), Snelling <i>et al.</i> (1994), Doyle <i>et al.</i> (2000), Martinez <i>et al.</i> (2005), Van Melis <i>et al.</i> (2007), Berry & Evans (2014), Hickson <i>et al.</i> (2015)
Heifer puberty	Onset of females reaching a regular oestrus cycle Age at which mature gametes are produced and reproductive activity of heifers is initiated Induced primarily by weight of the animal	Montgomery (1985), Foster & Nagatani (1999), McNaughton <i>et al.</i> (2002), Archbold <i>et al.</i> (2012)
Pregnancy rate (heifers/cows)	Ability of heifers and/or cows to conceive each mating season One of the main drivers of economic efficiency	Morris & Cullen (1994), Burrow (2001)

Trait	Definition and description	Reference
Days to calving	Often recorded separately for heifers and mature cows Time period in days between the start date of the mating season and subsequent birth date of the calf	Johnston & Bunter (1996), Forni & Albuquerque (2005), Berry <i>et al.</i> (2014)
Gestation length	Used as a measure of genetic variance in cow fertility Time in days between conception and birth of the calf Range: 282-283 for Angus and 284-286 for Hereford Longer gestation length may increase birth weight and calving difficulty	Burris & Blunn (1952), Bellows <i>et al.</i> (1971), Bourdon & Brinks (1982), McClintock <i>et al.</i> (2005), Coleman <i>et al.</i> (2018)
Calving difficulty (Dystocia)	Used to describe difficult calvings where parturition requires a higher level of assistance than considered desirable Single most important factor leading to dystocia is calf birth weight relative to the pelvic dimension of the dam Negative correlation with survival of calf and cow and rebreeding performance	Bellows <i>et al.</i> (1971), Price & Wiltbank (1978), Meijering (1984), Arthur <i>et al.</i> (1999), Hickson <i>et al.</i> (2006)
Milk production	Indicator of calf growth until weaning (about 70% of variation in calf weaning weights explained by the milk production of the dam) Higher milk production of the cow is associated with higher energy requirements for production	Montaño-Bermudez <i>et al.</i> (1990), Meyer <i>et al.</i> (1994), Cortés-Lacruz <i>et al.</i> (2017)
Mature live weight	Live weight of mature cows from about 5–6 years of age Relatively easy trait to measure; good indicator of feed requirements Dependent on breed, nutritional status, physiological state and size of the cows Higher mature live weight associated with higher feed intake and maintenance requirements	Northcutt <i>et al.</i> (1992), Smeaton <i>et al.</i> (2000), Morris <i>et al.</i> (2002), Tennant <i>et al.</i> (2002), Morris <i>et al.</i> (2010)
Body condition score	Tool to assess body energy reserves of the animals in terms of body fat and muscle reserves through visual assessment (0–5 or 1–10 scale) More accurate predictor for body fat than live weight Independent from live weight, frame size, gut-fill and weight of the conceptus during pregnancy Tool to improve feed planning and may be used to enhance reproductive performance of the breeding herd	Russel <i>et al.</i> (1969), Wagner <i>et al.</i> (1988), Bishop <i>et al.</i> (1994), Smeaton <i>et al.</i> (2000), Morris <i>et al.</i> (2002), Morris <i>et al.</i> (2006), Diskin & Kenny (2016), Hickson <i>et al.</i> (2017), Tait <i>et al.</i> (2017)

Trait	Definition and description	Reference
	Energy reserves used as buffer in times of feed shortage	

Cow performance is highly variable. Breeding cows with overall desirable maternal performance depends on a variety of different traits and their genetic correlations. Research has shown that most maternal traits are complex traits. They are usually of low genetic variability and/or heritability and expressed later in life, which can reduce their economic value (Newman *et al.*, 1992) and may limit their implementation in selection decisions due to reduced selection efficiency (Arthur & Makarechian, 1992, Gutiérrez *et al.*, 2002). This is especially the case for reproductive traits (Morris *et al.*, 1993, Morris & Cullen, 1994) or those traits related to lifetime production such as longevity or stayability (Martinez *et al.*, 2005, Boldt *et al.*, 2018). Direct selection for the latter is generally not feasible in young animals such that measuring traits early in life that are correlated with lifetime production could facilitate selection of young replacement heifers for the next generation (Martinez *et al.*, 2005, Van Melis *et al.*, 2010). Applicability in selection programs may, however, be limited due to low correlations among those traits (Arthur & Makarechian, 1992).

Alternatively selecting for traits that are easy to measure on farm such as LWT or BCS with potential impact (phenotypically or genetically) on reproductive performance and lifetime production of cows may provide a more applicable tool to enhance the profitability of the breeding herd. While previous research has shown that cows in higher BCS are more likely to show reproductive success in terms of reduced inter-calving interval or pregnancy rate (Ciccioli *et al.*, 2003, Renquist *et al.*, 2006), a cow's lifetime productivity may also be increased through selection on LWT. Puberty is induced primarily by LWT rather than age (McNaughton *et al.*, 2002, Archbold *et al.*, 2012) and occurs when heifers have reached about 50–57% of their MWT (Davis & Wettemann, 2009, Endecott *et al.*, 2013). Breeding for cows that reach their MWT at a younger age may result in earlier onset of puberty in heifers (Bourdon & Brinks, 1982, Boligon & Albuquerque, 2011) such that calving heifers for the first time at two rather than three years of age may be used to enhance profitability of the system (McNaughton *et al.*, 2002, Hickson *et al.*, 2006, Perry, 2016). Knowledge of genetic correlations with other production traits is, however, required to avoid detrimental effects on key

performance parameters with potential impact on the profitability of the production system.

Overall, there are various ways to determine maternal performance of cows within the breeding herd and research has shown that there is potential to improve maternal productivity through selection. A vast number of traits and their relationships have been studied and published in the literature related to maternal traits, however, their inheritance and genetic correlations among each other can vary largely among populations. Reproductive performance of the herd may be improved genetically but caution is required when selecting for traits with unfavourable correlations with other economically relevant production traits. Genetic improvements within the maternal herd are largely dependent on the individual breeding objective on each farm such that genetic parameters should best be evaluated for the population under consideration to make sensible selection decisions and for breeding program design.

### **1.5 Finishing traits and their impact on maternal performance**

Besides the contribution of the breeding herd, the beef cattle sector also depends on the performance of finishing animals destined for slaughter as the primary source of income within the beef herd (Beef + Lamb New Zealand, 2017f). It is essential to ensure that both systems complement each other (Fitzhugh, 1978) and genetic progress in certain traits does not lead to detrimental change in economically relevant correlated traits. The primary selection criteria in a finishing beef cattle enterprise are thereby based on growth performance and genetic merit of the beef carcass (Wilson *et al.*, 1976, Wolcott *et al.*, 2013). Some economically relevant traits and the potential impact of breeding for improved finishing performance on the performance of the maternal herd are discussed below.

#### **1.5.1 Growth traits**

Traditionally, in beef production, herd improvement in terms of overall profitability is primarily realised through selection for growth traits such as LWT at a certain age or LWG (Arango & Van Vleck, 2002, Pardo *et al.*, 2020) and the most commonly measured traits in beef cattle are presented in Table 1.3. Growth traits are relatively easy to measure under grazing conditions with moderate to high heritability (Bourdon & Brinks, 1982, Meyer *et al.*, 1993). Selecting for increased growth rates is beneficial to achieve high WWT (Meyer *et al.*, 1993) and/or CWT (Crews *et al.*, 2004) as the main measures for revenue on beef farms. Progeny from terminal sires used in crossbreeding

programs tend to have higher growth rates (Bass *et al.*, 1975), resulting in higher WWT, and this has been implemented on many farms (Charteris & Garrick, 1996). Weaning weight is one of the predominant parameters in which maternal performance is measured and is a good indicator for the overall productivity of the herd and for calf survival up until weaning (Nicoll *et al.*, 1978). Calves should achieve high WWT as a proportion of the dam's LWT (Morris & Smeaton, 2009). The WWT is genetically correlated with LWT in later life and can therefore be used as a selection criterion for improved growth rates (Bourdon & Brinks, 1982, Meyer *et al.*, 1993).

**Table 1.3** Definition of growth traits recorded in beef cattle.

<b>Trait</b>	<b>Definition and description</b>	<b>References</b>
Calf birth weight	Associated with growth performance and weight of the animal at its later age Directly related to calving difficulty	Morris <i>et al.</i> (1986), Johanson & Berger (2003)
Pre-weaning gain	Growth rate from birth to weaning	Morris (2013a)
Calf weaning weight	Live weight of calves at weaning Often measured on calves at approximately 200 days of age	Nicoll <i>et al.</i> (1978), Morris & Smeaton (2009)
Yearling weight/18-months weight	Live weight of the animal measured at approximately 1 year (400-day weight) or 18 months (600-day weight) of age Indicator of growth potential in later life	BREEDPLAN (2019)

Research has shown that improving growth in finishing cattle may have a detrimental impact on the performance of the breeding herd. Caution must be taken when selecting for those traits improving growth in finishing animals as this may lead to unfavourable correlated responses in traits such as calving difficulties through higher BWT (Morris *et al.*, 1986, Johanson & Berger, 2003). One of the largest impacts on profitability of the breeding herd may be induced through a correlated increase in MWT of cows (Bullock *et al.*, 1993, Arango & Van Vleck, 2002, Morris & Hickson, 2016), and subsequently higher maintenance and feed requirements of the animals (Jenkins & Ferrell, 1994, Morris & Smeaton, 2009). Using sires with high genetic merit for pre-weaning growth potential but moderate mature size genotypes may be beneficial to achieve WWT targets while at the same time maintaining cow size.

### 1.5.2 Ultrasound scan traits

Ultrasound traits are often used as predictor traits for carcass traits in finishing animals, allowing an early, cost-efficient way of estimating the genetic merit of the carcass in the live animal (Houghton & Turlington, 1992, Reverter *et al.*, 2000, Kemp *et al.*, 2002). Four traits are typically evaluated for pedigree-recorded finishing cattle in New Zealand (Table 1.4), namely eye muscle area (EMA), intra-muscular fat percent (IMF), fat depth rump (FD<sub>P8</sub>) and fat depth rib (FD<sub>RIB</sub>). Those traits must generally be recorded by accredited technicians in heifers and steers between 300 and 800 days of age (Reverter *et al.*, 2000, Graser *et al.*, 2005). Research has shown that genetic correlations of those traits measured in the live animal with the corresponding traits measured at slaughter are generally high (0.52–0.94; Kemp *et al.*, 2002, MacNeil & Northcutt, 2008), indicating that ultrasound scan traits are adequate predictor traits to generate genetic change in the beef carcass (Reverter *et al.*, 2000, Kemp *et al.*, 2002).

**Table 1.4** Definition of ultrasound scan traits recorded in beef cattle (Graser *et al.*, 2005).

Trait	Definition
Eye-muscle area	Cross sectional area (cm <sup>2</sup> ) of the <i>longissimus dorsi</i> muscle (eye muscle) between the 12/13 <sup>th</sup> rib
Intra-muscular fat percent	Percentage of fat (%) in the <i>longissimus dorsi</i> muscle between the 12/13 <sup>th</sup> rib
Fat depth rump	Fat depth (mm) measured at the P8 rump site
Fat depth rib	Fat depth (mm) at the 12/13 <sup>th</sup> rib site on the <i>longissimus dorsi</i> muscle

Only a limited number of studies have been published relating the carcass measures recorded in the live animal via ultrasound scanning to performance of the maternal herd. International literature indicates that selecting for backfat (i.e., FD<sub>P8</sub> or FD<sub>RIB</sub>) in the live animal may affect female reproduction, however, relationships are generally weak with sometimes opposing signs (Wolcott *et al.*, 2013, Boldt *et al.*, 2018). Thus, more research is required to examine genetic associations between both trait groups.

### 1.5.3 Carcass traits

Carcass traits typically assessed as part of genetic evaluation programs are outlined in Table 1.5. Most carcass traits are of medium to high heritability and may be improved through selection. From an economic perspective, certain industry specifications have

to be met to obtain the best value from an animal's carcass (Beef + Lamb New Zealand, 2017f) with CWT being the primary measure producers are paid for. The overall production in regard to CWT for bulls, steers, cows and heifers has increased over the last 30 years (Stats NZ, 2022) from about 301 kg and 214 kg in 1993 to about 312 kg and 243 kg in 2022 for steers and heifers, respectively (Beef + Lamb New Zealand, 2022), while the average age at slaughter has likely decreased concurrently. This trend is, however, difficult to quantify due to limited information on birth dates of slaughtered animals under commercial conditions. Terminal sire breeds are often mated to beef breeding cows with crossbred calves predominantly used for beef finishing to take advantage of the superior growth potential and higher CWT compared with purebred progeny (Bass *et al.*, 1975).

**Table 1.5** Definition of carcass traits recorded in beef cattle.

<b>Trait</b>	<b>Definition and description</b>	<b>References</b>
Beef carcass classification	Meat classification system ranking beef carcasses into categories according to sex, weight, muscling, fat cover and maturity Developed to provide a standardised system to assess the quality and value of the beef carcass	New Zealand Meat Classification Authority (2004)
Retail beef yield	Boned out saleable meat Measure of beef yield	Beef + Lamb New Zealand (2017e)
Hot carcass weight	Weight of the animal after head, hide and internal organs have been removed but no further processing has been conducted Measure on which producers are paid	New Zealand Meat Classification Authority (2004), Muir & Thomson (2008)
Carcass eye-muscle area	Cross sectional area (cm <sup>2</sup> ) of the <i>longissimus dorsi</i> muscle (eye muscle) between the 12/13 <sup>th</sup> rib A larger eye-muscle area is associated with higher carcass yield	AUS-MEAT (2020)
Rib fat depth	Depth of subcutaneous fat (mm) over the fourth quarter of the <i>longissimus dorsi</i> muscle at the 12/13 <sup>th</sup> rib site A minimum of 3mm fat cover is required to prevent deductions in carcass value Too little fat cover may increase the risk of dehydration or “cold-shortening” due to insufficient protection of the muscle, whereas excessive cover is associated with higher energy costs to accumulate fat depots and may increase processing costs at slaughter	Beef + Lamb New Zealand (2017e)
Marbling score	Accumulation of triacylglycerol between fibres in the <i>longissimus dorsi</i> muscle tissue Often contributes to the market value of beef Assessed on the carcass as visible spots of fat	Harper & Pethick (2004), Hocquette <i>et al.</i> (2010), Warner <i>et al.</i> (2010)
Ultimate pH	pH point, where glycogen can no longer be transformed into lactic acid by the muscle Meat quality trait (optimal range: 5.3–5.8) High stress levels prior to slaughter and therefore lower concentration of glycogen in the muscle increase risk of high pH, “dark cutting” or DFD (dark, firm, dry) meat	Purchas (2003), Young <i>et al.</i> (2004), Beef + Lamb New Zealand (2017e)
Meat/fat colour	Colour of the muscle or fat influenced by chemical (composition/concentration of pigments) and physical (light shattering/absorption) attributes or feed consumption Measured on the chilled carcass at the <i>longissimus dorsi</i> muscle	Troy & Kerry (2010), AUS-MEAT (2020)

As previously highlighted, improving the genetic merit for growth in finishing cattle may lead to reduced efficiency of the maternal cow in terms of higher proportion of dystocia in the herd (Hickson *et al.*, 2006) and higher feed intake and maintenance requirements of larger framed cows (Arthur *et al.*, 2004, Morris, 2008). It is therefore essential to align the reproductive performance of the maternal herd with the calf as the primary production output with the objectives of the finishing operation where the focus is on carcass merit of heifer and steer progeny. Similar to those traits measured at ultrasound scanning, studies of genetic relationships between carcass traits and maternal performance are scarce and have been primarily conducted for weight related traits such as MWT (Nephawe *et al.*, 2004) but are limited in terms of reproductive performance of the herd. Some researchers have studied the genetic relationship between age at first calving, age at puberty and heifer pregnancy or calving interval with certain carcass traits in breeds such as Red Angus (McAllister *et al.*, 2011, Boldt *et al.*, 2018), Angus and Hereford crosses (Splan *et al.*, 1998), Nellore (Buzanskas *et al.*, 2017) and Wagyu (Oyama *et al.*, 2004) beef cattle, but correlations were overall low. Although there is some evidence for favourable genetic relationships between both trait groups, potential antagonisms may exist and this needs to be further investigated for novel traits to be included in genetic evaluation programs.

### **1.6 Beef cattle production models**

The overall aim of each farming system is to make the best use of the available genotypes and land and to derive the most suitable management strategies to maintain or maximise the output while reducing production costs (Adams *et al.*, 1996) and, ultimately, enhancing the profitability of the entire system. Every enterprise is thereby required to play its role to optimise the farming system.

Overall, the financial contribution of beef breeding cows is realised directly in terms of sales of calves and through their own value as cull cows and indirectly through pasture management and increased performance and productivity of other livestock classes farmed alongside beef cows (Charteris *et al.*, 1999). Feed allocated to the breeding herd is generally based on availability rather than nutritional requirements (Morris & Hickson, 2016), thus cows are required to buffer themselves when feed is in short supply (Pleasants *et al.*, 1994). The flexible role beef breeding cows perform within the farming system makes them a valuable asset to extensive New Zealand hill country farms. Historically, however, determining the profitability of beef breeding cows often

did not account for the flexibility cows provide to the system. Pasture as the primary feed source for both sheep and cattle has the advantage of being a low cost alternative to grain or crop residues used in more intensive systems internationally (Males, 1987, Russell *et al.*, 1993, Beef + Lamb New Zealand, 2017a). Utilising cows for pasture management is a way to efficiently use the buffering capacity of the beef breeding cow in response to variable climates and/or management strategies (McCall, 1994). Her capability to adapt to fluctuations in feed availability by mobilising body energy reserves may be used as a tool to maintain and restore pasture quality on farm and allow fresh new pasture to regrow for other, less adaptable livestock enterprises (Pleasants *et al.*, 1991, Law *et al.*, 2013). Modelling the performance of beef cows of known genetic merit on hill country pasture while accounting for variability in feed allocation can be a valuable tool to determine profitability of cows under variable environments and may highlight relevant research areas that need to be further investigated (Long *et al.*, 1975).

### **1.6.1 Studying domesticated animals**

Hirooka (2010) has highlighted three different types of approaches to examine production systems of domesticated animals and those are:

- 1) Experimental studies
- 2) Use of models with laboratory animals
- 3) System approach

The advantage of experimental studies is that they can provide answers to most questions directly, provided that the setup and structure of the experiment is adequate for the research question under consideration (Spedding & Brockington, 1976). Large-scale experimental studies are, however, often limited due to time and/or resource constraints such that it is often impossible to construct a complete experimental design. Laboratory studies allow a reduction in time and input costs due to shorter reproductive cycles of laboratory animals, however, results may not always be representative and comparable to systems including domesticated animals. Applications of models using a systems approach can incorporate assumptions or hypothesis of complex systems, often only expressible as a computer model (Spedding, 1988). System approaches allow the inclusion of results from previous experimental studies and to quantify and examine large scale, complex systems in a mathematical format while taking interactions among components into account (Joandet &

Cartwright, 1975, Cartwright, 1979). Compared to a real-life experimental study, computer simulations have the added advantage of being able to accommodate variable input parameters to control the environment and, thus, provide additional valuable information and/or constraints about the system that may not be quantifiable under real-life conditions (Spedding, 1988). Modelling of farming systems is especially useful in situations where experimental studies would be required but data recording is too extensive or costly due to substantial numbers of animals or years required to make sensible and accurate predictions (Long *et al.*, 1975).

Modelling techniques are used as a way to represent real-life scenarios in a simplified, abstract version of reality and are often used as a decision support tool for livestock producers (Sørensen, 1998). The model needs to be adjusted in a way to incorporate essential features that are relevant to answer the research question and that may significantly impact on the outcome but should not contain information that would amplify the complexity of the model (Cartwright, 1979).

Over recent decades, research has helped to enhance the knowledge of the agricultural sector and many aspects of biological interactions have been identified. However, there are still certain areas where knowledge is limited but required to understand the complexity of farming systems. In order to model an accurate representation of reality and to make sensible predictions, knowledge of essential biological processes and interactions is required, and the use of models may become challenging if insufficient knowledge of the system is available (Groen *et al.* 1997). Knowledge gained through experimental designs can be used to inform models and to form an objective or critical review of systems. A certain number of assumptions are, however, often required and including them can be a useful technique when limited information is available on real-life data, provided that the conclusions drawn from the model are only applied within the limitations of the experimental assumptions (Cooke, 2018). Models may highlight research gaps that need to be further investigated through implementation of experimental studies and/or to quantify and justify the benefits of conducting experimental studies (Joandet & Cartwright, 1975, Long *et al.*, 1975). Furthermore, they may be used as a tool to understand complex systems and their interrelationships.

### ***1.6.2 Classifications of simulation models***

System approaches using modelling and simulation are a useful tool to combine existing knowledge and highlight new and future research areas for complex systems

in the agricultural sector. Models on agricultural systems can be classified as empirical versus theoretical models, deterministic versus stochastic models or static versus dynamic models (Sørensen, 1998). Models that include assumptions and observations based on experimental data are thereby referred to as empirical models whereas theoretical models use information derived from theory on real life situations and biological procedures. Given a certain set of input parameters, deterministic models predict definite, non-variable model outputs and those models are generally based on means. Stochastic models contain some sort of probability distribution in form of random input parameters such that outcomes are variable. Dynamic models represent models with time as a variable whereas static models are independent of time and remain constant over time (Hirooka, 2010).

### **1.6.3 Modelling process**

Based on Joandet & Cartwright (1975) and Cartwright (1979) the different steps involved in development of a beef production system model are as follows:

- 1) Conceptualisation of the beef production system

The first step in development of a computer model is the identification of the research gap/problem and the definition of the research objectives (Sørensen, 1998).

- 2) Highlight boundaries of the system under consideration

The degree of details required should be determined and the model reduced to incorporate only those aspects relevant to reach sensible outcomes. This should include available model resources as well as experimental constraints (Cooke, 2018).

- 3) Model parameterisation

The information required to parameterise the model needs to be considered and it is relevant to differentiate between information already available and information that needs to be generated (Ebersohn, 1976). Model components and interactions should be characterised based on literature research and/or data collection where applicable or accurately established when insufficient knowledge is available using biological assumptions and interactions among model components.

## 4) Verbal or mathematical (set of equations) description of the model

It is relevant to determine the type of model required to accurately represent the problem under consideration. More complex models may increase computation time and this needs to be considered when developing the model. The actual programming of the model may be an iterative process and restructuring of the model and/or manipulation of data can be required in situations where data availability or knowledge of biological processes is limited (Ebersohn, 1976, Cooke, 2018).

## 5) Model validation/sensitivity analysis

Validation of model results are a relevant step in developing mathematical models by comparing simulated values against real-life experimental data and knowledge, and this is traditionally realised through goodness-of-fit tests (Sørensen, 1998). This, however, requires knowledge of the observed data and validation may be based on subjective evaluations when no actual data is available (Sørensen, 1990). The modelling process should also incorporate sensitivity checks to verify model outputs are not skewed due to insufficient knowledge or inaccuracy of the available data and/or biological assumptions (Spedding, 1988). This may highlight areas where sensitive model parameters may greatly impact on the model outcomes and need to be treated with caution both in simulation models and under real-life scenarios.

## 6) Model application

Model outcomes may be derived from simulation models under variable scenarios and/or conditions but should also highlight the constraints of the model due to experimental assumptions (Cooke, 2018). Accurate documentation of the model processes is relevant to ensure repeatability and transparency of the steps involved in determining the outcomes.

**1.6.4 Types of models**

Beef cattle production systems can be regarded as complex systems incorporating various aspects such as management strategies, nutritional requirements of the animals and economics. Simulation models can be used to model farming systems, to predict animal performance and feed intake based on pasture availability and quality while also incorporating certain management strategies such as culling policies,

supplementation strategies and mating systems. Especially in New Zealand, where beef cattle are farmed primarily on pasture and often in conjunction with sheep, aspects such as interactions of animals with other enterprises and variable feed supply should ideally be considered. However, those models are often rather complex, and it is nearly impossible to incorporate every aspect on farm. Thus, an alternative approach is to model only parts of the production system and relationships among those sub-systems (Spedding, 1988, Sørensen, 1998, Rotz *et al.*, 2005). Beef cattle production may be defined from a tissue/organ level up to whole farm models. Various models have been developed over the last six decades to describe the functioning of beef cattle production systems in a mathematical format and to aid in strategic decisions-making (Jones *et al.*, 2017). Table 1.6 outlines models that have been applied to examine beef production systems worldwide.

**Table 1.6** Overview of models used for beef cattle production systems.

<b>Models</b>	<b>Description</b>	<b>References</b>
Growth models	Used to evaluate the change in body weight with age to examine differences in the growth potential of individual animals and to predict the impact of live weight on growth rates, feed requirements and selection response Non-linear mathematical models have been used for many years to describe the longitudinal data for the weight-age relationship in beef cattle from birth to maturity	Gompertz (1825), Brody & Lardy (1946), Von Bertalanffy (1957), Richards (1959), Fitzhugh (1976), Brown <i>et al.</i> (1976), Jenkins <i>et al.</i> (1991), Kaps <i>et al.</i> (2000)
Lactation models	More intensively studied in dairy cattle to predict lactation curves of individual animals Used to predict production potential until weaning Individual lactation curves may differ for beef and dairy breeds	Wood (1967), Jenkins & Ferrell (1984), Hohenboken <i>et al.</i> (1992)
Metabolism models	Prediction of production potential on the tissue/organ level Simulation of metabolism of nutrition (digestion, absorption and nutrient flow), primarily examination of utilisation of forage and pasture in the rumen	Koong <i>et al.</i> (1982), France <i>et al.</i> (1987)
Nutritional models	Used for the evaluation of dry matter intake and/or residual feed intake Fundamental to determine performance of cattle on pasture Prediction/measures of feed intake much more complex and challenging to obtain in	Sanders & Cartwright (1979a), Sanders & Cartwright (1979b), Mertens

<b>Models</b>	<b>Description</b>	<b>References</b>
Grazing models	<p>extensive grazing systems compared to feedlot scenarios</p> <p>Especially relevant for extensive, pasture-based farming systems where pasture availability influences the beef production system</p> <p>Models may include simulation of pasture cover, sward height, herbage quality and accessibility of feed</p>	<p>(1987), Ingvarsten (1994)</p> <p>Smith <i>et al.</i> (1985), Dowle <i>et al.</i> (1988), Doyle <i>et al.</i> (1989), Baker <i>et al.</i> (1992), Carlson &amp; Thurow (1996), Loewer <i>et al.</i> (1987), Senft (1989)</p>
Environmental models	<p>Current relevance due to the growing concern regarding impact of beef production on the environment</p> <p>Environmental models may address current issues such as nitrogen leaching and/or greenhouse gas emissions (methane, carbon dioxide)</p>	<p>Scholefield <i>et al.</i> (1991), Yan <i>et al.</i> (2007), Shibata <i>et al.</i> (1993), Samsonstuen <i>et al.</i> (2019)</p>
Beef cattle production models	<p>Designed to simulate beef cattle production systems under a range of environmental conditions to determine utilisation of resources within the farming system</p> <p>Used to determine the impact of certain production and management strategies on system efficiency and profitability</p>	<p>Sanders &amp; Cartwright (1979a), Kahn &amp; Spedding (1983), Bourdon &amp; Brinks (1987), Pang <i>et al.</i> (1999), Hirooka &amp; Yamada (1990)</p>
Whole farm models	<p>Comprehensive approach integrating all aspects on farm such as nutrition, management and animal handling procedures</p> <p>Useful research and teaching tools to evaluate animal performance, environmental impacts and economic efficiency of the entire production system</p> <p>Three types of farm models: flow analysis models (nutrient flows in the production system), optimisation models (often represent farms as linear combinations of activities) and system simulation models (impact of strategic management decisions on the whole farm)</p>	<p>White <i>et al.</i> (2010), Veysset <i>et al.</i> (2010), Machado <i>et al.</i> (2010)</p>
Breeding program models	<p>Evaluation of alternative breeding strategies under varying scenarios to examine breeding programs and the relative contribution of animals to the selection progress</p> <p>Used to derive economic values; often accomplished by evaluating the change in profitability when changing the genetic merit of a specific trait in an animal while keeping all other variables constant</p>	<p>Koots &amp; Gibson (1998), Nitter <i>et al.</i> (1994), Amer <i>et al.</i> (2001), Wilton &amp; Danell (1981)</p>

Models	Description	References
Bio-economic models	<p>Beef cattle production models have also been used to answer questions related to breeding programs</p> <p>Able to handle the complex nature of beef cow production systems by taking genetic, nutritional, management and economic factors into account</p> <p>Used to evaluate population dynamics based on biological aspects as well as economic performance of the herd</p> <p>Models consider a large number of parameters and complex production systems simultaneously while incorporating a variety of different models (i.e. growth or nutritional models)</p> <p>Total costs and revenues of such production systems are derived on the basis of phenotypic performance which is made up of genetic potential of the herd and feed resources and management strategies on farm</p> <p>Often used as a tool to predict the impact of genetic change on profitability and production efficiency and to derive economic values for production or functional traits considered for breeding programs</p>	<p>Amer <i>et al.</i> (1994), Amer <i>et al.</i> (1997), Roughsedge <i>et al.</i> (2003), Jones <i>et al.</i> (2004), Charmley <i>et al.</i> (2008), Åby <i>et al.</i> (2012), Campos <i>et al.</i> (2014), Pravia <i>et al.</i> (2014), Tanure <i>et al.</i> (2015)</p>

Most models, however, have been developed to examine the average performance of cows and rarely allow for animals of different genotype being investigated under variable environments. Profitable cow-calf production systems depend on various components and their interactions such as the genotype of the animals, feed intake and management decisions (Long *et al.*, 1975). In New Zealand beef farming systems, cows are used to provide flexibility to the farming system in terms of buffering body energy reserves in response to seasonal fluctuations in feed availability (Morris & Hickson, 2016). Thus, it is important to understand how cows respond to variable environments. A model that considers all these aspects simultaneously and allows for a combination of models as presented in Table 1.6 would enable the evaluation of different genotypes and management strategies under varying environments (Long *et al.*, 1975).

### 1.7 Summary and research gap

Traditionally, the role of beef breeding cows in New Zealand was based on producing calves to contribute to the next generation, either as replacement heifers or finishing

stock for slaughter (Morris & Smeaton, 2009, Morris, 2013b). With the calf generally being the sole production output within cow-calf production systems, profitability of the breeding herd is highly dependent on the reproductive performance of cows (Diskin & Kenny, 2016). To achieve an overall high lifetime production, cows are expected to get in calf early within the mating season, give birth without assistance, rear a live, healthy and heavy weaner calf and get back in calf the following mating season to repeat the same cycle (Walmsley *et al.*, 2018). Maintaining a 365-day calving interval is especially relevant under extensive, seasonal calving conditions (Berry *et al.*, 2014) such as in New Zealand where the production cycle of cows needs to align with the seasonal pasture growth curve.

Besides their contribution to the next generation of calves, beef breeding cows are used for pasture management (Pleasants *et al.*, 1991, McCall, 1994). Feed allocation to cows is thereby driven primarily by pasture availability rather than nutritional requirements of the animal (Morris & Hickson, 2016). Cows are, therefore, required to provide flexibility to cope with varying seasonal feed supply due to climatic conditions and management strategies by consuming surplus pasture when available and mobilising stored body energy reserved as a buffer during times of nutritional restrictions to maintain production (Pleasants *et al.*, 1994). The ability of cows to consume large amounts of pasture relative to their requirements (McCall & Scott, 1988) has resulted in their role of removing senescent pasture so as to maintain pasture quality for other, more profitable livestock classes that are less adaptable to seasonal fluctuations (McCall, 1994). The nutritional level of cows at various stages of the production cycle may impact on the productivity of the herd such that monitoring and managing performance parameters such as LWT and BCS throughout the year may provide an efficient tool to optimise the reproductive performance of cows throughout the season.

The key issue for commercial beef producers is the ability to maximise productivity of the beef breeding cow while maintaining pasture intake and minimising feed costs. The single largest expense in the cow-calf production system is thereby the feed required for maintenance and productivity of cows (Law *et al.*, 2013) which increases with frame size and LWT of the animal. The profitability of cows can be enhanced by improving calving percentage (number of calves weaned divided by the number of cows mated) or WWT as a proportion of LWT of the cows or energy intake per cow and calf unit (Walmsley *et al.*, 2018) or numbers of calves reared regarding a cow's lifetime production (Hickson *et al.*, 2011, Morris & Hickson, 2016). Although there is potential

to further enhance productivity of the entire herd, the low return of beef cows compared to other livestock classes has resulted in cows playing a subordinate role on farm. The overall profitability of the production system is, however, reliant on high performing cows. Maternal efficiency is thereby difficult to define and can vary largely due to cows contributing in various ways to the overall profitability of the production system.

Studies of maternal performance on extensive commercial New Zealand hill country farms are, however, sparse with only a limited number of traits being recorded on these properties. Measurements of maternal performance are not always straightforward and data recording may not always be feasible on commercial farms under extensive grazing conditions (Pardo *et al.*, 2020). While several researchers examined the genetic components of typical maternal traits in cows, most traits are rather complex and generally are only lowly heritable and/or expressed later in life, especially in regard to reproductive performance or lifetime production. This emphasises the need for performance parameters that can be easily measured and recorded on farm with potential impact on reproductive success or robustness such as LWT and BCS. More research is required to examine the genetic merit of key maternal traits within New Zealand commercial beef herds.

Generally, calves are the main output based on which the profitability of beef breeding cows is measured (Morris & Hickson, 2016). Traditionally, most emphasis in research has been placed on evaluation of finishing performance of beef cattle, as the revenue of a beef operation is predominantly measured through the weight of the carcass (New Zealand Meat Classification Authority, 2004). Investigating the compatibility among maternal and finishing performance in beef cattle may, therefore, provide a tool to further enhance the profitability of the beef breeding cow herd without compromising performance of the finishing operation. Better knowledge of trait correlations may be beneficial for selection decisions and for breeding program design.

Beef cattle production systems are rather complex, involving many factors such as the genetic potential of the animals, nutritional demands, management procedures, environmental factors and economic aspects. To better understand the complex nature of those systems and to derive the most profitable system approach it is necessary to examine interactions across all components simultaneously. The cow-calf production system can be defined on various levels and a vast number of models have been

developed and applied to aid in strategic decision-making and are useful tools to answer research questions where experimental studies are too cost- and/or time-consuming to implement. Current models that incorporate performance parameters and their effect on profitability of the production system often operate on basic genetic assumptions and on trait means. Calculating the profitability of beef breeding cows often does not account for their contribution to pasture management (McCall, 1994). Given that beef breeding cows are required to fulfil their role in pasture management and are not always fed to meet their nutritional requirements (Morris & Hickson, 2016) it is useful to know which type of cow is most suitable to cope with environmental variability. Models, however, rarely allow for cows to respond to seasonal variability of the environment. To determine the performance and profitability of beef cows under extensive pasture-based systems where cows are required to buffer annual fluctuations in feed supply such as in New Zealand it can be beneficial to account for variability within the production system. This may be achieved by combining various types of models (i.e., genetic, nutritional, growth, lactation and production models) and allowing for different cow genotypes to be evaluated under varying environmental conditions and management strategies.

Therefore, to investigate maternal performance and profitability of beef breeding cows the objectives of this thesis were to:

- Quantify the performance of mature beef breeding cows in terms of LWT and BCS and examine the relationship between both traits on a phenotypic level (Chapter 2)
- Evaluate the association of BCS with reproductive performance in mature beef cows (Chapter 3)
- Define key maternal productivity parameters for New Zealand cow-calf production systems and examine their relationships among each other (Chapter 4)
- Investigate to what extent maternal performance is related to growth and carcass performance in New Zealand finishing beef cattle (Chapter 5)
- Develop a bio-economic model to quantify the impact of variable feed supply on beef cow productivity and profitability and examine how cows respond to variable feed availability compared to a scenario with consistent annual pasture allowance (Chapter 6)

- Evaluate the performance and productivity of cows that differ in their MWT and other correlated traits when exposed to variable feed supply (Chapter 7)

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## **Chapter 2 – Live weight and body condition score of mixed-aged beef breeding cows on commercial hill country farms in New Zealand**

### **Publications arising from this chapter:**

Weik F, Archer JA, Morris ST, Garrick DJ, Miller SP, Boyd AM, Cullen NG, Hickson RE 2021. Live weight and body condition score of mixed-aged beef breeding cows on commercial hill country farms in New Zealand. *New Zealand Journal of Agricultural Research* 65: 172-187. DOI: 10.1080/00288233.2021.1901235

## **2.1 Abstract**

Extensive farming systems require beef cows to cope with varying environmental conditions while repeatedly producing calves. Cows use body energy reserves as a buffer in times of feed shortage and replenish reserves under a feed surplus. The aims of the research were to quantify live weight (LWT) and body condition score (BCS) fluctuations among farms, years and over the production cycle (mating, weaning and calving) and to quantify the relationship between LWT and BCS at mating, weaning and calving, for cows of different hip height (HIP). A total of 7,649 individual cow records from nine commercial New Zealand farms with information on LWT and BCS (1–10 scale, 1 = emaciated and 10 = obese) were analysed. Analyses revealed significant ( $P < 0.001$ ) within-year variation in mean LWT (32.4–77.2 kg) and BCS (0.4–1.8 scores) profiles among farms, but profiles were not consistent from year to year. There was a quadratic relationship ( $P < 0.001$ ) between LWT and BCS, such that one unit change in BCS corresponded to 15.1 kg LWT increase at BCS 4–5 compared to 41.1 kg LWT increase at BCS 8–9 at mating. This relationship was similar, irrespective of HIP.

## 2.2 Introduction

Beef breeding cows play a diverse role within the New Zealand farming system. They contribute to the sector through the production of calves that are either retained as replacement heifers within the breeding herd or finished for beef production. In addition to their contribution to beef production, breeding cows are used for pasture management. Cows are typically farmed alongside other livestock classes, such as sheep and deer, and take on a complementary role to benefit farm profit (McCall, 1994, Morris, 2013). Those farming systems that include beef breeding cows are usually located on steeper hill country (Beef + Lamb New Zealand, 2017) with lower soil fertility and feed quality.

The extensive, year-round grazing system in New Zealand has predictable seasonal fluctuations within a year which dictate the typical pasture growth curve, as well as atypical fluctuations in pasture growth in response to climatic variation in temperature and/or rainfall. Farming systems need to respond to typical and atypical fluctuations in feed supply through adaptive management practices. Beef breeding cows are often used as a buffer by increasing or decreasing feed offered to the herd in response to whole farm feed availability (Pleasant *et al.*, 1994) which enables more consistent feed to be offered to other stock classes. In times of increased pasture growth in spring, cows consume pasture surplus to their requirements. Cows use this additional feed to increase body energy reserves (Pleasant *et al.*, 1991). In times of feed shortage, especially over winter, cows can mobilise energy reserves as a nutritional buffer (Law *et al.*, 2013). The use of cows to manage feed surpluses and shortages results in fluctuations in live weight (LWT) and body condition score (BCS) of the cows over time.

Several parameters determine LWT which can differ due to breed, nutritional status, state of the reproductive cycle and size of the cow (Morris *et al.*, 2002). In beef cattle, BCS is determined by a visual assessment in terms of body fat and muscle reserves (Wagner, 1984, Bishop *et al.*, 1994) and is a better indicator of body reserves than is LWT (Russel *et al.*, 1969). Unlike LWT, it is independent of the frame size of the animal (Hickson *et al.*, 2017) and not affected by factors such as gut-fill and weight of the conceptus during pregnancy (Morris *et al.*, 2002). In New Zealand, BCS in beef cows is typically assessed on a 1–10 (Smeaton *et al.*, 2000, Hickson *et al.*, 2017) or 0–5 (Morris *et al.*, 2002) scale. Industry targets by Hickson *et al.* (2017) using the 10-point scale

recommended a target BCS of 6 at mating, 7 at weaning and at least 5 throughout the winter months.

Economic models of farming systems and calculation of feed demand require knowledge of the target LWT and BCS at key timepoints throughout the annual production cycle. The poor profitability of the beef cow relative to other stock classes has resulted in declining beef cow numbers on New Zealand farms (Stats NZ, 2019). Ascertaining their profitability, however, often does not account for their indirect value to the farming operation. Data highlighting the extent of flexibility offered by the cow in response to variable feed supply is useful to farmers considering replacing their cows with other stock classes. Few reports have been published in recent years, and those that exist typically report on a single herd (Law *et al.*, 2013, Tait *et al.*, 2017), and/or report on first calving heifers (Hickson *et al.*, 2008, Morris *et al.*, 2014) or beef-cross-dairy-breed cows (Smeaton *et al.*, 2000, Morris *et al.*, 2006) which are likely to differ from beef-breed cows. A large-scale comparison of cows on multiple farms across multiple years is needed to better understand annual fluctuations in LWT and BCS among farms and years, and to quantify these under a range of commercial conditions. Furthermore, knowledge of the LWT change required to achieve BCS targets is useful information for feed budgeting purposes if data recording is limited.

Therefore, the objectives of this study were to (1) evaluate and quantify LWT and BCS fluctuations of mixed-aged beef breeding cows among farms, years and over the production cycle (mating, weaning and calving), and to (2) quantify the relationship between LWT and BCS to predict the necessary LWT change per unit BCS over the production cycle and for cows of different hip height (HIP) as a measure of frame size.

## **2.3 Materials and methods**

All measurements and related procedures described in this report were approved (or formally exempted from approval where data was considered to be collected for routine farm management practice) by the AgResearch Invermay Animal Ethics Committee (Approval numbers: 13358, 13373, 13394, 13693, 14031, 14311, 14588, 14851; AEC Notification 57).

This study used data collected as part of two beef cattle projects: a progeny test, and a maternal cow study. Both projects were conducted on New Zealand hill country farms in commercial environments with the aim of producing calves for beef production. The beef progeny test (BPT) is an ongoing research project carried out by Beef + Lamb New Zealand Genetics (Tweedie *et al.*, 2019). The BPT was established in 2014 and conducted to compare the offspring performance of bulls. Every year about 2,200 beef cows were artificially inseminated at a synchronised oestrus at the start of each mating season before natural service bulls were introduced to the herd for a confined mating period. Bull breeds used for insemination were Angus, Hereford, Stabilizer, Simmental or Charolais. The maternal cow project (MCP) recorded cow performance of naturally-mated cows from 2014 until 2017 with performance recordings of a total of 4,151 beef cows. Animals within both projects grazed pasture year-round with little to no supplementary feed. No data were collected on pasture quality and feed availability due to the extensive nature of the project.

### ***2.3.1 Participating farms***

The BPT is being carried out within five large-scale beef farming operations throughout New Zealand, three of which are based in the North Island, and two are located in the South Island. The MCP included four farms, all situated on the South Island of New Zealand (Table 2.1). Farm I included a commercial and a bull breeding herd in the project and these were treated as two separate farms in this study. Each farm varies in the overall farming system, scale, altitude, climate and stocking rate.

### ***2.3.2 Animals and management***

Data available for this analysis were collected over a period of five years (November 2014–September 2019) on the BPT farms and four years (February 2014–September 2017) on the farms involved in the MCP. All cows that made up the original population of commercial cows inseminated for the BPT as well as replacement animals within each farm, and all cows recorded in the MCP were used in the present study, provided

they were at least 3 years old at the time of recording. Cows were Angus or Hereford and were run under commercial conditions dictated by the manager on each farm. All cows included in the BPT were inseminated once by fixed-time artificial insemination (AI) at a synchronised oestrus at the start of each mating season before bulls were introduced to the herd, generally two to three days following AI and always less than 21 days after AI. Treatments for oestrus synchronisation were based on a 3-yarding protocol for most farms. Cows were given 100 µg of gonadorelin (Ovurelin, Bayer New Zealand Ltd., Auckland, New Zealand) on day 0 and were treated with an intravaginal P4-releasing device (Cue-mate, Bayer New Zealand Ltd, or CIDR, Zoetis New Zealand Ltd., Auckland, New Zealand) from days 0–7. At the day of device removal, cows received 200 µg cloprostenol (Ovuprost, Bayer New Zealand Ltd.) and 200 µg gonadotrophin (Pregnecol, Bayer New Zealand Ltd.). A second treatment of 100 µg of gonadorelin was given on day 10 at the time of AI. One farm used a 4-yarding protocol, where the final treatment was conducted the day prior to AI. Bulls remained with the herd for a minimum of seven weeks after AI for all BPT herds, the exact dates the bulls left each herd, however, were not recorded.

**Table 2.1** Description of farms involved in the beef progeny test and the maternal cow project (Climate information derived from NIWA (2022)).

Farm label	Location	Climate	Stock units <sup>1</sup>	Farm size (ha)	Cow breed
<b>Beef progeny test</b>					
A	Gisborne	Dry summers Mild winters	70,000	7,100	Angus
B	Central Plateau	Wet summers Cold winters	83,000	8,350	Angus
C	Southern Hawkes Bay	Dry summers Mild winters	29,500	3,700	Angus
D	North Canterbury	Dry summers Cold winters	34,000	6,130	Hereford
E	South Canterbury	Dry summers Cold winters	30,000	6,000	Angus
<b>Maternal cow project</b>					
F	Canterbury	Dry summers Cold winters	5,000	990	Hereford
G	South Canterbury	Dry summers Cold winters	24,000	4,350	Hereford
H	MacKenzie Basin	Dry summers Cold winters	35,000	20,000	Angus/ Hereford
Ia, Ib <sup>2</sup>	Southland	Wet summers Cold winters	100,000	12,145	Angus

<sup>1</sup>One stock unit being the equivalent of feed required by a 55 kg breeding ewe rearing a single lamb, representing approximately 550 kg DM per year.

<sup>2</sup>Farm I included commercial (Ia) and bull breeding herds (Ib) within the project.

### 2.3.3 Measurements

On each farm LWT and BCS were recorded simultaneously for all cows in the dataset at three events throughout the year: before the start of ‘mating’ (recorded between October–January, depending on the mating date policy of each individual farm), at ‘weaning’ of the calf (February–April) and prior to ‘calving’ (July–September). Timing of these recordings varied among farms and years but was consistent for all cows within farm and year. Hip height was recorded once a year before calving for cows in the BPT in 2017 and 2018 only. Measures of LWT and HIP were on a continuous scale. Scoring of BCS was on a 1–10 scale with 0.5 increments (1 = emaciated and 10 = obese; Hickson *et al.*, 2017) and conducted by an experienced BCS scorer or by the farmer under regular supervision and training by the scorer. Birth years were recorded for all cows based on tags assigned as part of the compulsory national animal identification

scheme. Pregnancy diagnosis (PD) was conducted around weaning at approximately 90 days post-AI for cows in the BPT using trans-rectal ultrasound by an experienced commercial operator. Fetal age was recorded at the time of PD based on the operator's assessment of conceptus developmental features and size. The number of records for each trait is reported in Table 2.2 for the BPT and for the MCP.

**Table 2.2** Number (n) of live weight (LWT), body condition score (BCS, 1–10 score) and hip height (HIP) records of mixed-aged beef breeding cows for all farms involved in the beef progeny test (Label A–E) and the maternal cow project (Label F–I) throughout the years 2014–19; LWT and BCS were recorded on three events within a year (mating, weaning and calving).

	n of records per farm and year						Total n of records per farm	Total n of unique cows
	2014	2015	2016	2017	2018	2019		
A								
LWT/BCS	-	1,122	2,338 <sup>1</sup>	2,445	2,498	2,054	10,457 <sup>1</sup>	1,191
HIP	-	-	-	730	731	-	1,461	892
B								
LWT/BCS	-	1,130	1,318	1,316	1,236	888	5,888	757
HIP	-	-	-	378	350	-	728	445
C								
LWT/BCS	-	1,100 <sup>1</sup>	1,280 <sup>1</sup>	1,430	1,487	819	6,116 <sup>1</sup>	754
HIP	-	-	-	411	425	-	836	533
D								
LWT/BCS	-	671	962 <sup>1</sup>	908	1,186	904	4,631 <sup>1</sup>	637
HIP	-	-	-	370	351	-	721	423
E								
LWT/BCS	-	-	-	213	416	270	899	159
HIP	-	-	-	68	129	-	197	141
F								
LWT/BCS	-	305	486 <sup>1</sup>	455 <sup>1</sup>	-	-	1,246	240
G								
LWT/BCS	-	410 <sup>1</sup>	415 <sup>1</sup>	440	-	-	1,265 <sup>1</sup>	240
H								
LWT/BCS	603 <sup>1</sup>	1,110 <sup>1</sup>	1,169	1,129 <sup>1</sup>	-	-	4,011 <sup>1</sup>	703
Ia								
LWT/BCS	-	1,665 <sup>1</sup>	2,763 <sup>1</sup>	3,012 <sup>1</sup>	-	-	7,440 <sup>1</sup>	1,629 <sup>1</sup>
Ib								
LWT/BCS	818 <sup>1</sup>	2,003 <sup>1</sup>	2,410 <sup>1</sup>	2,209 <sup>1</sup>	-	-	7,440 <sup>1</sup>	1,339 <sup>1</sup>
Total n of records per year								
LWT/BCS	1,421	9,516 <sup>1</sup>	13,141 <sup>1</sup>	13,557 <sup>1</sup>	6,823	4,935	49,393 <sup>1</sup>	7,649 <sup>1</sup>
HIP		-	-	1,957	1,986	-	3,943	2,434

<sup>1</sup>n of records differed by up to 20 records between LWT and BCS.

### 2.3.4 Data manipulation

Birth years of cows were used at each recording event to compute age as time in years from birth to LWT and BCS measurement, respectively. Cows that experienced similar management practices were grouped together into four categories: 3-year-olds, 4-year-olds, 5–9-year-olds and 10 or more years old. All cows were first mated at around 15 months of age and calved as 2-year-olds. Cows were considered to be 3-year-olds at the start of the mating season after the birth of their second calf until the end of the subsequent calving season. During that time the cow is bred to generate her third calf, is rearing and weaning her second calf and experiences the winter prior to the birth of her third calf.

The LWT of the beef cows involved in the BPT was adjusted for the weight of the fetus and related tissues to account for the additional weight throughout gestation and is referred to as  $LWT_{adj}$ . Weight of the conceptus was calculated based on the estimated age of the fetus at the recording date of the LWT or BCS measurement, respectively, and derived from the formula by Freer *et al.* (2007):

$$Y_t = SBW \times \exp(A - B(\exp(-Ct))) \quad (2.1)$$

with  $Y_t$  being the weight of the conceptus at time  $t$  (in days),  $SBW$  the scaled birth weight, calculated by the expected birth weight of the fetus divided by 40,  $A$ ,  $B$  and  $C$  are parameters to predict the total weight of the gravid uterus, with  $A = 6.75$  kg,  $B = 7.71$  kg and  $C = 4.06 \times 10^{-3}$  kg. Birth weight was not recorded in this study, so a uniform birth weight of 37.9 kg was assumed, using the most recently published value for Angus calves in New Zealand (Tait *et al.*, 2017). The computed conceptus weight was then subtracted from the actual LWT to obtain  $LWT_{adj}$ .

### 2.3.5 Statistical analysis

All analyses were performed using R version 3.6.0 (Packages 'lme4' and 'lsmeans'; R Core Team, 2019).

#### *Live weight and body condition score fluctuations*

For all analyses, year was defined relating to the annual production cycle starting at the beginning of the mating season in October and ending prior to the subsequent mating. Linear mixed model analysis was conducted to describe the repeated measurements of LWT and BCS of cows with farm (Label A–I), year (2014–19), event (mating, weaning and calving) and age of cows (3, 4, 5–9 and 10+ years of age) as fixed effects. Farm, year,

event and age of cows and their two-way interactions with farm were included in the model. A second model considered a three-way interaction between event and farm within the year to account for LWT and BCS fluctuations among time periods and years. Animals were fitted as random effects to allow for correlations between residuals so as to account for repeated measurements over time. Analyses of variance (ANOVA) were conducted using an F-statistic on type-III sums of squares to test for significance of each predictor variable. Due to insufficient datapoints, farm E was excluded from the final model for the first part of the analysis. Least-square means (lsmeans) for LWT, LWT<sub>adj</sub> and BCS were estimated from the model for farm, event and year to compare cow performance among farms as well as their variation among years and within a year (among events).

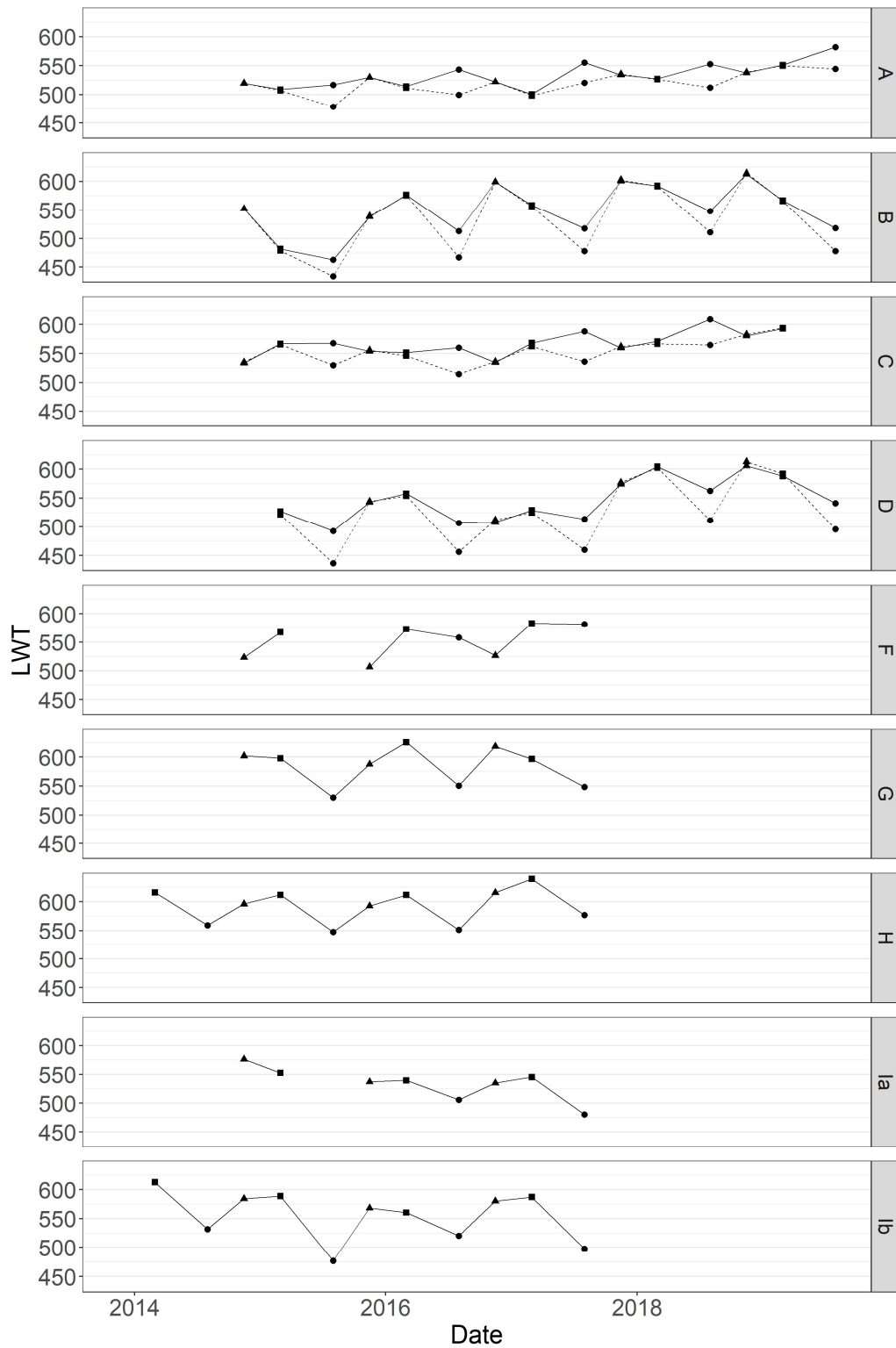
### *Relationship between live weight and body condition score*

Regression analysis was performed to evaluate relationships between LWT and BCS. The same model was fitted using either LWT or LWT<sub>adj</sub> as the dependent variable. Prior to analysis HIP of cows was adjusted for the age of cows in years. A model was fitted with the age of cows as a covariate. Animal effects and contemporary groups (farm × year) were included as random variables in the model. The mean age-adjusted deviation of each animal within a farm was then used to assign an equal number of cows to 'small', 'medium' or 'tall' HIP. The final model included the fixed effects of event (mating, weaning and calving), age-adjusted HIP category (small, medium and tall) and age of cows (3, 4, 5–9 and 10+ years of age). Linear and quadratic covariates for BCS were included in the model with a test for deviation from linearity. Interactions were tested between BCS (both linear and quadratic terms) and either event or HIP category. No significant interaction was found between HIP and the quadratic term of BCS, and the term was excluded from the final model. A contemporary group (farm × year) and an animal effect were fitted as random variables in the model to account for repeated measurements over time. The change of LWT per unit BCS was calculated for each level of BCS using linear and quadratic estimates from the model. A second approach only included the linear term of BCS in the model to allow for a more practical application.

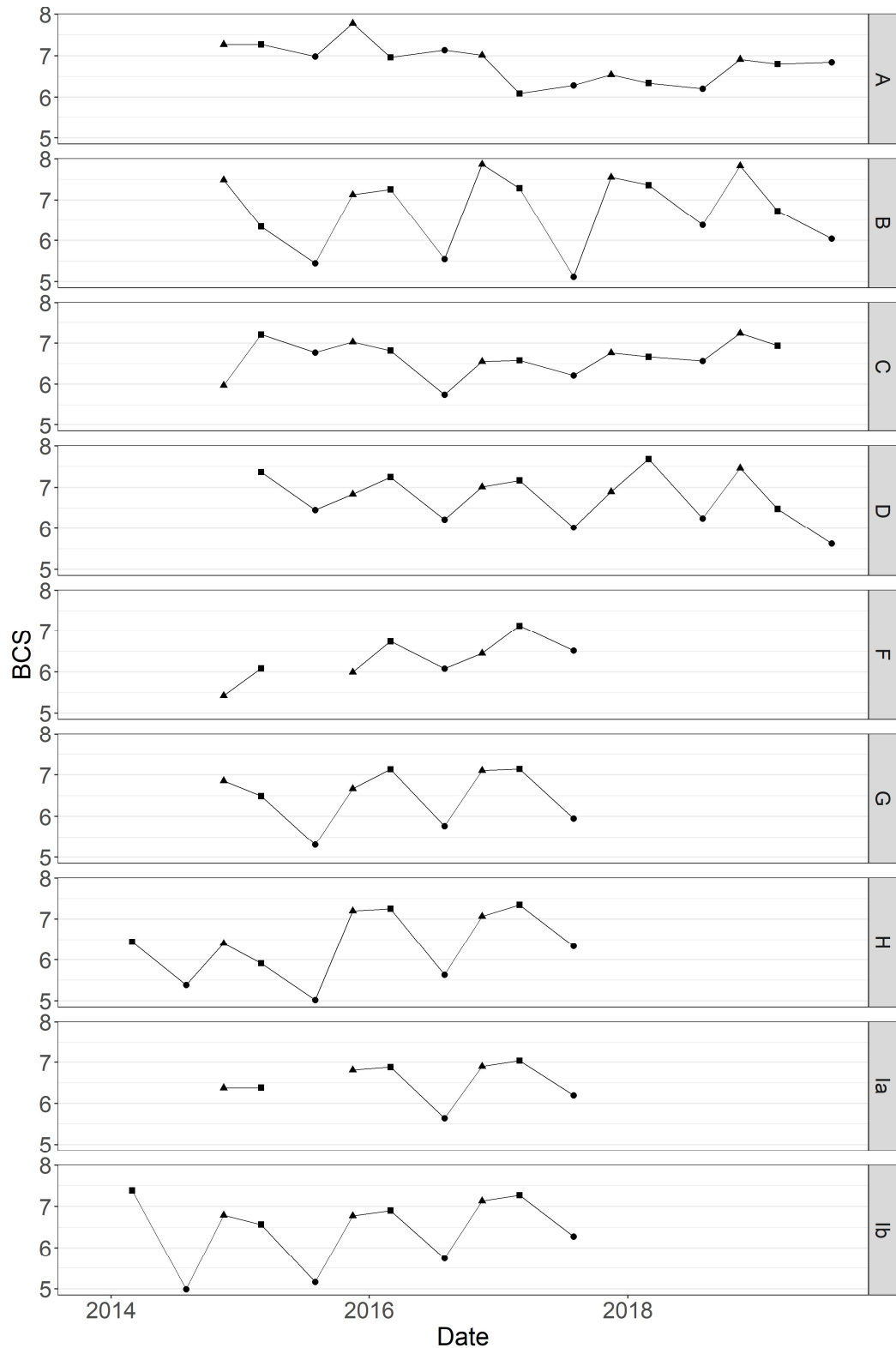
## **2.4 Results**

### ***2.4.1 Live weight and body condition score fluctuations***

A total of 7,649 mixed-aged beef breeding cows on nine commercial farms throughout New Zealand were measured for LWT and BCS. These cows exhibited BCS from 3.0 to 10.0. The raw means of LWT and BCS across the entire dataset were 564.9 kg and 7.0 before mating, 568.1 kg and 6.9 at weaning and 541.4 kg and 6.1 around the timing of calving. All farms showed significant differences ( $P < 0.001$ ) in their LWT and BCS profiles. Those differences were present within ( $P < 0.001$ ) and among years ( $P < 0.001$ ) following the annual production cycle (Figures 2.1 and 2.2).



**Figure 2.1** Live weight (LWT, kg) fluctuations within and between years of mixed-aged beef breeding cows on commercial hill country farms (Label A-I) in New Zealand (solid line); dashed line: fluctuations of LWT adjusted for weight of the conceptus during gestation; fluctuations within a year were recorded at three events ( $\blacktriangle$  = mating,  $\blacksquare$  = weaning,  $\bullet$  = calving).



**Figure 2.2** Body condition score (BCS, 1-10 score) fluctuations within and between years of mixed-aged beef breeding cows on commercial hill country farms (Label A-I) in New Zealand; fluctuations within a year were recorded at three events (▲ = mating, ■ = weaning, ● = calving).

Profiles for LWT and BCS varied significantly ( $P < 0.001$ ) throughout the production cycle (Table 2.3). Farm A and C showed less variation among the recorded events compared with the other farms included in the analysis and were the only two farms with an increased calving weight following weaning. All other farms tended to have their highest LWT recorded either before mating or at weaning and lowest prior to calving. Body condition score was greatest either around mating or at weaning for all farms, whereas cows tended to lose condition between weaning and calving, resulting in the smallest BCS records around calving.

**Table 2.3** Least-square means of live weight (LWT, kg) and body condition score (BCS, 1–10 score) of mixed-aged beef breeding cows and their standard errors ( $\pm$ SEM) at different events throughout the production cycle (mating, weaning and calving) for each farm (Label A–I); results are adjusted for age of cows and year of data recording.

	n	mating	weaning	calving	Range within year
<b>LWT</b>					
A	1,191	527.6 $\pm$ 1.4 <sup>b</sup>	519.0 $\pm$ 1.4 <sup>a</sup>	551.4 $\pm$ 1.5 <sup>c</sup>	32.4
B	757	576.3 $\pm$ 2.0 <sup>c</sup>	554.3 $\pm$ 2.0 <sup>b</sup>	511.1 $\pm$ 2.0 <sup>a</sup>	65.2
C	754	551.3 $\pm$ 1.9 <sup>a</sup>	569.1 $\pm$ 1.9 <sup>b</sup>	587.7 $\pm$ 1.9 <sup>c</sup>	36.4
D	637	552.0 $\pm$ 2.1 <sup>b</sup>	561.3 $\pm$ 2.0 <sup>c</sup>	525.3 $\pm$ 2.1 <sup>a</sup>	36.0
F	240	519.0 $\pm$ 3.5 <sup>a</sup>	575.2 $\pm$ 3.5 <sup>c</sup>	569.6 $\pm$ 3.8 <sup>b</sup>	56.2
G	240	603.9 $\pm$ 3.7 <sup>b</sup>	607.3 $\pm$ 3.7 <sup>b</sup>	544.3 $\pm$ 3.8 <sup>a</sup>	63.0
H	703	602.0 $\pm$ 2.2 <sup>b</sup>	621.0 $\pm$ 2.1 <sup>c</sup>	559.9 $\pm$ 2.2 <sup>a</sup>	61.1
Ia	1,629	548.8 $\pm$ 1.6 <sup>c</sup>	546.6 $\pm$ 1.6 <sup>b</sup>	500.7 $\pm$ 1.7 <sup>a</sup>	48.1
Ib	1,339	585.5 $\pm$ 1.5 <sup>b</sup>	586.8 $\pm$ 1.5 <sup>b</sup>	509.6 $\pm$ 1.6 <sup>a</sup>	77.2
<b>BCS</b>					
A	1,191	7.1 $\pm$ 0.02 <sup>b</sup>	6.7 $\pm$ 0.02 <sup>a</sup>	6.7 $\pm$ 0.02 <sup>a</sup>	0.4
B	757	7.5 $\pm$ 0.03 <sup>c</sup>	7.0 $\pm$ 0.03 <sup>b</sup>	5.7 $\pm$ 0.03 <sup>a</sup>	1.8
C	754	6.7 $\pm$ 0.02 <sup>b</sup>	6.8 $\pm$ 0.02 <sup>c</sup>	6.4 $\pm$ 0.03 <sup>a</sup>	0.4
D	637	7.1 $\pm$ 0.03 <sup>b</sup>	7.2 $\pm$ 0.03 <sup>c</sup>	6.1 $\pm$ 0.03 <sup>a</sup>	1.1
F	240	6.0 $\pm$ 0.05 <sup>a</sup>	6.7 $\pm$ 0.05 <sup>b</sup>	6.0 $\pm$ 0.06 <sup>a</sup>	0.7
G	240	6.9 $\pm$ 0.05 <sup>b</sup>	6.9 $\pm$ 0.05 <sup>b</sup>	5.7 $\pm$ 0.06 <sup>a</sup>	1.2
H	703	6.8 $\pm$ 0.03 <sup>b</sup>	6.8 $\pm$ 0.03 <sup>b</sup>	5.6 $\pm$ 0.03 <sup>a</sup>	1.2
Ia	1,628	6.7 $\pm$ 0.02 <sup>b</sup>	6.8 $\pm$ 0.02 <sup>c</sup>	5.8 $\pm$ 0.03 <sup>a</sup>	1.0
Ib	1,338	6.9 $\pm$ 0.02 <sup>b</sup>	7.0 $\pm$ 0.02 <sup>c</sup>	5.6 $\pm$ 0.02 <sup>a</sup>	1.4

<sup>a,b,c</sup>Means within each row with different superscripts are significantly different ( $P < 0.05$ ).

Examining Figures 2.1 and 2.2 (refer also to Appendix I, Table 1 and 2), however, reveals, that those differences among farms and events were not consistent between years and, therefore, the figures provide a better representation of LWT and BCS fluctuations over time. Cow live weight and BCS varied significantly ( $P < 0.001$ ) among the recorded years in the current study. Both traits behaved in a similar manner and tended to be lowest in 2015 and 2016, and highest in 2017.

Compared to the unadjusted LWT, the analysis of  $LWT_{adj}$  showed that conceptus weight had a more prominent impact on the pre-calving measurements, as conceptus weight is small at the early stages of pregnancy around weaning and is not applicable at mating time. Fluctuations of  $LWT_{adj}$  during pregnancy are displayed in Figure 2.1 for all BPT farms.

#### ***2.4.2 Relationship between live weight and body condition score***

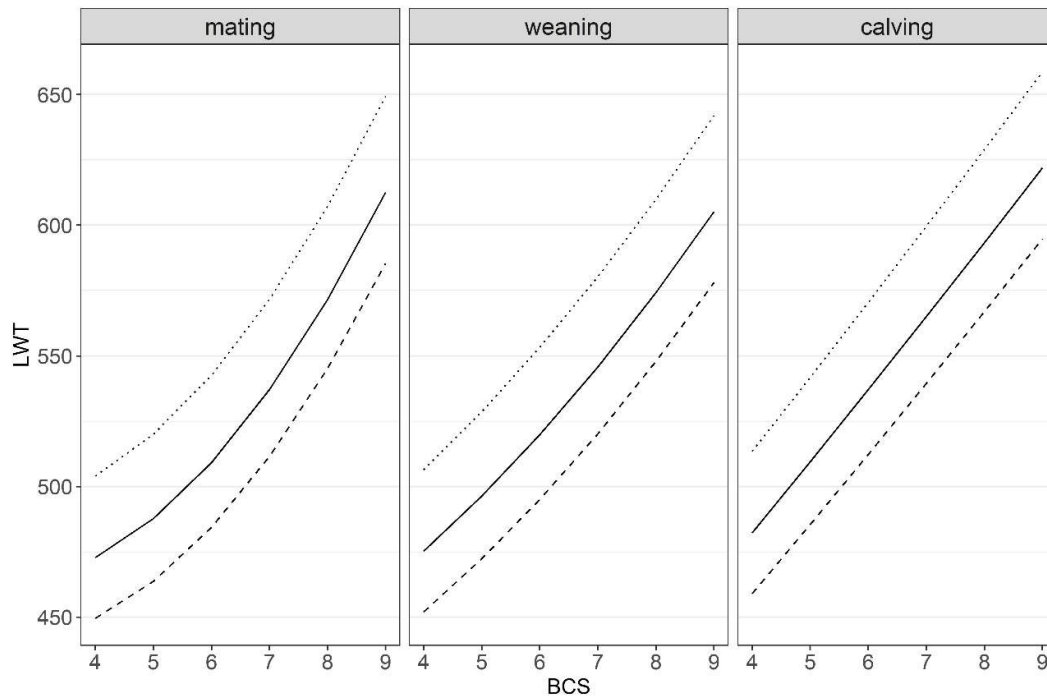
The relationship between LWT and BCS was highly significant ( $P < 0.001$ ) for both the actual LWT and  $LWT_{adj}$ . Analysis revealed that adjustments for the weight of the conceptus changed the intercept of the model at calving but did not have a meaningful impact on the slope of the regression. Therefore, all results in this study are only displayed for the actual LWT, rather than  $LWT_{adj}$ .

Event had a significant ( $P < 0.001$ ) effect on the regression of BCS on LWT. This was apparent as a main effect as well as an interaction with BCS, both for the linear and the quadratic term (Table 2.4), implying a different relationship between BCS and LWT at crucial time points throughout the annual cycle. The non-linear component was more prominent before mating and at weaning, such that a higher LWT change was required to change between high BCS units compared to low units, whereas the slope of the regression was almost linear at calving time (Figure 2.3). The necessary LWT change associated with change in one unit BCS ranged from 15.1 kg (from BCS 4 to BCS 5) to 41.1 kg (BCS 8–9) around mating, 21.2 kg (BCS 4–5) to 31.1 kg (BCS 8–9) at weaning and 27.3 kg (BCS 4–5) to 28.8 kg (BCS 8–9) prior to calving, respectively (Table 2.5).

**Table 2.4** Coefficients (Estimate) and standard errors of the coefficient (SE) with P values for all variables in the model to describe the relationship of body condition score (BCS) with live weight; the quadratic model included BCS both as a linear (BCS) and a quadratic (BCS<sup>2</sup>) term, whereas the linear model only considered the linear effect of BCS; results are relative to medium sized cows within the age category 5–9 years-of-age recorded at weaning.

	Quadratic model			Linear model		
	Estimate	SE	P value	Estimate	SE	P value
(Intercept)	432.9	13.3	< 0.001	376.9	6.8	< 0.001
BCS	9.9	3.5	0.004	26.7	0.4	< 0.001
BCS <sup>2</sup>	1.2	0.3	< 0.001			
Event						
pre-mating	62.2	16.9	< 0.001	-34.9	3.0	< 0.001
pre-calving	-38.9	15.9	0.014	10.4	3.0	< 0.001
Cow hip height						
small	-20.2	3.6	< 0.001	-19.1	3.6	< 0.001
tall	26.6	3.6	< 0.001	26.1	3.6	< 0.001
Age						
3	-43.6	0.8	< 0.001	-43.8	0.8	< 0.001
4	-19.0	0.6	< 0.001	-19.0	0.6	< 0.001
10+	-5.2	1.2	< 0.001	-5.2	1.2	< 0.001
Interaction terms						
BCS: pre-mating	-24.2	5.0	< 0.001	4.0	0.4	< 0.001
BCS: pre-calving	15.7	4.9	0.001	1.1	0.4	0.013
BCS <sup>2</sup> : pre-mating	2.0	0.4	< 0.001			
BCS <sup>2</sup> : pre-calving	-1.1	0.4	0.004			
BCS: small	-0.8	0.5	0.103	-0.9	0.5	0.053
BCS: tall	1.1	0.5	0.016	1.2	0.5	0.010

Blank cells were not included in the analysis.



**Figure 2.3** Relationship between live weight (LWT, kg) and body condition score (BCS, 1–10 score) for different events (mating, weaning, calving) and hip height categories (dashed line = small, solid line = medium, dotted line = tall cows) of mixed-aged beef breeding cows on commercial hill country farms in New Zealand; results are adjusted for age of cows.

**Table 2.5** Effect of event (mating, weaning and calving) on the relationship of body condition score (BCS, scale 1–10) with live weight (LWT, kg) for mixed-aged beef breeding cows and cow live weight change ( $\Delta$ LWT, kg) per unit BCS; results are adjusted for hip height and age of cows.

BCS	mating		weaning		calving	
	LWT $\pm$ SEM	$\Delta$ LWT	LWT $\pm$ SEM	$\Delta$ LWT	LWT $\pm$ SEM	$\Delta$ LWT
4	475.4 $\pm$ 6.4	15.1	477.9 $\pm$ 6.3	21.2	484.9 $\pm$ 6.2	27.3
5	490.5 $\pm$ 6.1	21.5	499.1 $\pm$ 6.1	23.6	512.2 $\pm$ 6.0	27.7
6	512.0 $\pm$ 6.0	28.1	522.7 $\pm$ 6.0	26.1	539.9 $\pm$ 6.0	28.1
7	540.1 $\pm$ 6.0	34.6	548.8 $\pm$ 6.0	28.6	568.0 $\pm$ 6.0	28.4
8	574.7 $\pm$ 6.0	41.1	577.4 $\pm$ 6.0	31.1	596.4 $\pm$ 6.0	28.8
9	615.8 $\pm$ 6.1		608.5 $\pm$ 6.1		625.2 $\pm$ 6.3	

Category for HIP was also significant ( $P < 0.001$ ), showing a different relationship between LWT and BCS for different HIP of cows. This effect was significant as an interaction with BCS as a linear term, such that a higher LWT change was necessary to

change between the same unit of BCS for tall compared with small or medium-sized cows (Table 2.6).

When only including a linear rather than a quadratic term in the regression model, the average weight change adjusted for HIP and age of cows was 30.8, 26.8 and 27.9 kg before mating, at weaning and before calving, respectively.

**Table 2.6** Effect of hip height (small, medium and tall) on the relationship of body condition score (BCS, scale 1–10) with live weight (LWT, kg) for mixed-aged beef breeding cows and cow live weight change ( $\Delta$ LWT, kg) per unit BCS; results are adjusted for event and age of cows.

	small		medium		tall	
	LWT $\pm$ SEM	$\Delta$ LWT	LWT $\pm$ SEM	$\Delta$ LWT	LWT $\pm$ SEM	$\Delta$ LWT
<b>BCS</b>						
4	453.5 $\pm$ 6.2	20.3	476.8 $\pm$ 6.2	21.1	507.9 $\pm$ 6.2	22.2
5	473.8 $\pm$ 6.1	23.4	497.9 $\pm$ 6.1	24.2	530.1 $\pm$ 6.1	25.3
6	497.2 $\pm$ 6.1	26.5	522.0 $\pm$ 6.1	27.3	555.4 $\pm$ 6.1	28.4
7	523.7 $\pm$ 6.1	29.6	549.3 $\pm$ 6.1	30.4	583.9 $\pm$ 6.1	31.5
8	553.4 $\pm$ 6.1	32.8	579.7 $\pm$ 6.1	33.5	615.4 $\pm$ 6.1	34.7
9	586.1 $\pm$ 6.2		613.3 $\pm$ 6.2		650.1 $\pm$ 6.2	

## 2.5 Discussion

### 2.5.1 Live weight and body condition score fluctuations

Cow LWT and BCS profiles reported in this study varied within a year following the annual production cycle. Cows tended to be at their lowest LWT and BCS before calving, which is likely caused by nutritional restrictions over winter when cows are expected to provide flexibility by mobilising body energy reserves as a nutritional buffer throughout periods of restricted feeding (Pleasant *et al.*, 1994) and supplementary feed is not usually offered despite the reduced pasture availability (Smeaton *et al.*, 1983). At weaning LWT and BCS tended to be greatest, which concurs with the finding reported by Morris *et al.* (2006) in Hereford × Friesian cows. In New Zealand, LWT and BCS are often recorded only once a year around weaning, which is likely to result in over-estimated averages of those cow traits throughout the annual production cycle (Muir & Thomson, 2011). Fluctuations between mating and weaning are likely to be primarily caused by climatic conditions and variable feed supply and quality over summer (Hickson *et al.*, 2017) such that droughts can result in LWT and BCS loss throughout this period (Morris *et al.*, 2006). Given the variation in profiles observed in this study, calculating an average LWT and BCS across animals can be challenging and both traits should best be recorded at key time points as outlined in this study to provide suitable information that can be used for feed planning (Morris & Smeaton, 2009). Beef cow management systems vary considerably around the world including seasonal versus non-seasonal calving, supplementation policies during feed deficits and intensity of farm management. International literature, however, supports the results found in this study where research has shown that climatic conditions and corresponding pasture availability and quality can dictate seasonal patterns in LWT and BCS of grazing beef cattle in the United States (Adams *et al.*, 1996) and Australia (Meyer, 2000, Lee *et al.*, 2018), especially in systems where little to no supplementary feed is provided for the cow-calf unit (McBride & Kenneth, 2011).

Among farms LWT and BCS fluctuated to various degrees, and across years within properties, however, no attempt was made to ascertain the driving factors behind these differences. Possible factors include differences among farms or years in the temperature and/or rainfall, along with different management strategies, competing stock classes and the presence of animal health challenges. Farmers can use the values presented in this paper as a benchmark to compare the condition of their own cows and

evaluate how they are using BCS change of their cows to manage feed demand on their farm in response to fluctuations in feed availability. The results found in this study reflect the extent of flexibility cows offer to the farming system in response to variable feed supply. At farm B, the change in mean LWT from mating to weaning ranged among years from a 70 kg LWT loss to a 38 kg LWT gain, indicating substantial variation in feed allocated to the cow herd from year to year.

When considering  $LWT_{adj}$ , the effect of state of pregnancy during gestation is apparent and had the largest impact on pre-calving LWT. Evaluating BCS is independent of the frame size of the animal (Hickson *et al.*, 2017) and not influenced by factors such as stage of pregnancy (Morris *et al.*, 2002), allowing a more accurate prediction of the energy reserves of cows (Russel *et al.*, 1969, Beef + Lamb New Zealand, 2017), irrespective of size and weight of the conceptus (Morris & Smeaton, 2009). The results found in this study reflect this trend as fluctuations in BCS match the fluctuations in  $LWT_{adj}$  more closely than those for actual LWT.

### **2.5.2 Relationship between live weight and body condition score**

Knowledge of relationships between LWT and BCS can be a useful tool to optimise the reproductive performance of cows. Research has shown that the pregnancy rate can be enhanced by reaching an acceptable BCS level at mating time (Morris *et al.*, 2006). Information about the amount of LWT change that corresponds to one unit change in BCS can be used to predict feed requirements necessary to reach BCS targets where no LWT data has been recorded.

The current study reinforced that LWT in cows was significantly related to BCS ( $P < 0.001$ ); and high correlations between LWT and BCS within individual cows being previously reported in several studies on beef cows (Buskirk *et al.*, 1992, Northcutt *et al.*, 1992, Lalman *et al.*, 1997, Tennant *et al.*, 2002). The relationship between  $LWT_{adj}$  and BCS was also significant in the current study. However, regression analysis only indicated a change of the intercept at calving, such that the  $LWT_{adj}$  of the cows was lower for the same BCS than the unadjusted LWT but had no effect on the weight necessary to change between the same BCS units and supports the results reported by Berry *et al.* (2011) in Holstein-Friesian dairy cows.

In the current study, the LWT necessary to change between one unit of BCS was not consistent among different measurement times within the production cycle which concurs with the results reported by Tennant *et al.* (2002) in American Angus cows and

Morris *et al.* (2002) in Hereford × Friesian cows. Wagner (1984) reported that the quadratic relationship between LWT and BCS accounted for more of the variation than did the linear model, implying that change in LWT for lower-conditioned cows was smaller than for fatter cows. Although the results found in this study agree with this trend for the mating and weaning measurement, the weight change around calving seems to be more accurately described by a linear relationship (Figure 2.3). Including only the linear regression term in the model allows for a more practical application and predicted an average weight of 30.8, 26.8 and 27.9 kg around mating, at weaning and before calving, respectively, to change between one unit of BCS based on the 1–10 scale of BCS used in this study. These estimates are consistent with previous reports for beef cows of 38 kg LWT change per unit BCS on a 0–9 scale (Wagner, 1984), 33 kg LWT change per unit BCS on a 1–9 scale (Lalman *et al.*, 1997), 68 kg LWT change per unit BCS on a 1–5 scale (Buskirk *et al.*, 1992), and 30 kg on a 1–10 scale (Hickson *et al.*, 2017).

The interaction between BCS and HIP of cows was statistically significant in the current model, implying that taller cows require an increased weight change than small or medium-sized cows to change between the same units of BCS. The difference in LWT change for tall compared to small cows, however, was less than 5% when changing between the same BCS units and may not be practically relevant under extensive hill country conditions.

## **2.6 Conclusions**

Beef cows varied largely in LWT and BCS within a year and fluctuations ranged from 32.4 to 77.2 kg and 0.4 to 1.8 scores, respectively, across farms. Those trends were not consistent among years, indicating that LWT and BCS of cows can vary considerably over time. This variation in BCS reflects the variability in feed allocated to the cow herd and therefore the flexibility beef cows offer to pastoral farming systems. Cow live weight and BCS were significantly related in the current study. This relationship varied for different events throughout the annual production cycle in a quadratic manner but was similar for different HIP categories of the cows, indicating that the same LWT change is needed to change between BCS units, regardless of the size of the cow. Considering only a linear regression term, 30.8, 26.8 and 27.9 kg LWT gain were required to achieve one unit increase of BCS around the timing of mating, at weaning

and before calving, respectively, and this information can be incorporated into economic models and used for feed budgeting purposes.

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## **Chapter 3 – Relationship between body condition score and pregnancy rates following artificial insemination and subsequent natural mating in beef cows on commercial farms in New Zealand**

### **Publications arising from this chapter:**

Weik F, Archer JA, Morris ST, Garrick DJ, Hickson RE 2020. Relationship between body condition score and pregnancy rates following artificial insemination and subsequent natural mating in beef cows on commercial farms in New Zealand. *New Zealand Journal of Animal Science and Production* 80: 14-20.

### **3.1 Abstract**

Body condition scoring is an efficient on-farm visual-assessment tool used to describe the energy reserves of animals. Cow body condition score (BCS) at crucial time points throughout the year is likely to influence reproductive performance. The aim of this experiment was to examine the influence of BCS before calving, before mating and at weaning on reproductive performance of mature beef cows. Percentage of cows conceiving to a single artificial insemination (AI) at a synchronised oestrus and pregnancy rate after 49 days of mating were determined for a total of 2,683 individual cows. Cows with a greater than average BCS had greater pregnancy rate to AI than did those with low BCS ( $P < 0.001$ ). The percentage of animals conceiving to AI was on average 54.8% but was lower at 42.5% for pre-mating BCS 4.5 or greater at 64.5% for BCS 9.0 ( $P < 0.001$ ). Cows had greater overall pregnancy rate after 49 days of mating with greater BCS; ranging from 88.3%, 75.7% and 79.7% for BCS 4.5 before calving, before mating and at weaning, respectively, to 93.5%, 93.3% and 93.3% for BCS 8.0 at the same time points. Increasing BCS up to 7 is likely to improve overall pregnancy rate, and most benefit tends to come from improving BCS in lower-conditioned cows to achieve high pregnancy results.

### 3.2 Introduction

Body condition scoring is an easy and efficient tool to assess the energy reserves of livestock which reflects their recent nutritional management. It is used to evaluate energy reserves of the animals based on their body fat and muscle reserves (Wagner *et al.*, 1988, Bishop *et al.*, 1994) and is a better predictor of body fat than is live weight (LWT) (Russel *et al.*, 1969). The assessment of body condition score (BCS) should not simply reflect the LWT of the animals nor be influenced by factors like gut-fill, mature size or weight of the conceptus in pregnant cows. Body condition score can be used to evaluate the body reserves of cows at crucial time points throughout the year to improve feed planning, which is known to influence reproductive performance (Morris *et al.*, 2006). Typically, BCS is evaluated through visual assessment that is easily implemented on-farm, without the need for any off-site training or further equipment. In New Zealand BCS in beef cows is typically assessed on a 1-10 (Smeaton *et al.*, 2000, Hickson *et al.*, 2017) or a 0-5 (Morris *et al.*, 2002) scale. A report by Hickson *et al.* (2017) using the 10-point scale suggested a target BCS of 6 at mating, 7 at weaning and 5 throughout the winter months.

Reproductive performance has been reported as being influenced by BCS, in terms of pregnancy rates or inter-calving interval, in New Zealand sheep (Kenyon *et al.*, 2014), beef cattle in the United States (Ciccioli *et al.*, 2003, Renquist *et al.*, 2006) and New Zealand dairy cows (Buckley *et al.*, 2003). According to Selk *et al.* (1988) BCS before calving and at the start of mating are the main factors influencing pregnancy rates in beef cows. Similarly, DeRouen *et al.* (1994) reported a significant positive effect of BCS at calving on subsequent pregnancy rate. However, few studies have been conducted to describe this relationship for beef cows in New Zealand. Morris *et al.* (2006) reported higher pregnancy rates for cows with greater BCS at joining than for lower-conditioned cows. Tait *et al.* (2017) indicated that cows that had higher BCS at mating or at pregnancy diagnosis were more likely to have reproductive success.

Artificial insemination (AI) is an efficient reproductive technology with the potential to incorporate favoured genetics into the herd to increase productivity and genetic gain (Vishwanath, 2003). Artificial insemination is widespread within the New Zealand dairy industry, but not yet as well established in beef cow herds (Smeaton *et al.*, 2003). This is mainly due to management issues as beef cattle are not yarded together on a regular basis. One approach to overcome this limitation has been the introduction of

oestrus synchronisation. There is scope for a wider use of AI programs within the industry to further improve the beef herd (Morris & Archer, 2007). To the authors' knowledge, there is no published literature that examined the relationship between BCS and AI success rate in New Zealand beef cows. However, some studies around the New Zealand dairy industry (Roche *et al.*, 2007) as well as the beef industry outside New Zealand (Spratt *et al.*, 1998, Ayres *et al.*, 2014) have identified higher pregnancy rate to AI for cows with higher than average BCS.

The aim of this study was to evaluate and quantify the relationship of BCS before calving, before mating and at weaning with pregnancy rate to AI and overall pregnancy rate following a 49-day mating period of beef breeding cows on commercial hill-country farms in New Zealand.

### **3.3 Materials and methods**

#### **3.3.1 Dataset**

The beef progeny test (BPT) and all related procedures were approved by the AgResearch Ethical Committee. The dataset consisted of an ongoing BPT carried out by Beef + Lamb New Zealand Genetics on four large-scale commercial farms in New Zealand. The farms are located on North (Gisborne, Central Northern plateau, Southern Hawkes Bay) and South Island (North Canterbury) hill country with varying climatic conditions and, therefore, diverging seasonal trait recordings. Data were collected over a period of five years from November 2014 to September 2019. Each year, beef cows were artificially inseminated with semen from New Zealand or foreign bulls. Bull breeds used for mating were Angus, Hereford, Stabilizer, Simmental and Charolais. Data for this experiment was taken from the base population of the BPT, including all cows that built up the population at the start of the progeny test as well as all replacement animals from within the property. Consistent with normal farm practices, animals were typically managed separately in different mobs. However, the overall recording scheme followed the same system for each of those mobs within farm and year. All animals included in this analysis were mixed-aged beef breeding cows (3–10+ years of age) with their second or later calf at foot. Body condition score and pregnancy data representing a total of 5,484 pregnancy outcomes of 2,683 cows with a total of 16,105 BCS recordings were available for this experiment. All cows in the project were Angus or Hereford. Consistent with normal farm practices, cows failing to conceive were culled following weaning of their calves.

#### **3.3.2 Measurements**

Body condition score was recorded within each herd for all base cows in the dataset on three events throughout the year: pre-calving (July–September), pre-mating (November–January) and weaning (February–April). Timing of these events varied among farms and years but was consistent for all cows within farm and year. Body condition scoring was conducted on a 1–10 scale with 0.5 increments (1=emaciated and 10=obese; Hickson *et al.*, 2017). Birth years were recorded for each cow. All cows included in the analysis were inseminated once by fixed-time AI at a synchronised oestrus before bulls were introduced to the herd, generally two to three days following AI and always less than 21 days after AI. Details on the synchrony protocol are outlined in Chapter 2. Bulls remained with the herd for a minimum of seven weeks after AI. Date of AI was recorded with corresponding sire ID. Pregnancy diagnosis (PD) was

conducted approximately 90 days after AI using trans-rectal ultrasound by an experienced commercial operator. Fetal age was recorded at pregnancy scanning based on a combination of characteristics. Pregnancy was recorded as either 0 (not pregnant) or 1 (pregnant) at the time of PD.

### ***3.3.3 Data manipulation***

Pregnancy rates represent the number of pregnant cows as a proportion of total number of cows with pregnancy records at the time of PD. Day of conception was calculated from the fetal age recorded at PD. A gestation length of 282 days (Burriss & Blunn, 1952) was assumed to compute probable calving dates based on the fetal age at PD. The interval from this probable calving date to the following AI date was calculated and is referred to as “days from previous calving” (DfPC). The fetal age record was used to determine whether each cow had conceived to AI or natural mating. Cows were defined as conceived to AI when the days between the estimated conception date and AI-Date were less than eight days. Similarly, fetal-age records were used to determine pregnancy rate, where cows for which the fetal age indicated they conceived more than seven weeks after AI were recoded as not pregnant to allow calculation of a standardised 49-day pregnancy rate. Age of cows was calculated from their birth year. Cows were grouped according to their age into four categories: 3-year-olds, 4-year-olds, 5–9-year-olds and 10 or more years old. Body condition score ranks with fewer than five records for each time point were excluded from this study, leaving a range of BCS from 4.0 to 9.0 for further analysis (Table 3.1).

**Table 3.1** Number of cow records for each body condition score (BCS), mean and standard deviation (SD) of BCS and days from previous calving date to first day of mating (DfPC), pregnancy rate to artificial insemination (AI; cows pregnant to a single AI by cows with pregnancy records, %) and 49-day pregnancy rate (cows pregnant after a 49-day mating period by cows with pregnancy records, %) recorded before calving, before mating and at weaning.

	Before calving	Before mating	At weaning
BCS records <sup>1</sup>			
4	57	5	13
4.5	263	30	58
5	539	154	212
5.5	719	305	358
6	1,116	593	717
6.5	736	564	789
7	922	1,023	1,309
7.5	602	874	772
8	389	1,168	841
8.5	86	426	225
9	6	99	135
Total n of records	5,435	5,241	5,429
BCS			
Mean $\pm$ SD	6.33 $\pm$ 1.01	7.14 $\pm$ 0.97	6.92 $\pm$ 0.97
DfPC			
Mean $\pm$ SD	71.63 $\pm$ 15.74	71.68 $\pm$ 15.80	71.63 $\pm$ 15.73
49-day pregnancy rate (%)	90.82	91.01	90.88
AI pregnancy rate (%)	54.98	55.43	54.93

<sup>1</sup>BCS was scored on a 1-10 scale with 1=emaciated and 10=obese.

### 3.3.4 Statistical analysis

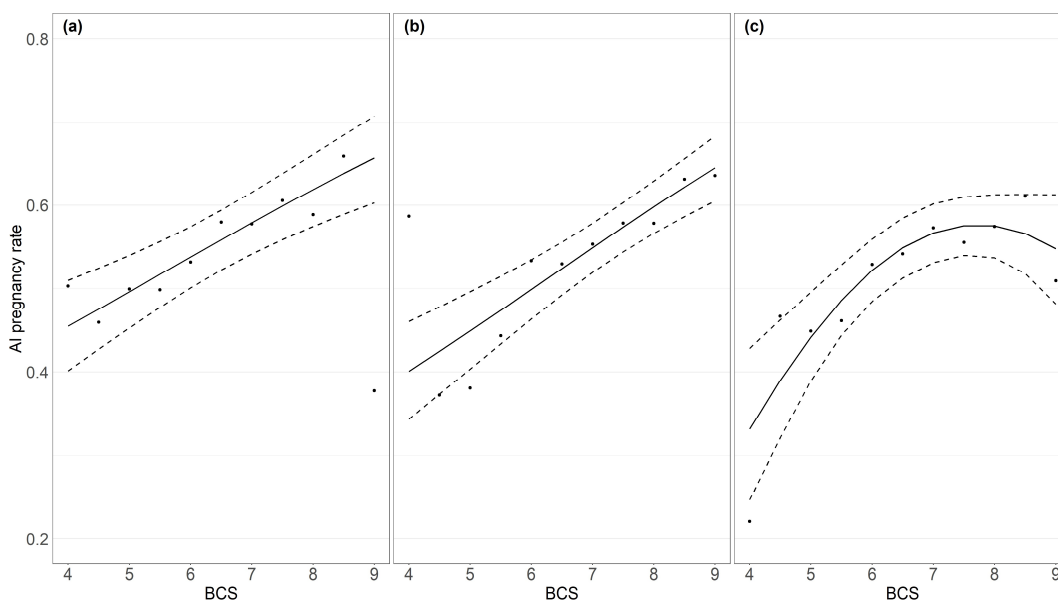
Binomial regression analysis was performed using R version 3.6.0 (Packages 'lme4' and 'lsmeans'; R Core Team, 2019) to evaluate the relationship between pre-calving BCS, pre-mating BCS and BCS at weaning on reproductive performance. Percentage of cows conceiving to a single AI, and pregnancy rate after 49 days of mating, were analysed using logit transformation for categorical data analysis. Age of cow (3, 4, 5-9 and 10+) was considered as a class effect but was not significant for any model and was excluded from the final models. Body condition score and DfPC were included as covariates for each model. Body condition score was fitted as a linear and quadratic effect to test for deviation from linearity. The covariates for each model were standardised prior to analysis by subtracting the overall mean and dividing by the standard deviation (SD) (Table 3.1). A contemporary group (herd  $\times$  season  $\times$  mob) and the sire used for AI were

fitted as random effects. Analyses of variance (ANOVA) were conducted to test for significance of the model effects and the form of relationship between the predictor and the response variables. Probabilities of pregnancy rates to AI and pregnancy rate after 49 days of mating were calculated for each level of BCS. In a second approach, BCS was fitted as a fixed effect in each model to estimate least-square means (lsmeans) for each category of BCS. All probabilities and estimates were calculated based on the mean DfPC in this experiment of 71.6 days.

### 3.4 Results

#### 3.4.1 AI pregnancy rate

The overall percentage of animals conceiving to AI was 54.8%. Cows tended to have greater pregnancy rate ( $P < 0.001$ ) to AI with increasing BCS for all measured time points, ranging from 45.5% (95% CI 40.1–51.0) to 65.7% (95% CI 60.3–70.8) for BCS 4.0–9.0 pre-calving, 40.0% (95% CI 34.3–46.1) to 64.5% (95% CI 60.5–68.3) for BCS 4.0–9.0 pre-mating and 33.1% (95% CI 24.7–42.8) to 57.5% (95% CI 54.0–61.0) for BCS 4.0–8.0 at weaning (Figure 3.1). No quadratic relationship between the predictor and the response variable could be identified for pre-calving and pre-mating ( $P > 0.05$ ), however, BCS at weaning showed a significant quadratic ( $P < 0.01$ ) relationship (Table 3.2). In addition, cows that calved early in the previous mating season had a significantly greater chance ( $P < 0.001$ ) of conceiving to AI the following year.



**Figure 3.1** Relationship of body condition score (BCS) before calving (a), before mating (b) and at weaning (c) with pregnancy rate to artificial insemination (AI; cows pregnant to a single AI by cows with pregnancy records); solid line: predicted probabilities from regression analysis, dashed line: 95% CI, dots: least square means for each level of BCS; results are based on an average 71.6 days between previous calving date and first day of mating.

**Table 3.2** Standardised coefficients and standard errors (Estimates  $\pm$  SE) with P-values and unstandardised coefficients (log odds) for all variables in the model to describe the relationship of body condition score (BCS) before calving, before mating and at weaning with pregnancy rate to artificial insemination (AI; cows pregnant to a single AI by cows with pregnancy records) and 49-day pregnancy rate (cows pregnant after a 49-day mating period by cows with pregnancy records) on the logit scale.

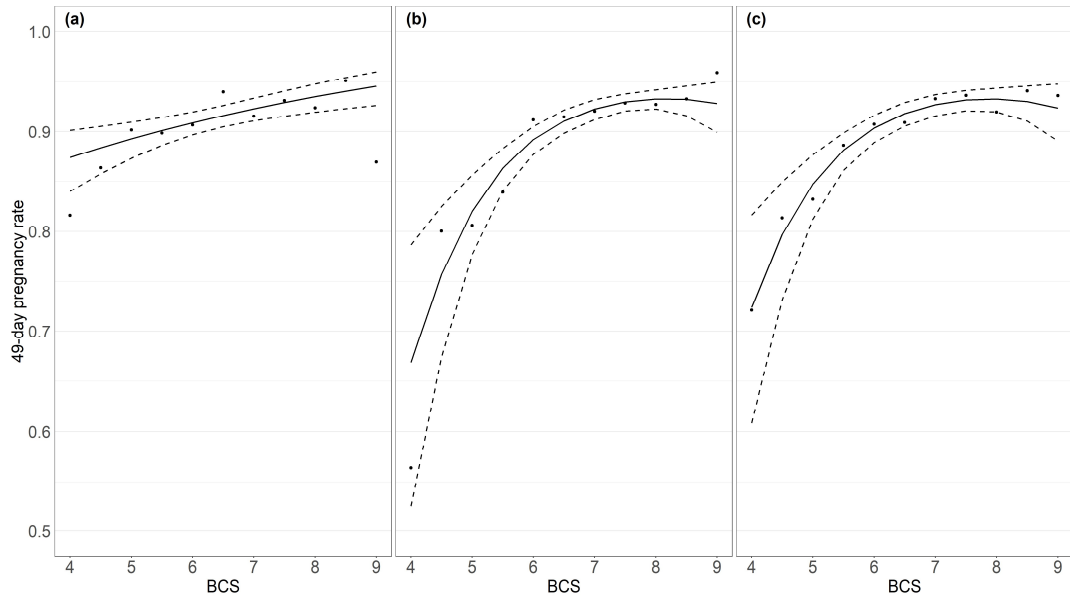
	Pregnancy rate to AI			49-day pregnancy rate		
	Estimates ( $\pm$ SE)	P value	Log odds	Estimates ( $\pm$ SE)	P value	Log odds
<b>Model 1 – pre-calving</b>						
Intercept	0.21 $\pm$ 0.07	0.005	-1.93	2.36 $\pm$ 0.07	<0.001	-0.35
BCS	0.17 $\pm$ 0.04	<0.001	0.17	0.19 $\pm$ 0.05	<0.001	0.18
DfPC <sup>1</sup>	0.24 $\pm$ 0.03	<0.001	0.02	0.34 $\pm$ 0.04	<0.001	0.02
<b>Model 2 – pre-mating</b>						
Intercept	0.22 $\pm$ 0.06	<0.001	-2.46	2.41 $\pm$ 0.06	<0.001	-6.30
BCS	0.19 $\pm$ 0.03	<0.001	0.20	1.75 $\pm$ 0.53	<0.001	1.81
BCS <sup>2</sup>				-1.49 $\pm$ 0.54	0.006	-0.11
DfPC <sup>1</sup>	0.28 $\pm$ 0.04	<0.001	0.02	0.34 $\pm$ 0.05	<0.001	0.02
<b>Model 3 – weaning</b>						
Intercept	0.19 $\pm$ 0.07	0.006	-5.10	2.42 $\pm$ 0.07	<0.001	-5.67
BCS	1.08 $\pm$ 0.33	0.001	1.12	1.68 $\pm$ 0.48	<0.001	1.74
BCS <sup>2</sup>	-0.96 $\pm$ 0.33	0.004	-0.07	-1.46 $\pm$ 0.49	0.003	-0.11
DfPC <sup>1</sup>	0.24 $\pm$ 0.03	<0.001	0.02	0.32 $\pm$ 0.05	<0.001	0.02

Blank cells were not included in the analysis.

<sup>1</sup>Days from previous calving date to first day of mating.

### 3.4.2 Forty-nine-day pregnancy rate

The 49-day pregnancy rate for all cows was 90.8%. Pregnancy rate was significantly ( $P < 0.001$ ) associated with BCS before calving, before mating or at weaning (Table 3.2), with a higher proportion of cows conceiving at greater BCS. Cows with a greater than average BCS had greater pregnancy rates; ranging from 87.4% (95% CI 84.0–90.1) to 94.5% (95% CI 92.6–96.0) for BCS 4.0–9.0 pre-calving, 66.9% (95% CI 52.5–78.7) to 93.3% (95% CI 92.3–94.2) for BCS 4.0–8.0 pre-mating and 72.4% (95% CI 60.8–81.6) to 93.3% (95% CI 92.0–94.4) for BCS 4.0–8.0 at weaning (Figure 3.2). Pre-mating BCS and BCS at weaning followed a quadratic function with little increase in pregnancy rate for BCS above 7. In contrast, pre-calving BCS was linearly related to 49-day pregnancy rate. 49-day pregnancy rate increased ( $P < 0.001$ ) as the time increased between the preceding probable calving date and the first day of mating.



**Figure 3.2** Relationship of body condition score (BCS) before calving (a), before mating (b) and at weaning (c) with 49-day pregnancy rate (cows pregnant after a 49-day mating period by cows with pregnancy records); solid line: predicted probabilities from regression analysis, dashed line: 95% CI, dots: least square means for each level of BCS; results are based on an average 71.6 days between previous calving date and first day of mating.

### **3.5 Discussion**

#### ***3.5.1 AI pregnancy rate***

Nutritional status has been demonstrated to influence reproductive performance in beef cows (Whitman, 1975, Sprott *et al.*, 1998). Body condition score as a measure of nutritional status can, therefore, be manipulated in order to improve reproductive performance. From a management perspective, a high percentage of cows conceiving early in the breeding season is desired and may subsequently lead to increased calf weaning weights (Lesmeister *et al.*, 1973).

Regression analysis showed a positive association between BCS and pregnancy rate to AI, indicating that an increase in BCS would result in a greater proportion of cows conceiving to AI early in the mating season. The form of relationship between BCS before calving and before mating and the pregnancy rate to AI was linear. This implies that any increase in BCS around calving and before mating would result in improved pregnancy rate to AI. Ayres *et al.* (2014) found that Zebu beef cows were more likely to conceive to first mating by AI when they were at their greatest BCS at parturition. Similarly, studies on dairy cows reported a positive effect of higher BCS at calving on pregnancy rate at first mating by AI (Roche *et al.*, 2007), while cows in poor condition at parturition tended to have lower pregnancy rates (Lopez-Gatius *et al.*, 2003). Ayres *et al.* (2014) did not identify a relationship between BCS around mating and AI conception rate, whereas Roche *et al.* (2007) reported a significant effect.

Results from this experiment support the conclusion that beef cows need to be in BCS of at least 6, around the time of calving and/or mating, to achieve approximately 50% conception to a single synchronised AI, and that greater BCS will likely lead to further improvements in conception rate. Adequate number of days between previous calving and the start of mating and good BCS at calving has been demonstrated to increase the probability of oestrus (Whitman, 1975, Sprott *et al.*, 1998). In agreement with this, the current experiment showed that an increase in time from previous calving results in greater pregnancy rate to AI at the start of mating, indicating that cows that calved early were more likely to conceive to AI at the following breeding.

#### ***3.5.2 Forty-nine-day pregnancy rate***

The mean pregnancy rate reported by McFadden *et al.* (2005) was 91% for a total of 1,005 beef cow herds in New Zealand and matches the findings of this study with an overall pregnancy rate of 90.8–91.0% across all herds and years.

Several studies have described the relationship between pre-calving BCS and BCS around mating on pregnancy rate. Pre-calving BCS had a significant effect on 49-day pregnancy rate in this experiment, which agrees with the findings of DeRouen *et al.* (1994) and Selk *et al.* (1988), however, neither Morris *et al.* (2006) nor Tait *et al.* (2017) found an effect of calving BCS on pregnancy rate. Pre-mating BCS and BCS at weaning were significantly related to 49-day pregnancy rate in the current study. Renquist *et al.* (2006) and Morris *et al.* (2006) demonstrated an increase in pregnancy rate for higher BCS at joining, whereas Tait *et al.* (2017) did not report a significant relationship of BCS at joining or PD with pregnancy rates.

Pre-mating BCS and BCS at weaning were quadratically related to 49-day pregnancy rate in the current experiment. Improving condition around mating to BCS 7 is beneficial whereas further increase is unlikely to result in greater pregnancy rates. This outcome could explain the absence of a significant relationship between BCS at joining and PD on pregnancy results reported by Tait *et al.* (2017), as the cows in their study were all above BCS 6, and based on the results found in this experiment, a strong response would have been unlikely. Compared to the curvilinear trend for pre-mating BCS and BCS at weaning, pre-calving BCS followed a linear relationship. This indicates that increasing pre-calving BCS would result in higher pregnancy rates without a detrimental effect of very high BCS. This finding concurs with Renquist *et al.* (2006), who also reported a quadratic relationship between BCS around breeding and a linear relationship between BCS at calving on pregnancy rates. This experiment outlines an optimum BCS between 6 and 7 at mating and weaning, whereas overall higher pre-calving BCS would be advantageous. From a commercial perspective, this demonstrates the value of separating lower-conditioned cows and increasing their feed levels to ensure sufficient BCS gain. However, increasing BCS before calving is associated with higher feed costs for grazing cows compared to after calving when more feed is becoming available as a response to increased pasture growth in early spring. The results found in this experiment tend to agree with industry targets outlined by Hickson *et al.* (2017), which seem to be adequate guidelines to improve pregnancy results.

Compared among pre-calving BCS, pre-mating BCS and BCS at weaning, the pre-mating BCS tends to be the most valuable in predicting pregnancy rates and might therefore be a key point for achieving pregnancy rate targets. Those findings coincide with those of Renquist *et al.* (2006) who identified a greater variation in pregnancy rate being explained by BCS at breeding compared to BCS at calving. Nevertheless, BCS at weaning

is often the only measurement available for New Zealand farmers in their day-to-day practices. Cows that are in better condition at weaning may be more likely to have gained or at least maintained condition over the mating period compared with cows that were in poorer condition at weaning. This could explain why those cows with greater BCS at weaning were more likely to have conceived during the mating period.

Pre-calving BCS did have an influence on 49-day pregnancy rate in the current experiment, but the slope of the relationship at lower BCS was greater before mating than before calving. This suggests that the focus for management should be to ensure that cows achieve a minimum BCS of 6 to 7 at time of mating. Based on the relationship persisting through to weaning, it seems that it is likely that maintaining target BCS of 6 to 7 at least across the mating period may also improve 49-day pregnancy rates.

### **3.6 Conclusions**

This study quantified the relationship of BCS before calving, before mating and at weaning with AI and 49-day pregnancy rate. Increasing BCS tends to be advantageous to achieve higher pregnancy rates. The linear relationship between BCS and AI pregnancy rate suggests that aiming for the highest possible BCS before calving and before mating would lead to improved outcomes from AI programs. For overall pregnancy rate (after 49 days of natural mating post-AI), the curvilinear relationship with BCS suggests that most value can be obtained by reducing the percentage of low conditioned cows in the herd.

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## **Chapter 4 – Genetic parameters for maternal performance traits in commercially farmed New Zealand beef cattle**

### **Publications arising from this chapter:**

Weik F, Hickson RE, Morris ST, Garrick DJ, Archer JA 2021. Genetic parameters for maternal performance traits in commercially farmed New Zealand beef cattle. *Animals* 11: 2509. DOI: [10.3390/ani11092509](https://doi.org/10.3390/ani11092509).

#### 4.1 Abstract

Maternal performance is a major driver of profitability in cow-calf beef cattle enterprises. The aim of this research was to evaluate the inheritance of maternal performance traits and examine the intercorrelation among reproduction, live weight (LWT), hip height (HIP), body condition score (BCS) and maternal contribution to calf weaning weight (WWT) in 15-month-old heifers, 2-year-old cows and mature cows in New Zealand beef herds. Data were collected on a total of 14,241 cows and their progeny on five commercial New Zealand hill country farms. Heritabilities were low for reproductive traits in heifers and mature cows (0–0.06) but were greater in 2-year-old cows (0.12–0.21). Body condition scores were lowly (0.15–0.26) and LWT (0.42–0.48) and HIP (0.47–0.65) highly heritable in heifers, 2-year-old cows and mature cows. Results indicate that 2-year-old cows with higher genetic potential for rebreeding ability may have greater genetic merit for LWT, HIP and BCS as heifers ( $r_g = 0.19$ – $0.54$ ) but are unlikely to be larger cows at maturity ( $r_g = -0.27$ – $-0.10$ ). The maternal genetic effect on WWT had a heritability of 0.20 and was negatively genetically correlated with BCS in lactating cows ( $r_g = -0.55$ – $-0.40$ ) but positively genetically correlated with rebreeding performance ( $r_g = 0.48$ ).

## 4.2 Introduction

Beef cows contribute indirectly to the profitability of a beef enterprise by producing calves that are either retained as herd replacements or finished for beef production. In New Zealand commercial farming operations, the profitability of beef cows is low due to low reproduction rates in terms of number of calves weaned per cow per year and high feed costs for raising herd replacements for the next generation. Thus, improving maternal and progeny performance is required to increase profitability of the cow-calf unit.

Potential antagonisms exist between increasing growth in finishing beef cattle systems and correlated response in mature live weight (MWT) (Archer *et al.*, 1998). The live weight (LWT) of cows is often used as a predictor for feed requirements and represents the combined weight of muscle, fat, bones and internal organs (Owens *et al.*, 1995) and varies by physiological state, frame size and gut-fill (Morris *et al.*, 2002). Heavier MWT are associated with higher energy requirements for maintenance, thus an increase would reflect higher costs for maintaining performance (Smeaton *et al.*, 2000, Ochsner *et al.*, 2017) and, therefore, may affect the profitability of the beef cow herd. In times of feed shortage, where feed requirements cannot be met, cows are required to mobilise body energy reserves. Body condition scoring is a measure of body energy reserves and is independent of the previously described factors influencing cow LWT (Wagner, 1984, Bishop *et al.*, 1994, Morris *et al.*, 2002, Hickson *et al.*, 2017). Body condition is associated with reproductive performance of cows and a decline in energy reserves may adversely affect traits such as pregnancy rate or inter calving interval (refer to Chapter 3, Osoro & Wright, 1992, Morris *et al.*, 2006). Dependent on breed and region, research has shown that an increase in LWT traits can, although only to a limited extent, adversely affect reproduction traits including days to calving ( $r_g = 0.07-0.08$ ) (Johnston & Bunter, 1996, Forni & Albuquerque, 2005) or pregnancy rate at 15 months of age ( $r_g = -0.32$ ) (Wolcott *et al.*, 2014a) whereas other studies reported no impact on reproduction (Mercadante *et al.*, 2003).

Selection for improved maternal performance is often inefficient as it relies on traits only measured on those females retained in the breeding herd and often expressed later in life (Cammack *et al.*, 2009). Furthermore, most reproductive traits tend to be of low heritability (Koots *et al.*, 1994a, Cammack *et al.*, 2009, Johnston, 2014), resulting in reduced prediction accuracy and, thus, constraining the rate of genetic gain. In

commercial cattle environments, breeders are often concerned with the rebreeding ability of herd replacements after the first successful calving (Hickson *et al.*, 2008, Valente *et al.*, 2017). During that time, cows require energy levels to exceed maintenance requirements to achieve growth and milk production in combination with environmental challenges (Boligon *et al.*, 2012). Without proper management, cows may in some years experience reduced conception rates in their second mating season (Hickson *et al.*, 2008).

Reports on the genetic variability of maternal performance in New Zealand beef cattle are relatively sparse and the inheritance of maternal performance traits has not yet been examined in commercial herds across a range of different environments and years. Better knowledge of the inheritance and relationships between key maternal performance traits in commercially farmed beef cattle is needed to make informed breeding decisions. Therefore, the objective of this study was to estimate genetic parameters for reproduction, LWT, hip height (HIP), body condition score (BCS) and maternal weaning weight traits measured in 15-month-old heifers, 2-year-old cows and mature cows in New Zealand beef herds.

## **4.3 Materials and methods**

### ***4.3.1 Dataset and animal management***

All measurements and related procedures were approved by the AgResearch Animal Ethics Committee (Approval numbers: 13358, 13373, 13394, 13693, 14031, 14311, 14588, 14851, 15153).

Data available for this research originated from an ongoing beef progeny test (BPT) by Beef + Lamb New Zealand Genetics conducted on five large-scale commercial hill country farms in New Zealand and initiated in 2014 (refer to Chapter 2 and Chapter 3). The BPT was designed to compare the performance of cattle across a range of different breeds and environments.

Records were available from 2014 until 2021 for a total of 14,241 animals and the number of records is further outlined in Table 4.1. The data contained records on several traits for performance evaluation and records were obtained for the original population of cows in the project as well as all progeny resulting from each mating, and the corresponding pedigree was recorded. Calves were identified to the dam and sire by DNA parentage verification. Parentage of calves born prior to 2018 was determined by genotyping progeny and dams using a 120 SNP chip (Zoetis, Auckland, New Zealand) and sires through either 120, 10K or 50K SNP chips (Neogen, Gatton, Australia) and for calves born in 2018 or later was verified through 10K SNP chips for progeny and dams and 50K or above for sires (AgResearch GenomNZ, Dunedin, New Zealand).

**Table 4.1** Trait abbreviations, units of measurement, number (n) of records, individual animals, sires and dams, range of measurements, means and standard deviations (SD) after adjustments and scaling.

Abb.	Unit	n of Records		n of Individual Records	n of Dams	n of Sires	Range	Mean (SD)
		Females	Males					
<b>Reproduction</b>								
HP	%	1,660	-	1,660	1,349	232	0/1	88.1 <sup>1</sup>
DtCH	Days	1,904	-	1,904	1,532	242	0–82	24.4 (21.3)
RB	%	1,189	-	1,189	1,041	203	0/1	92.0 <sup>1</sup>
DtC2	Days	1,220	-	1,220	1,072	206	0–91	25.4 (21.0)
PR	%	11,730	-	4,240	596	148	0/1	93.3 <sup>1</sup>
<b>Live weight, hip height and body condition</b>								
HWT	kg	2,347	-	2,347	1,822	328	282–444	357.0 (27.1)
HBCS	Score	2,340	-	2,340	1,822	328	6–9	7.9 (0.6)
HHIP	cm	2,948	-	2,948	2,185	358	99–133	115.3 (4.7)
WT2	kg	1,488	-	1,488	1,265	243	299–656	470.0 (52.4)
BCS2	Score	1,484	-	1,484	1,263	242	4–9	7.1 (0.8)
HIP2	cm	1,535	-	1,535	1,295	257	116–139	127.1 (3.9)
MWT	kg	35,375	-	4,658	897	195	408–728	562.4 (47.2)
MBCS	Score	35,393	-	4,660	897	195	3–10	6.9 (1.0)
MHIP	cm	5,172	-	3,552	858	186	118–143	130.3 (4.0)
WWT	kg	3,454	3,524	6,978	3,861	381	110–338	226.5 (32.1)

HP = pregnancy rate of 15-month-old heifers; DtCH = days to conception in 15-month-old heifers; RB = rebreeding performance in 2-year-old cows; DtC2 = days to conception in 2-year-old cows; PR = pregnancy rate of mature cows; HWT = live weight of 15-month-old heifers; HBCS = body condition score of 15-month-old heifers; HHIP = hip height of 15-month-old heifers; WT2 = live weight of 2-year-old cows; BCS2 = body condition score of 2-year-old cows; HIP2 = hip height of 2-year-old cows; MWT = mature live weight; MBCS = body condition score of mature cows; MHIP = hip height of mature cows; WWT = weaning weight of calves.

<sup>1</sup>Percentage.

All replacement heifers were naturally mated in their first two breeding seasons, at approximately 15 and 27 months of age. Only those cows that calved each year were retained in this study. From their third mating onwards, cows received a one-off artificial insemination (AI) at a synchronised oestrus at the start of mating followed by multi-sire natural mating for the remainder of the breeding season. Bull breeds used for AI were Angus, Hereford, Stabilizer, Charolais or Simmental and the foundation cows were Angus or Hereford. Details on the synchrony protocol are presented in Chapter 2. The seasons aligned with extensive spring-calving production systems within the Southern Hemisphere such that the mating season began between

November and January (dependent on the mating date policy on each individual farm). Pregnancy diagnosis (PD) was conducted approximately 90 days following AI and usually coincided with weaning of the calves. Trans-rectal ultrasound scans were conducted by an experienced commercial operator to confirm pregnancy and estimate fetal age. Cows diagnosed as not pregnant were culled following weaning of their previous calf. Culling was primarily conducted due to unsuccessful pregnancy but was also practiced because of health-related reasons. All cows calved in spring with the calving season ranging from September until November across all herds. Birth dates were not recorded but calculated for each calf based on the fetal age estimated at PD and assuming a 282-day gestation length (Burris & Blunn, 1952) whereas only birth years were available for the original population of cows.

Animals were kept on pasture year-round with little to no supplementary feed. No data have been collected on pasture availability and feed quality due to cattle grazing extensive hill country pastures.

#### ***4.3.2 Trait definitions***

The number of observations, range of data measures, means and standard deviations (SD) for recorded traits are outlined in Table 4.1.

Maternal traits were recorded for all cows present in the herd on the recording day. Traits were pregnancy rate of 15-month-old heifers (HP), days to conception in 15-month-old heifers (DtCH), rebreeding performance in 2-year-old cows (RB), days to conception in 2-year-old cows (DtC2), pregnancy rate of mature cows (PR), live weight of 15-month-old heifers (HWT), BCS of 15-month-old heifers (HBCS), hip height of 15-month-old heifers (HHIP), live weight of 2-year-old cows (WT2), BCS of 2-year-old cows (BCS2), hip height of 2-year-old cows (HIP2), mature live weight (MWT), MWT adjusted for BCS ( $MWT_{BCS}$ ), MWT adjusted for hip height ( $MWT_{HIP}$ ), body condition score of mature cows (MBCS), hip height of mature cows (MHIP) and weaning weight of calves (WWT). Except for HIP records where data recording started in 2017 all other traits were recorded throughout the entire project. Recording dates for individual traits differed among farms involved in the BPT but were consistent for all cows within farm and year.

Observations for pregnancy outcomes (HP, RB, PR) were recorded as binary traits and were either 0 or 1 coded to represent unsuccessful and successful results, respectively. The HP relates to the percentage of naturally-mated heifers recorded as pregnant

among all heifers present at PD conducted between 370 and 454 days of age. Likewise, RB describes the ability of a cow to successfully rebreed between 745 and 841 days of age and is defined as the percentage of all 2-year-old cows recorded as pregnant of all 2-year-olds present at PD. The trait PR was the percentage of cows aged 3 years or older present at PD that were diagnosed as pregnant.

The reproductive traits DtCH and DtC2 were defined as the number of days from the start of the mating season to the conception day in 15-month-old heifers and 2-year-old cows, respectively. Both measures were from calculations based on estimated fetal age recorded at PD used to ascertain probable conception dates. The date the first female within a mating contemporary group (CG) conceived was taken to be the start of the breeding season for that CG. Further information on CG assignment is provided in the data editing section. To allow for the inclusion of non-pregnant cows in the analyses, cows that failed to conceive were assigned a penalty of 21 days from the last conception date within their CG (Meyer *et al.*, 1990, Johnston & Bunter, 1996).

Live weights (HWT, WT2 and MWT) were recorded using electronic scales. The traits HWT and WT2 were defined as the LWT of females prior to their first or second mating season, respectively. The trait MWT was defined as the LWT of a cow from three years of age. Measurements for MWT were recorded at three timepoints throughout the annual production cycle: prior to mating (November–January), at weaning of the calf (February–April) and prior to calving (July–September) and were included as repeated measures in the analyses. Similarly, BCS traits (HBCS, BCS2 and MBCS) were recorded at the same timepoints within the production cycle and females were included according to their age as previously described for LWT records. Data for BCS were obtained by visual assessment based on a 1 to 10 scale (1 = emaciated and 10 = obese, Hickson *et al.*, 2017). Scoring was conducted by an experienced scorer or by the farmer after training and under regular calibration to the trained scorer. Hip height records were obtained once a year around calving on a continuous scale using a tape measure. Based on the age of the cow, records were either HHIP, HIP2 or MHIP, according to the grouping criteria used for LWT and BCS records. Records for MWT, MBCS and MHIP were adjusted to 5 years of age (Graser *et al.*, 2005) prior to analysis by fitting a fixed effects model with age and CG as factors in the model. Further adjustments were applied for MWT to either a constant BCS of 6 or HIP of 130 cm and they are referred to as  $MWT_{BCS}$  and  $MWT_{HIP}$ , respectively. The procedure used was the same as the 4-step procedure presented by Reverter *et al.* (2000) using linear and quadratic effects for the

covariate (MBCS or MHIP), with the modification that adjustments were obtained on an individual animal basis as opposed to a CG mean to account for within CG variation.

Weaning weight of calves was recorded at weaning, at which time the calves' age varied from 110 to 228 days. Linear adjustments to a constant age of 200 days of age were applied using the same method previously described for MWT adjustments to a constant BCS or HIP following the approach by Reverter *et al.* (2000). The ancestry of animals born within the BPT was generally traced back only one generation, but progeny from naturally-mated heifers with own pedigree records were weighed at weaning and matched to their sire and dam to allow estimation of the maternal effect on calf weaning weight. The direct additive genetic effect of WWT is referred to as  $WWT_D$  and the maternal component of weaning weight as  $WWT_M$ . The  $WWT_M$  describes the maternal contribution of the dam to the 200-day weight of the calf (descriptive of genetic potential for milk production; Meyer *et al.*, 1994, Mwansa *et al.*, 2002).

#### **4.3.3 Data editing**

Recording errors were removed from the existing dataset prior to analyses and twin births were deleted.

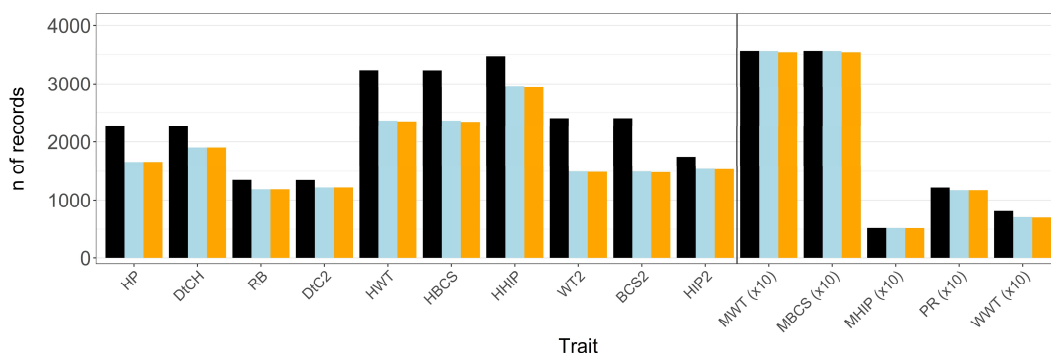
For animals that were two years of age or younger, the estimated birth date as determined by fetal age scanning was used to derive age at data recording in days from birth. For mature cows, the exact birth date was not known and only the birth year was recorded. Consequently, the recorded birth year was used to compute age of animals in years for traits that were measured on mature cows (MWT, MBCS, MHIP and PR). Similarly, birth years were used to calculate age of dam. Grouping was only applied to age-in-years parameters such that each individual age represented a separate age class but animals older than 12 years of age were grouped together due to a limited number of animals in higher age classes.

Definitions for CGs are shown in Table 4.2. Animals with missing information required to define CG or CGs that contained only one animal were removed from the analyses. For binary traits, CGs that contained only the same values (0 or 1) for all animals were excluded. Possible outliers were excluded from the dataset by removing any observation further than three standard deviations from the CG mean (Brown *et al.*, 2005). The original number of records and the size of the dataset following data editing are shown in Figure 4.1.

**Table 4.2** Contemporary group (CG) definitions for each trait and number (n) of CGs.

<b>Traits</b>	<b>CG Definition</b>	<b>n of CGs</b>
<b>Reproduction</b>		
HP; DtCH	Herd × recording date × birth year × birth group × weaning group × yearling group × management group at recording	59; 85
RB; DtC2	Herd × recording date × birth year × management group at recording	11; 12
PR	Herd × recording date × management group	71
<b>Live weight, hip height and body condition</b>		
HWT; HBCS; HHIP	Herd × recording date × birth group × weaning group × yearling group × management group at recording	128-137
WT2; BCS2; HIP2	Herd × recording date × management group at recording	19-33
MWT; MBCS	Herd × recording date × management group	247
MHIP	Herd × recording date	18
WWT	Herd × sex × recording date × birth management group × weaning management group	189

HP = pregnancy rate of 15-month-old heifers; DtCH = days to conception in 15-month-old heifers; RB = rebreeding performance in 2-year-old cows; DtC2 = days to conception in 2-year-old cows; PR = pregnancy rate of mature cows; HWT = live weight of 15-month-old heifers; HBCS = body condition score of 15-month-old heifers; HHIP = hip height of 15-month-old heifers; WT2 = live weight of 2-year-old cows; BCS2 = body condition score of 2-year-old cows; HIP2 = hip height of 2-year-old cows; MWT = mature live weight; MBCS = body condition score of mature cows; MHIP = hip height of mature cows; WWT = weaning weight of calves.



**Figure 4.1** Original size of dataset (black bar) and number (n) of records after animals with missing contemporary group (CG) and/or age of animal or dam information (blue bar) as well as outliers (orange bar) have been removed from the dataset; n of records were divided by 10 for traits presented to the right of the divide; HP = pregnancy rate of 15-month-old heifers; DtCH = days to conception in 15-month-old heifers; RB = rebreeding performance in 2-year-old cows; DtC2 = days to conception in 2-year-old cows; HWT = live weight of 15-month-old heifers; HBCS = body condition score of 15-month-old heifers; HHIP = hip height of 15-month-old heifers; WT2 = live weight of 2-year-old cows; BCS2 = body condition score of 2-year-old cows; HIP2 = hip height of 2-year-old cows; MWT = mature live weight; MBCS = body condition score of mature cows; MHIP = hip height of mature cows; PR = pregnancy rate of mature cows; WWT = weaning weight of calves.

All traits were examined for the presence of heterogeneous variances. Linear regression was used to evaluate the relationship between CG mean and SD and a significant relationship was considered evidence for deviation from homogeneity (Everett & Keown, 1984, Lopez-Villalobos *et al.*, 1994). Traits were scaled to homogenise the variances where appropriate (Brown *et al.*, 2005) based on the deviation of each record from the CG mean to the average of the entire dataset (Pickering *et al.*, 2012).

#### 4.3.4 Statistical analysis

Data editing and pre-adjustments of phenotypes were conducted using R version 3.6.0 (R Core Team, 2019). (Co)variance components were estimated using various animal models in the ASREML 4.1 software package (Gilmour *et al.*, 2015). Heritability, repeatability and correlations (genetic and phenotypic) were calculated from the estimates with their approximate standard errors.

The models used for estimation of genetic parameters were of the general form:

$$y = \mathbf{Xb} + \mathbf{Z}_a \mathbf{u}_a + \mathbf{Z}_m \mathbf{u}_m + \mathbf{Z}_{pe} \mathbf{u}_{pe} + \mathbf{Z}_{me} \mathbf{u}_{me} + \varepsilon \quad (4.1)$$

where  $y$  is the vector of pre-adjusted observations;  $\mathbf{X}$  is an incidence matrix relating the fixed effects in  $b$  to the observations in  $y$ ;  $\mathbf{Z}_a$ ,  $\mathbf{Z}_m$ ,  $\mathbf{Z}_{pe}$  and  $\mathbf{Z}_{me}$  are the incidence matrices relating the random effects  $u_a$  for direct additive genetic,  $u_m$  for maternal genetic,  $u_{pe}$  for permanent environmental and  $u_{me}$  for maternal environmental effects to observations in  $y$ ; and  $\varepsilon$  is the vector of residual effects unique to each observation in  $y$ .

Expected values of  $y$  and variances for the random effects included in the model were assumed to be as follows:

$$E[y] = \mathbf{X}b, \quad (4.2)$$

$$\text{var} \begin{bmatrix} a \\ m \\ pe \\ me \\ \varepsilon \end{bmatrix} = \begin{bmatrix} \mathbf{A}\sigma_a^2 & \mathbf{A}\sigma_{am} & 0 & 0 & 0 \\ \mathbf{A}\sigma_{am} & \mathbf{A}\sigma_m^2 & 0 & 0 & 0 \\ 0 & 0 & \mathbf{I}\sigma_{pe}^2 & 0 & 0 \\ 0 & 0 & 0 & \mathbf{I}\sigma_{me}^2 & 0 \\ 0 & 0 & 0 & 0 & \mathbf{I}\sigma_\varepsilon^2 \end{bmatrix} \quad (4.3)$$

where  $\mathbf{A}$  is the numerator relationship matrix,  $\mathbf{I}$  are identity matrices with their order equal to the number of observations,  $\sigma_a^2$  the additive genetic variance,  $\sigma_m^2$  the maternal genetic variance,  $\sigma_{am}$  the direct-maternal genetic covariance,  $\sigma_{pe}^2$  the permanent environmental variance,  $\sigma_{me}^2$  the maternal environmental variance and  $\sigma_\varepsilon^2$  the residual variance.

Given the amount of data and number of traits, a single multivariate analysis was not feasible such that a variety of uni- and bivariate animal models were used to allow computation of genetic parameter estimates. Variance components for heritability and repeatability estimates were obtained from univariate animal models including all traits on the observed scale. In a second approach all binary traits were analysed using threshold models with a logit-link function. Heritabilities for threshold traits were estimated on the underlying (logit) scale ( $h_L^2$ ) as follows:

$$h_L^2 = \frac{\sigma_a^2}{\frac{\pi^2}{3} + \sigma_a^2} \quad (4.4)$$

where  $\pi^2/3$  is the residual variance on the underlying scale (Johnston *et al.*, 2014, Gilmour *et al.*, 2015).

The convergence criterion was the default value used by ASREML such that convergence was presumed when the log-likelihood changed less than 0.002 times the number of iterations and the change of individual variance parameter estimates was below 1%. Initial analysis of variance components considered bivariate animal models

including one maternal trait plus WWT to account for any selection prior to data recording. However, these models failed to converge in some cases or estimates converged close to a boundary of the parameter space. For those models that did converge, variance components varied only slightly from the univariate models, such that further analyses were conducted using only single-trait models. Genetic and phenotypic correlations between trait pairs were obtained by estimating (co)variance components from bivariate analyses. Linear animal models were assumed among all traits (Johnston *et al.*, 2014). The inclusion of reproductive traits in bivariate analyses was limited to those with heritabilities greater than 0.05 (Wolcott *et al.*, 2014a).

Fixed and random effects for each trait are displayed in Table 4.3. Genetic parameters were analysed on an across-breed basis and a breed percentage and heterosis were fitted for each trait. For those traits that were not pre-adjusted to a standard age, age in days was fitted as a covariate in the final model for traits measured on animals 2 years of age and younger and age in years was fitted as a factor for mature cow traits. Ancestors were traced back up to two generations. The **A** matrix comprised 14,241 individual animals including 423 sires and 4,473 dams. No back pedigree was available for the original population of cows in the project, or the sires used for mating such that the base generation was assumed to be unrelated.

**Table 4.3** Fixed and random effects for each trait included in the variance component analyses.

	Fixed Effects					Random Effects <sup>2</sup>			
	Age <sup>1</sup>	Age of Dam	Breed of Animal	Heterosis	CG	a	m	pe	me
<b>Reproduction</b>									
HP	✓	✓	✓	✓	✓	✓			
DtCH	✓	✓	✓	✓	✓	✓			
RB	✓	✓	✓	✓	✓	✓			
DtC2	✓	✓	✓	✓	✓	✓			
PR	✓		✓	✓	✓	✓			
<b>Live weight, hip height and body condition</b>									
HWT	✓	✓	✓	✓	✓	✓			
HBCS	✓	✓	✓	✓	✓	✓			
HHIP	✓	✓	✓	✓	✓	✓			
WT2	✓	✓	✓	✓	✓	✓			
BCS2	✓	✓	✓	✓	✓	✓			
HIP2	✓	✓	✓	✓	✓	✓			
MWT			✓	✓	✓	✓		✓	
MWT <sub>BCS</sub>			✓	✓	✓	✓		✓	
MWT <sub>HIP</sub>			✓	✓	✓	✓		✓	
MBCS			✓	✓	✓	✓		✓	
MHIP			✓	✓	✓	✓		✓	
WWT		✓	✓	✓	✓	✓	✓		✓

HP = pregnancy rate of 15-month-old heifers; DtCH = days to conception in 15-month-old heifers; RB = rebreeding performance in 2-year-old cows; DtC2 = days to conception in 2-year-old cows; PR = pregnancy rate of mature cows; HWT = live weight of 15-month-old heifers; HBCS = body condition score of 15-month-old heifers; HHIP = hip height of 15-month-old heifers; WT2 = live weight of 2-year-old cows; BCS2 = body condition score of 2-year-old cows; HIP2 = hip height of 2-year-old cows; MWT = mature live weight; MWT<sub>BCS</sub> = mature live weight adjusted for body condition score; MWT<sub>HIP</sub> = mature live weight adjusted for hip height; MBCS = body condition score of mature cows; MHIP = hip height of mature cows; WWT = weaning weight of calves.

<sup>1</sup>Age fitted as a linear covariate for HP, DtCH, RB, DtC2, HWT, HBCS, HHIP, WT2, BCS2, HIP2 and factor for PR.

<sup>2</sup>a = additive-genetic effect; m = maternal genetic effect; me = maternal permanent environmental effect; pe = permanent environmental effect

## 4.4 Results

### 4.4.1 Univariate analyses

Estimates of variance components, heritabilities and repeatabilities evaluated in this study are presented in Table 4.4 for all traits.

**Table 4.4** (Co)variance components ( $\sigma^2_a$  = additive genetic variance,  $\sigma^2_m$  = maternal genetic variance,  $\sigma_{am}$  = direct-maternal genetic covariance,  $\sigma^2_{pe}$  = permanent environmental variance,  $\sigma^2_{me}$  = maternal environmental variance,  $\sigma^2_\epsilon$  = residual variance), heritabilities ( $h^2 \pm SE$ ) and repeatabilities ( $t \pm SE$ ) from univariate animal models for maternal performance traits in New Zealand beef cattle.

	Model <sup>1</sup>	$\sigma^2_a$	$\sigma^2_m$	$\sigma_{am}$	$\sigma^2_{pe}$	$\sigma^2_{me}$	$\sigma^2_\epsilon$	$h^2$	$t$
<b>Reproduction</b>									
HP	LM	0.00					0.11	0.00	
	THM	0.20					3.29	0.06 ± 0.08	
DtCH	LM	2.61					430.71	0.01 ± 0.05	
	RB	LM	0.01				0.06	0.14 ± 0.09	
DtC2	THM	0.46					3.29	0.12 ± 0.11	
	LM	80.85					305.60	0.21 ± 0.09	
PR	LM	0.00					0.06	0.00	
	THM	0.00					3.29	0.00	
<b>Live weight, hip height and body condition</b>									
HWT	LM	289.19					401.08	0.42 ± 0.07	
HBCS	LM	0.02					0.14	0.15 ± 0.05	
HHIP	LM	5.83					5.49	0.51 ± 0.06	
WT2	LM	705.23					887.29	0.44 ± 0.09	
BCS2	LM	0.09					0.26	0.25 ± 0.08	
HIP2	LM	5.57					6.16	0.47 ± 0.09	
MWT	LM	1,157.14			790.86		481.64	0.48 ± 0.04	0.80 ± 0.004
MWT <sub>BCS</sub>	LM	952.07			403.78		324.36	0.57 ± 0.04	0.81 ± 0.004
MWT <sub>HIP</sub>	LM	522.81			548.30		587.32	0.32 ± 0.06	0.65 ± 0.014
MBCS	LM	0.15			0.10		0.34	0.26 ± 0.03	0.42 ± 0.007
MHIP	LM	8.21			1.25		3.08	0.65 ± 0.05	0.75 ± 0.010
WWT <sub>D</sub> <sup>3</sup>	LM	84.37	122.38	-53.77		187.87	235.03	0.14 ± 0.02	
WWT <sub>M</sub> <sup>3</sup>	LM							0.20 ± 0.07	0.51 ± 0.03

HP = pregnancy rate of 15-month-old heifers; DtCH = days to conception in 15-month-old heifers; RB = rebreeding performance in 2-year-old cows; DtC2 = days to conception in 2-year-old cows; PR = pregnancy rate of mature cows; HWT = live weight of 15-month-old heifers; HBCS = body condition score of 15-month-old heifers; HHIP = hip height of 15-month-old heifers; WT2 = live weight of 2-year-old cows; BCS2 = body condition score of 2-year-old cows; HIP2 = hip height of 2-year-old cows; MWT = mature live weight; MWT<sub>BCS</sub> = mature live weight adjusted for body condition score; MWT<sub>HIP</sub> = mature live weight adjusted for hip height; MBCS = body condition score of mature cows; MHIP = hip height of mature cows; WWT<sub>D</sub> = direct genetic effect on calf weaning weight; WWT<sub>M</sub> = maternal genetic effect on calf weaning weight

<sup>1</sup>LM = linear model; THM = threshold model

<sup>3</sup> Only one model was fitted for WWT such that the variances presented for WWT<sub>D</sub> also apply for WWT<sub>M</sub>

Heritability estimates were low or zero for the binary traits HP (0.00), RB (0.14) and PR (0.00) on the observed scale. Estimates obtained on the underlying scale using a logit link function differed from those on the observed scale only marginally. Estimates were slightly higher for HP on the logit scale with 0.06 and similar for RB with 0.12. The approximate standard errors obtained on the underlying scale, however, were larger for both traits (0.08–0.11) than those on the observed scale. The trait PR was not heritable using either analysis method.

Live weight and HIP traits were moderately to highly heritable for 15-month-old heifers, 2-year-old cows and mature cows. Generally, variance components and heritabilities were larger for traits observed in mature cows compared with the same traits measured in 15-month-old heifers and 2-year-old cows and heritabilities ranged from 0.42 to 0.48 for LWT and from 0.47 to 0.65 for HIP traits. Adjusting MWT for BCS increased the heritability from 0.48 to 0.57. Variance components were overall lower for  $MWT_{BCS}$  compared to MWT and the largest decrease in variance was observed for the permanent environmental effect. The estimated heritability for MWT was lower following HIP adjustments (0.32). Adjustments reduced the additive genetic variance substantially but had little effect on the permanent environmental variance. Compared to MWT, the residual variance was greater for  $MWT_{HIP}$ . Heritability estimates for BCS traits were generally low. Similar to LWT and HIP traits, estimates were greater (0.26) for mature cows compared to those obtained for heifers (0.15) but did not differ from the estimates for 2-year-old females (0.25). Repeatability was high overall for LWT traits of mature cows and ranged from 0.65 to 0.81. Estimates were also high for MHIP (0.75) and moderate for MBCS (0.42).

The estimated heritability was slightly greater for  $WWT_M$  (0.20) than for  $WWT_D$  (0.14). The permanent environmental effect of the dam on WWT was high (0.51). The genetic correlation for direct and maternal genetic effect of weaning weight was moderate and negative ( $r_{am} = -0.53$ ).

#### **4.4.2 Bivariate analyses**

Estimates of heritability obtained from bivariate analyses were generally similar to those from univariate analyses (Table 4.5). However, estimates were slightly higher for WT2 (0.52) and HIP2 (0.51), as well as for MWT (0.51) and  $MWT_{BCS}$  (0.61).

**Table 4.5** Averaged heritabilities ( $\pm$ SEM, diagonal), genetic ( $\pm$ SE, below diagonal) and phenotypic ( $\pm$ SE, above diagonal) correlations from bivariate animal models among 15-month-old heifer, 2-year-old cow and mature cow traits in New Zealand beef cattle.

	RB	DtC2	HWT	HBCS	HHIP	WT2	BCS2	HIP2	MWT	MWT <sub>BCS</sub>	MWT <sub>HIP</sub>	MBCS	MHIP	WWT
RB	<u>0.13</u>	-0.74	0.01	0.05	-0.01	0.05	0.01	0.01	-0.25	-0.23	-0.31	-0.40	-0.20	0.02
	(0.01)	(0.01)	(0.03)	(0.03)	(0.03)	(0.03)	(0.03)	(0.03)	(0.03)	(0.04)	(0.04)	(0.03)	(0.04)	(0.04)
DtC2	-0.99	<u>0.21</u>	-0.03	-0.04	-0.02	-0.07	-0.06	-0.02	0.19	0.13	0.25	0.25	0.05	0.00
	(0.12)	(0.00)	(0.03)	(0.03)	(0.03)	(0.03)	(0.03)	(0.03)	(0.03)	(0.04)	(0.04)	(0.04)	(0.04)	(0.04)
HWT	0.19	-0.23	<u>0.45</u>	0.38	0.61	0.73	0.26	0.53	0.54	0.62	0.32	0.17	0.48	0.79
	(0.25)	(0.20)	(0.01)	(0.02)	(0.01)	(0.01)	(0.03)	(0.02)	(0.02)	(0.02)	(0.03)	(0.03)	(0.03)	(0.02)
HBCS	0.49	-0.32	0.26	<u>0.15</u>	0.12	0.23	0.25	0.05	0.09	0.06	0.12	0.12	-0.03	0.26
	(0.37)	(0.30)	(0.16)	(0.00)	(0.02)	(0.03)	(0.03)	(0.03)	(0.03)	(0.03)	(0.04)	(0.03)	(0.03)	(0.03)
HHIP	0.54	-0.57	0.71	-0.07	<u>0.53</u>	0.52	0.09	0.65	0.42	0.49	0.07	0.10	0.62	0.68
	(0.23)	(0.18)	(0.06)	(0.17)	(0.01)	(0.02)	(0.03)	(0.02)	(0.03)	(0.02)	(0.04)	(0.03)	(0.02)	(0.02)
WT2	-0.05	-0.11	0.84	0.00	0.66	<u>0.52</u>	0.57	0.54	0.74	0.79	0.47	0.35	0.59	0.57
	(0.26)	(0.21)	(0.05)	(0.20)	(0.08)	(0.03)	(0.02)	(0.02)	(0.01)	(0.01)	(0.03)	(0.03)	(0.02)	(0.03)
BCS2	-0.17	0.04	0.34	0.55	-0.13	0.57	<u>0.27</u>	0.09	0.33	0.24	0.33	0.40	0.18	0.17
	(0.32)	(0.27)	(0.16)	(0.23)	(0.16)	(0.12)	(0.01)	(0.03)	(0.03)	(0.03)	(0.03)	(0.03)	(0.03)	(0.03)
HIP2	-0.14	-0.11	0.66	-0.03	0.94	0.61	-0.09	<u>0.51</u>	0.48	0.58	0.09	0.09	0.75	0.45
	(0.28)	(0.22)	(0.08)	(0.20)	(0.04)	(0.10)	(0.19)	(0.02)	(0.03)	(0.02)	(0.04)	(0.04)	(0.01)	(0.03)
MWT	-0.15	0.08	0.94	0.35	0.69	0.96	0.68	0.85	<u>0.51</u>	0.87	0.80	0.47	0.56	0.25 <sup>1</sup>
	(0.21)	(0.10)	(0.05)	(0.12)	(0.05)	(0.03)	(0.09)	(0.05)	(0.01)	(0.00)	(0.01)	(0.01)	(0.01)	(0.02)
MWT <sub>BCS</sub>	-0.32	0.17	0.95	0.18	0.75	0.95	0.55	0.89	0.92	<u>0.61</u>	0.61	-0.01	0.62	0.31 <sup>1</sup>
	(0.17)	(0.10)	(0.04)	(0.10)	(0.04)	(0.02)	(0.09)	(0.04)	(0.01)	(0.02)	(0.01)	(0.01)	(0.01)	(0.02)
MWT <sub>HIP</sub>	-0.18	0.13	0.53	0.18	-0.04	0.69	0.50	0.16	0.71	0.60	<u>0.31</u>	0.56	-0.04	0.20
	(0.26)	(0.19)	(0.11)	(0.17)	(0.09)	(0.11)	(0.15)	(0.12)	(0.04)	(0.06)	(0.00)	(0.01)	(0.02)	(0.03)
MBCS	-0.10	-0.08	0.26	0.61	0.01	0.62	0.87	0.11	0.24	-0.14	0.50	<u>0.27</u>	0.07	0.05
	(0.19)	(0.14)	(0.08)	(0.14)	(0.06)	(0.08)	(0.09)	(0.08)	(0.07)	(0.07)	(0.08)	(0.00)	(0.01)	(0.03)
MHIP	-0.27	-0.04	0.61	-0.16	0.88	0.64	-0.03	0.97	0.77	0.80	0.16	0.15	<u>0.65</u>	0.31
	(0.18)	(0.14)	(0.07)	(0.13)	(0.05)	(0.06)	(0.12)	(0.03)	(0.04)	(0.03)	(0.09)	(0.08)	(0.00)	(0.03)
WWT <sub>D</sub>	-0.08	-0.05	0.87	0.52	0.56	0.70	0.51	0.69	1.00 <sup>1</sup>	0.99 <sup>1</sup>	0.64	0.89	0.53	<u>0.16</u>
	(0.28)	(0.23)	(0.05)	(0.16)	(0.08)	(0.10)	(0.17)	(0.11)	(0.07)	(0.06)	(0.18)	(0.12)	(0.14)	(0.01)
WWT <sub>M</sub>	0.48	-0.19	0.71	0.32	0.74	0.39	-0.40	0.33	-0.28 <sup>1</sup>	-0.22 <sup>1</sup>	-0.36	-0.55	0.15	-0.53 <sup>2</sup>
	(0.28)	(0.20)	(0.14)	(0.18)	(0.12)	(0.14)	(0.19)	(0.14)	(0.09)	(0.08)	(0.12)	(0.12)	(0.09)	(0.17)

RB = rebreeding performance in 2-year-old cows; DtC2 = days to conception in 2-year-old cows; HWT = live weight of 15-month-old heifers; HBCS = body condition score of 15-month-old heifers; HHIP = hip height of 15-month-old heifers; WT2 = live weight of 2-year-old cows; BCS2 = body condition score of 2-year-old cows; HIP2 = hip height of 2-year-old cows; MWT = mature live weight; MWT<sub>BCS</sub> = mature live weight adjusted for body condition score; MWT<sub>HIP</sub> = mature live weight adjusted for hip height; MBCS = body condition score of mature cows; MHIP = hip height of mature cows; WWT<sub>D</sub> = direct genetic effect on calf weaning weight; WWT<sub>M</sub> = maternal genetic effect on calf weaning weight

<sup>1</sup>Convergence only achieved if parameters were allowed to exceed limits of the parameter space (i.e., correlations >1.00 for direct genetic correlations)

<sup>2</sup>Genetic correlation between WWT<sub>M</sub> and WWT<sub>D</sub>

The reproductive traits RB and DtC2 were highly correlated (-0.99). This is also reflected in the correlations of both reproduction traits with LWT, HIP and BCS traits, such that the correlations with RB had the opposite sign to the correlation with DtC2.

The exceptions were with WT2, HIP2, MBCS, MHIP and WWT<sub>D</sub>, all of which were negatively correlated with both reproduction traits. Genetic correlations, however, were low for each of those trait combinations. Generally, 15-month-old heifer traits were moderately to highly correlated with RB (0.19–0.54) and DtC2 (-0.57– -0.23). Genetic correlations tended to decrease with increasing age and correlations changed towards the opposing sign, such that LWT, HIP and BCS traits ranged from -0.17 to -0.05 and -0.11 to 0.04 for 2-year-old cows and from -0.32 to -0.10 and -0.08 to 0.17 for mature cows for RB and DtC2, respectively. A moderate genetic correlation has been observed between WWT<sub>M</sub> and RB (0.48) and the correlation with DtC2 was low and negative (-0.19).

Genetic correlations for LWT traits were lower among young animals (0.84) compared with correlations with MWT (0.94–0.96). For HIP traits, genetic correlations were similar among consecutive ages (0.94–0.97) and decreased with increasing age difference between traits. Estimates among BCS records were slightly lower compared with LWT and HIP records and ranged from 0.55 to 0.87.

Live weight and HIP traits were highly genetically correlated among all ages (0.61–0.85). Genetic correlations varied between LWT and BCS traits dependent on the age. Estimates were moderate among HWT and different BCS traits (0.26–0.34). The highest genetic correlations were observed between WT2 and either BCS2 (0.57) or MBCS (0.62) and between MWT and BCS2 (0.68) whereas no association was observed between HBCS and WT2. Body condition score traits were generally only lowly correlated with HIP measures and genetic correlations ranged from -0.16 to 0.15.

Analyses revealed high genetic correlations among WWT<sub>D</sub> and all female LWT, HIP and BCS traits among all age classes (0.51–1.00). Fifteen-month-old heifer and 2-year-old cow LWT, HIP and BCS traits were moderately to highly genetically correlated with WWT<sub>M</sub> and correlations were positive (0.32–0.74) with the exception of BCS2 (-0.40). Genetic correlations among WWT<sub>M</sub> and mature cow traits were generally low to moderate and negative (-0.55– -0.22) but was low and positive between WWT<sub>M</sub> and MHIP (0.15).

Phenotypic correlations were lower than genetic correlations among most traits. Phenotypic correlations were overall low among female reproduction and LWT, HIP and BCS traits in 15-month-old heifers and 2-year-old cows (-0.07–0.05). Mature cow traits were lowly to moderately correlated with RB and DtC2 on a phenotypic level.

Among female LWT, HIP and BCS traits correlations were similar to genetic correlations and were generally moderate to high between LWT and HIP traits (0.42–0.61). Estimates among BCS traits and LWT traits ranged from a low correlation between HBCS and MWT (0.09) to a high correlation between BCS2 and WT2 (0.57). Similar to genetic correlations, only low phenotypic correlations were observed between BCS and HIP traits (-0.03–0.18). Phenotypic correlations among WWT and other LWT, HIP and BCS traits were generally higher for 15-month-old heifers than for 2-year-old or mature cows and decreased with increasing age difference between animals.

## 4.5 Discussion

### 4.5.1 Effect of genetics on reproduction

It is well documented in the literature that most reproduction traits have only low heritability (Meyer *et al.*, 1990, Morris *et al.*, 2000, Burrow, 2001, Cavani *et al.*, 2015) and the same trend was observed in the current analyses. The estimates for HP on the underlying scale are consistent with the pooled results reported in the review by Koots *et al.* (1994a) of 0.05. McAllister *et al.* (2011) reported slightly higher values of 0.17 in Red Angus cattle using a probit link function. On the observed scale heritabilities for yearling pregnancy rates ranged from 0.04 to 0.12 in New Zealand beef cattle (Morris & Cullen, 1994, Morris *et al.*, 2000). The trait DtCH basically describes the same trait using a continuous measure of HP while also including non-pregnant females. In agreement with the low heritability estimates for HP, estimates for DtCH were equally low. Under the commercial environments the cattle were managed in as part of this study, no additive genetic variation could be detected for heifer pregnancy outcomes.

Rebreeding ability is considered a major challenge for first-calving heifers (Valente *et al.*, 2017). Heifers failing to conceive after their first successful calving are usually culled following weaning of that calf. Due to high costs for replacement animals and limited return from calf weaning up until this point, this is the most expensive time to replace females in the breeding herd. Reports, however, are sparse on the genetic potential for rebreeding success in 2-year-old beef cattle. Breeders are often concerned with a reduced pregnancy rate following the first successful calving (Hickson *et al.*, 2008). This trend, however, could not be observed in the current study, such that the percentage of animals that conceived to the second mating was higher (92.0%) compared to HP (88.1%). Although heritability was low for RB on both the observed (0.14) and the underlying scale (0.12), the results obtained in this study show that genetic variation exists, such that using sires with higher genetic potential for this trait would likely result in a positive response in female progeny. Estimates published by Morris *et al.* (2000) suggest slightly lower heritabilities for pregnancy outcomes for 2-year-old cows (0.08) on the observed scale. The high correlation between RB and DtC2 (-0.99) indicates that they are essentially measures of the same trait. Heritability for DtC2 was slightly greater (0.21) compared to RB in the current study. The greater heritability of 2-year-old cow traits indicates that breeding for greater RB and DtC2 in combination with adequate management practices has the potential to result in desirable enhancements of rebreeding ability in young herd replacements in the long term.

In the present study, PR was not heritable on either scale. This is in agreement with the low estimate of 0.04 reported by Morris *et al.* (2000) and 0.03 by Burrow (2001). The absence of variance estimates for PR may also be attributable to animal management. Beef cows analysed for PR were subject to oestrus synchronisation prior to AI in the current study which may explain the lack of any estimable variance in the trait. Goodling *et al.* (2005) found that oestrus synchronisation reduced the residual variance for pregnancy rate in dairy cattle but had no substantial effect on the estimated heritability in their study.

Given the different outcomes for heifers, 2-year-old females and mature cows observed in this study, the first two matings should be evaluated as different traits compared to mature cows.

#### ***4.5.2 Live weight, hip height and body condition score among 15-month-old heifers, 2-year-old cows and mature cows***

Heritability estimates for LWT, HIP and BCS traits were higher for mature cows compared to heifers and 2-year-olds and those estimates are generally in agreement with the literature. The heritability of HWT in the current study is similar to the estimate of 0.43 presented by Costa *et al.* (2011) for Angus heifers in the United States. Heritability estimates for MWT ranged from 0.29 to 0.60 dependent on breed, age, time of the year and modelling approach (Morris *et al.*, 1987, Koots *et al.*, 1994a, Meyer, 1995, Kaps *et al.*, 1999, Arango *et al.*, 2002, Nephawe *et al.*, 2004, Boligon *et al.*, 2008). Mercadante *et al.* (2003) reported lower heritabilities for heifer hip height (0.44) compared to MHIP (0.55) in Nellore cattle. The estimated heritability for MHIP in the current study is within the range of values presented by Arango *et al.* (2002) of 0.59–0.72 for cows between 3 and 8 years of age. The heritability of BCS in heifers (0.09) presented by Mercadante *et al.* (2003) was slightly lower than for mature cows (0.20) and this aligns with the range of estimates (0.16–0.21) reported by Arango *et al.* (2002) and Johnston *et al.* (1996) for different breeds.

Heritability estimates for HIP were generally greater than for LWT across all ages in the current study and this agrees with previous reports (Northcutt & Wilson, 1993, Arango *et al.*, 2002, Nephawe *et al.*, 2004). The results, however, are in contrast to estimates reported by Meyer (1995) where heritabilities for MHIP (0.19–0.33) were generally in the same range as MWT (0.30–0.33) and were lower than the estimates reported in this

study. In agreement with other studies (Meyer, 1995, Arango *et al.*, 2002), heritability estimates for BCS traits were always lower than for LWT or HIP traits.

Adjusting MWT for BCS reduced all variance components slightly. The lower heritabilities for MWT compared to  $MWT_{BCS}$  can be primarily explained by the difference in permanent environmental variance and this agrees with the results reported by Arango *et al.* (2002) who suggested that those differences may be attributable to variable cow environmental effects on body energy reserves that are better accounted for when adjusting MWT to a constant BCS. The higher heritability of  $MWT_{BCS}$  compared to MWT agrees with the results reported by Arango *et al.* (2002) of 0.54 and Nephawe *et al.* (2004) of 0.57. Meyer (1995) also reported slightly higher estimates following BCS adjustments, but estimates were overall lower (0.31–0.34) than in the current study (0.57).

Estimates on MWT adjusted to a constant HIP are rare in the literature. The results of 0.32 found in this study agree with the estimates reported by Hickson & Pitchford (2021) of 0.25–0.35 in Australian Angus cows. Adjusting MWT to a standard HIP reduced the heritability considerably and this is primarily due to a reduction in the additive genetic variance. Hip height is a highly heritable trait and taking out the effect of differences in HIP may remove most of the variation in MWT that is explained through skeletal size. The majority of effects that influence MWT following HIP adjustments are likely related to muscle and fat deposition and heritability for those traits tends to be lower. Heritability for  $MWT_{HIP}$  (0.32) was slightly greater than for MBCS (0.26) in the current study. Genetic and phenotypic correlations among  $MWT_{HIP}$  and other female LWT, HIP and BCS traits, however, indicate that  $MWT_{HIP}$  behaves in a similar manner to MBCS. Hickson & Pitchford (2021) found that estimating  $MWT_{HIP}$  did not add significant value to MBCS as a selection criterion for improved condition. In practice, HIP may be a more complex trait to measure compared to MBCS. The advantage of this method is, however, that measuring HIP is a more standardised method and does not require a trained technician to accurately record body energy reserves, thus would remove bias due to subjective assessment of animals.

Repeatability estimates were high for MWT (0.65–0.81) and this is within the range of estimates reported in the literature between 0.57 and 0.85 using REML (Morris *et al.*, 1987, Meyer, 1995, Johnston *et al.*, 1996, Arango *et al.*, 2002). Burrow (2001), however, reported a higher repeatability for MWT of 0.93. Repeatability of MHIP was similar

compared to LWT traits and this is in agreement with the reported estimates of 0.75 by Arango *et al.* (2002) and 0.73 to 0.77 by Meyer (1995). Among LWT, HIP and BCS traits, MBCS was the least repeatable in the current study (0.42) and the same has been observed in previous research (Meyer, 1995). The estimated repeatability was within the range (0.32–0.52) reported by Johnston *et al.* (1996) for different beef cow breeds.

Genetic correlations were high among LWT and HIP traits and this was expected (Northcutt & Wilson, 1993, Meyer, 1995, Arango *et al.*, 2002). In agreement with literature findings (Arango *et al.*, 2002), the genetic correlations were low between BCS and HIP traits. Moderate to high genetic correlations were estimated in the current study between LWT and BCS traits and this agrees with the estimates (0.49–0.65) reported by Johnston *et al.* (1996) across different breeds. Thus, selecting for reduced MWT (without adjustment for BCS) to decrease maintenance requirements can reduce BCS. Results from Chapter 3 have shown that lower conditioned mixed-aged cows may experience reduced reproductive performance compared to better conditioned cows on a phenotypic level. Besides reproduction related reasons, other rationales, such as health and animal welfare, exist for breeders to produce cows that are able to maintain or increase MBCS. The current study indicates that breeding for limited MWT and size to reduce maintenance requirements while at the same time maintaining MBCS requires an alternative approach to using this information to prevent any unfavourable selection against correlated traits with potential impact on productivity.

#### ***4.5.3 Association among reproduction, live weight, hip height and body condition***

Results from the current study suggest a positive genetic correlation between RB and LWT, HIP and BCS traits in 15-month-old heifers, indicating that cows with a higher genetic potential for RB performance would be likely to show increased HWT, HBCS and HHIP. With increasing age, the correlation decreased among RB or DtC2 and the corresponding LWT, HIP and BCS traits toward the opposing sign. The correlations, however, were only low in 2-year-old cows (-0.17–0.04) and low to moderate in mature cows (-0.32–0.17). Given the large standard errors among those correlations with both reproductive traits, females with genetically superior reproductive performance at rebreeding are unlikely to exhibit an unfavourable reduction in body energy reserves as a cow. Comparing the genetic correlations of reproductive traits with other heifer and mature cow traits indicates that improvement in RB and DtC2 may result in faster

growing, better conditioned heifers but those heifers are unlikely to become bigger cows. The correlation between DtC2 and MWT was low and positive (0.08) in the current study and was not significantly different from zero. Burrow (2001) also reported a low but negative genetic correlation of -0.15 between MWT and days to calving. According to Mercadante *et al.* (2003), selection for growth-related traits would not compromise reproductive performance, which in their case was measured as days to calving and calving success. Generally, results from the current analyses tend to agree with their assertion. Comparing results of DtC2 analysed in the current study with days to calving, however, needs to be treated with caution as gestation length will explain part of the variation in days to calving.

#### ***4.5.4 Maternal contribution to calf weaning weight and its impact on reproduction, live weight, hip height and body condition score***

Heritability estimates for WWT found in the current study agree with the estimates reported by Splan *et al.* (2002) for the direct genetic effect of WWT (0.14) and the maternal genetic effect (0.19) in United States crossbred beef cattle. Similar estimates were reported by Burrow (2001) in Australian Belmont cattle with 0.17 for the direct genetic and 0.34 for the maternal genetic effect of WWT. Those values are consistent with those reported by Morris *et al.* (2000) of 0.14 for direct and 0.35 for maternal weaning weight. Meyer *et al.* (1993) reported slightly higher estimates for WWT<sub>D</sub> (0.22) and lower heritabilities for the maternal component of WWT (0.18) in Australian Hereford cattle. The permanent environmental effect of the dam was also lower in their study (0.20) compared to the result in the current analysis (0.51). Results from this study indicate that a large proportion of differences in calf WWT are attributable to the genetics and permanent environments of the dam after the effects of CG and age of dam have been removed.

The additive maternal genetic correlation between WWT<sub>D</sub> and WWT<sub>M</sub> in the current study was moderate and negative (-0.53) and an unfavourable correlation has been previously reported by several researchers (Koots *et al.*, 1994b, Kaps *et al.*, 2000, Burrow, 2001, Mwansa *et al.*, 2002, Cortés-Lacruz *et al.*, 2017). Genetic correlations between the direct genetic component of WWT<sub>D</sub> and LWT, HIP and BCS traits are similar to those correlations among other LWT, HIP and BCS traits and this was expected. The highest correlations were estimated between WWT<sub>D</sub> and LWT and HIP traits of all ages which agrees with the literature (Koots *et al.*, 1994b, Mwansa *et al.*,

2002, Wolcott *et al.*, 2014b) and estimates were generally lower among  $WWT_D$  and BCS traits.

The contribution of the dams to the WWT of their calves in terms of milk production has been previously described in the literature but correlations with other maternal and production type traits are sparse. In the current study, the genetic correlations were moderate to high between  $WWT_M$  and LWT, HIP and BCS traits in 15-months-old heifers. Once females calve for the first time, cows with genetics for higher  $WWT_M$  are likely to exhibit lower BCS as shown in the current study. Results from the current study are in agreement with Wolcott *et al.* (2014b) who reported a moderate negative genetic correlation between the maternal component of WWT and BCS (-0.50) as well as low correlations with LWT (0.15) and HIP traits (0.19) for 2-year-old Brahman cows recorded prior to their second mating season. The positive genetic correlations among  $WWT_M$  and any HIP measure observed in this study indicate that cows with greater genetic merit for HIP are more likely to exhibit greater overall  $WWT_M$  and, therefore, are likely to show greater milk production. Those correlations were, however, low at maturity and this has been previously reported for dairy cows (Morris & Wilton, 1976). The negative genetic correlation between MWT and  $WWT_M$  in the current study agrees with the estimates reported by Mwansa *et al.* (2002) of -0.17 and Kaps *et al.* (2000) of -0.34.

#### **4.6 Conclusions**

This study has shown that there is potential to improve reproductive performance in 2-year-old cows through selection. Animals with greater genetic potential for rebreeding performance as 2-year-olds tend to be heavier, taller heifers at 15 months of age with greater body energy reserves, but those animals do not tend to be genetically bigger at maturity and this may reduce cow maintenance requirements. Traits measured on heifers prior to their first calving can be substantially different from similar traits measured in cows following their first and subsequent calving. This should be taken into account when considering maternal performance for genetic evaluations and selection program design.

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## **Chapter 5** – Genetic parameters for growth, ultrasound and carcass traits in New Zealand beef cattle and their correlations with maternal performance

### **Publications arising from this chapter:**

Weik F, Hickson RE, Morris ST, Garrick DJ, Archer JA 2021. Genetic parameters for growth, ultrasound and carcass traits in New Zealand beef cattle and their correlations with maternal performance. *Animals* 12: 25. DOI: 10.3390/ani12010025.

### **5.1 Abstract**

Research has shown that enhancing finishing performance in beef cattle is feasible; however, any adverse impact of selection strategies for finishing performance on the performance of the maternal herd should be taken into account. The aim of this research was to examine the inheritance of growth, ultrasound and carcass traits in finishing beef cattle and to evaluate their correlations with maternal performance traits. Data were collected from a nationwide progeny test on commercial New Zealand hill country farms comprising a total of 4,473 beef cows and their progeny. Most finishing traits were moderately to highly heritable (0.28–0.58) with the exception of meat or fat colour and ossification (0.00–0.12). Ultrasound scan traits had high genetic correlations with corresponding traits measured at slaughter ( $r_g = 0.53–0.95$ ) and may be used as a selection tool for improved genetic merit of the beef carcass. Fat content determined via ultrasound scanning in the live animal or at slaughter in finishing cattle is positively genetically correlated with rebreeding performance ( $r_g = 0.22–0.39$ ) in female herd replacements and negatively correlated with mature live weight ( $r_g = -0.40$  to  $-0.19$ ). Low-magnitude associations were observed between the genetic merit for carcass fat traits with body condition in mature cows.

## 5.2 Introduction

The key driver for performance and profit in a beef cow herd is calf output relative to cow feed requirement (Bullock *et al.*, 1993, Jenkins & Ferrell, 1994). The key drivers in a beef finishing system are growth, carcass traits and feed costs (Wilson *et al.*, 1976, Robinson *et al.*, 1993, Wolcott *et al.*, 2013). To improve the performance of beef cattle on pasture, it is relevant to balance the requirements of the entire operation (Fitzhugh, 1978). Breeding programs can incorporate both maternal and finishing traits as selection criteria with different emphasis dependent on the breeding objective (Ponzoni & Newman, 1989). Knowledge of the genetic components that influence maternal and finishing performance and of potential antagonisms between both systems is necessary to enhance breeding strategies, optimise selection decisions (Koots *et al.*, 1994b, Splan *et al.*, 1998) and ultimately improve the efficiency of the herd (Meyer *et al.*, 1990, Bullock *et al.*, 1993, Nephawe *et al.*, 2004).

Many researchers have published genetic and phenotypic parameters for either maternal or finishing traits (Koots *et al.*, 1994a, Koots *et al.*, 1994b) but literature describing antagonisms among those trait groups is sparse. New Zealand's farming systems rely on extensive grass-fed beef production (Morris & Kenyon, 2014). Beef cattle are primarily farmed alongside sheep on steeper, less cultivable hill country farms. It is usually impractical to deliver supplementary feed to cows grazed in these systems, and stocking rates are low and determined by the available pasture supply as a result (Morris & Kenyon, 2014). Different genotypes may be required compared to other systems internationally where cattle are finished on grain (Robinson & Oddy, 2004, Greenwood *et al.*, 2018) and/or cows are fed on crop residues (Males, 1987, Russell *et al.*, 1993). Thus, to assess those differences, an understanding of antagonisms among maternal performance, growth, ultrasound and carcass traits based on data from commercial New Zealand farming systems is needed to further investigate relevant traits to be considered for genetic evaluation and breeding program design.

The current study builds on outcomes from Chapter 4 while further exploring a subset of the maternal traits for the purpose of correlation analysis. The aim of this study was to examine the inheritance of growth, ultrasound and carcass traits measured in finishing beef cattle on commercial New Zealand hill country farms and to evaluate their correlations with key maternal performance traits.

## **5.3 Materials and methods**

### ***5.3.1 Animal management***

Animal ethics approval was obtained for all related procedures and measures involved in this study (AgResearch Invermay Animal Ethics Committee approval numbers: 13358, 13373, 13394, 13693, 14031, 14311, 14588, 14851, and 15153).

The current study used data collected as part of a beef progeny test (BPT) on five large-scale commercial hill country farms in New Zealand. The BPT was established by Beef + Lamb New Zealand Genetics in 2014 to compare sire performance across a range of commercial environments over multiple years. An in-depth description of the animal management procedures and data collection was provided in Chapter 2 and Chapter 3. In summary, the BPT comprises Angus or Hereford breeding cows where some female calves (sired by Angus, Hereford or Stabilizer bulls) were retained as herd replacements and the remaining female and male calves were raised for slaughter. All cattle grazed exclusively on pasture (including some forage crops) and finishing cattle were processed at 18–34 months of age. Heifers within the breeding herd were naturally mated for the first two breeding seasons then cows received a one-off artificial insemination to synchronised oestrus followed by natural mating from their third mating season onwards. Insemination was conducted using semen from a range of New Zealand and international bulls including Angus, Hereford, Charolais, Simmental and the Stabilizer composites over the foundation Angus or Hereford cows, with most bulls in common across herds. Pregnancy diagnosis was conducted approximately 90 days after the start of the mating season and fetal age determined. Birthdate of calves was assigned based on fetal age records, assuming a 282-day gestation (Burriss & Blunn, 1952). Calving occurred in spring between September and November aligning with the seasonal production cycle typical of extensive beef farming systems in New Zealand.

### ***5.3.2 Measurements and trait definitions***

Performance records were obtained for a range of traits for females within the breeding herd and for heifers and steers as part of the finishing operation. Female herd replacements were assessed for their maternal performance in terms of reproduction, weight, size and body condition, whereas animals destined for slaughter were measured for growth, ultrasound and carcass traits to examine finishing performance.

Where appropriate, phenotypic records were pre-adjusted to either a constant age, weight, body condition score (BCS) or hip height (HIP) at the time of measurement, where pre-adjustments were based on continuous variables using the 4-step procedure of Reverter *et al.* (2000). Adjustments were made using linear models with contemporary group (CG) as a fixed effect and definitions for CG are presented in the data editing section. Age, weight, and BCS or HIP were fitted as linear or quadratic covariates and pre-adjustments are detailed in the trait descriptions. Quadratic effects of covariates were tested using an F-statistic on type-III sums of squares (analysis of variance) and discarded from the final model via backward elimination if not significant. Adjustments were made on an individual animal basis as opposed to a CG mean to account for within-CG variation.

### *Maternal traits*

Maternal traits were a subset of those previously described in Chapter 4, chosen based on their relevance for the New Zealand beef sector. Rebreeding performance (RB) was defined as pregnancy outcome for 2-year-old cows present at pregnancy diagnosis and was coded as a binary trait (0 = not pregnant, 1 = pregnant). Cows that were not present at their second pregnancy diagnosis were coded as missing. Days to conception (DtC2) describes the time in days from start of the mating season to conception day for 2-year-old cows in their second mating period. Cows that failed to conceive were included in the analysis and assigned a penalty of 21 days after the last conception date within their CG (Meyer *et al.*, 1990, Johnston & Bunter, 1996).

Mature live weight (MWT), body condition score of mature cows (MBCS) and hip height of mature cows (MHIP) were recorded on cows that were aged 3 years or older. Animals were measured for MWT and MBCS at three timepoints throughout the year (mating, weaning, calving) and only one annual measure of MHIP was made prior to calving. All three mature cow traits were pre-adjusted to 5 years of age. Age adjustments were made using a fixed-effects model with age (in years) with cows older than 12 years of age grouped in a single group and CG as factors in the model. Scoring MBCS was through visual assessment of body energy reserves with 1 being emaciated and 10 being obese (Hickson *et al.*, 2017). The trait MWT was also pre-adjusted to either a constant BCS of 6 (MWT<sub>BCS</sub>) or a constant HIP of 130 cm (MWT<sub>HIP</sub>) to evaluate MWT irrespective of stored energy reserves or size. Adjustments were made using either BCS or HIP as a linear and quadratic covariate, for MWT<sub>BCS</sub> and MWT<sub>HIP</sub>, respectively.

Weaning weight of calves (WWT) was pre-adjusted to a constant 200 days of age using linear models with age (in days) as a covariate.

### *Growth traits*

Live weights (LWT) for growing animals were recorded unfasted for WWT between 108 and 228 days of age, yearling weight (YWT) between 272 and 388 days of age and 18-month weight (W18) between 475 and 616 days of age. Weight traits were chosen based on their relevance for the New Zealand beef sector and are commonly recorded traits for growing animals within genetic evaluation programs worldwide (Graser *et al.*, 2005). Live weights were pre-adjusted to 200 days for WWT, and to the mean age in the dataset of 344 and 560 days for YWT and W18, respectively. Pre-adjustment models included the covariate of age (in days), and the quadratic effect of age was retained in the model for W18 only. Age-adjusted LWT was used to compute post-weaning gain (PWG) as the difference between YWT and WWT and post-yearling gain (PYG) as the difference between W18 and YWT. Yearling hip height (YHIP) was recorded from 2016 onwards and measured at the same time as YWT. A linear model was used to pre-adjust YHIP to the mean age at data recording of 351 days, with the linear and quadratic effect of age (in days) as a covariate.

### *Ultrasound scan traits*

Ultrasound scanning was conducted on live animals for traits commonly recorded in pedigree-recorded cattle (Graser *et al.*, 2005), namely eye-muscle area of the longissimus dorsi muscle measured between the 12 and 13th rib (EMA) and the three fat-related traits: intramuscular fat percent (IMF) at the 12/13th rib site, fat depth at the P8 rump site ( $FD_{P8}$ ), and fat depth at the 12/13th rib site ( $FD_{RIB}$ ). Scans were conducted by BREEDPLAN-accredited technicians on replacement heifers and on steers and heifers destined for processing, resulting in records for 1,904 steers and 2,049 heifers. Recording coincided with W18, between 475 and 616 days of age. All ultrasound traits were pre-adjusted to a constant LWT of 432 kg, the mean LWT at 18 months of age, using linear and quadratic LWT as covariates. This adjustment was used to compare muscularity and fatness rather than absolute size.

### *Carcass traits*

Following ultrasound scanning, animals were assigned to slaughter management groups based on their LWT. Within these groups, all animals were slaughtered on the

same day without further selection prior to slaughter. Measurements on the carcass included carcass weight (CWT), carcass eye-muscle area (CEMA), marbling score (MB), fat colour (FC), meat colour (MC), ossification score (OSS) and rib fat depth (RF) for a total of 1,636 steers and 354 heifers and were recorded between 541 and 1,029 days of age. The trait CWT was recorded at the time of slaughter, whereas grading measures were assessed by trained graders using the Meat Standards Australia chiller assessment system (AUS-MEAT, 2018) on the day following slaughter. Measures were taken at the 12/13th rib site for CEMA, MB, FC, MC and RF, whereas the OSS of the carcass was determined on the dorsal spinous processes. A visual score for MB was assigned by the grader. Pre-adjustments were applied for CWT to the average age at slaughter within the dataset of 811 days, whereas all other carcass traits were pre-adjusted to the average CWT in the dataset of 310 kg using age (in days) or weight as linear and quadratic covariates.

### **5.3.3 Data editing**

#### *Contemporary group definitions*

Definitions of CG for maternal, growth, ultrasound and carcass traits are outlined in Table 5.1. Only animals for which all information to form CG was available were considered for analyses, allowing animals that had been treated alike up until the time of measurement to be grouped together. Animals were removed from the dataset when less than one individual was recorded for a CG or when all animals within the same CG had identical values. Following pre-adjustments of the phenotypes, possible outliers were removed from the dataset by deleting any observation further than three standard deviations (SD) from the CG mean (Brown *et al.*, 2005).

**Table 5.1** Contemporary group (CG) definitions for maternal, growth, ultrasound and carcass traits and number (n) of CGs.

Trait	CG	n of CGs
<b>Maternal traits</b>		
RB; DtC2	Herd × recording date × birth year × management group at recording	12; 13
MWT; MBCS	Herd × recording date × management group	261; 259
MHIP	Herd × recording date	18
WWT	Herd × sex × recording date × birth management group × weaning management group	200
<b>Growth traits</b>		
PWG/YWT	Herd × sex × recording date × birth group × weaning group × yearling group	239
PYG/W18	Herd × sex × recording date × birth group × weaning group × yearling group × W18 group	224
YHIP	Herd × sex × recording date	43
<b>Ultrasound traits</b>		
EMA/IMF/FD <sub>P8</sub> FD <sub>RIB</sub>	Herd × sex × recording date × birth group × weaning group × yearling group × W18 group	214–220
<b>Carcass traits</b>		
CWT/CEMA/MB/FC/MC/OSS/RF	Herd × sex × recording date × birth group × weaning group × yearling group × W18 group × slaughter group	105–209

RB = rebreeding; DtC2 = days to conception; MWT = mature live weight; MBCS = body condition score of mature cows; MHIP = hip height of mature cows; WWT = weaning weight of calves; PWG = post-weaning gain; YWT = yearling weight; PYG = post-yearling gain; W18 = 18 month weight; YHIP = yearling hip height; EMA = eye-muscle area (ultrasound); IMF = intramuscular fat (ultrasound); FD<sub>P8</sub> = P8 fat depth (ultrasound); FD<sub>RIB</sub> = rib fat depth (ultrasound); CWT = hot carcass weight; CEMA = eye-muscle area (carcass); MB = marbling (carcass); FC = fat colour (carcass); MC = meat colour (carcass); OSS = ossification (carcass); RF = rib fat depth (carcass)

#### *Heterogeneous variances*

Traits were tested for departures from homogeneity, and this was evaluated by examining the relationship between the CG mean and CG SD (Everett & Keown, 1984, Lopez-Villalobos *et al.*, 1994). A linear model was fitted following pre-adjustments by regressing the SD on the mean of the CG. A significant regression coefficient ( $P < 0.05$ ) was considered evidence for the presence of heterogeneous variances, and this was the case for MWT, MWT<sub>B<sub>CS</sub></sub>, MWT<sub>H<sub>IP</sub></sub>, FD<sub>P<sub>8</sub></sub>, FD<sub>R<sub>IB</sub></sub>, MC and OSS. Consequently, these traits

were scaled to homogenise the variances (Brown *et al.*, 2005) and this was achieved by multiplying each observation by the population mean divided by the mean of the CG of that observation (Pickering *et al.*, 2012).

Each trait included in this study with number of records, range of data measure, mean and SD is presented in Table 5.2.

**Table 5.2** Trait abbreviations (Abb.), numbers (n) of records, individual animals, sires and dams, range of measurements, means and standard deviations (SD) after adjustments and scaling.

Abb.	Unit	n of Records		n of Individual Records	n of Dams	n of Sires	Range	Mean (SD)
		Females	Males					
<b>Maternal traits</b>								
RB	%	1,272	-	1,272	1,107	227	-	91.6
DtC2	Days	1,303	-	1,303	1,138	230	0-91	25.8 (21.3)
MWT	kg	37,110	-	4,660	897	195	408-728	562.3 (47.3)
MWT <sub>BCS</sub>	kg	37,098	-	4,660	897	195	411-668	535.1 (39.5)
MWT <sub>HIP</sub>	kg	4,953	-	3,447	817	185	440-703	572.4 (40.3)
MBCS	Score	37,111	-	4,662	897	195	3-10	6.9 (1.0)
MHIP	cm	5,172	-	3,552	857	186	118-143	130.4 (4.0)
WWT	kg	3,740	3,797	7,537	4,102	406	110-338	226.4 (32.1)
<b>Growth traits</b>								
PWG	kg	2,937	3,118	6,055	3,396	376	-68-161	47.0 (37.6)
YWT	kg	2,964	3,149	6,113	3,420	376	152-439	276.3 (38.7)
PYG	kg	2,020	1,879	3,899	2,482	296	19-279	149.8 (39.3)
W18	kg	2,044	1,899	3,943	2,501	296	295-639	431.7 (50.2)
YHIP	cm	2,993	2,090	5,083	3,053	373	94-133	115.8 (4.9)
<b>Ultrasound traits</b>								
EMA	cm <sup>2</sup>	2049	1,893	3,942	2,498	296	45-82	63.2 (5.0)
IMF	%	2040	1,904	3,944	2,501	296	0-9	3.2 (1.7)
FD <sub>P8</sub>	mm	2025	1,902	3,927	2,489	296	1-11	5.1 (1.5)
FD <sub>RIB</sub>	mm	2023	1,900	3,923	2,496	296	1-7	3.5 (1.0)
<b>Carcass traits</b>								
CWT	kg	351	1,636	1,987	1,548	248	231-416	315.9 (26.4)
CEMA	cm <sup>2</sup>	228	960	1,188	1,025	170	52-98	74.6 (6.7)
MB	Score	352	1,626	1,978	1,539	248	100-741	350.5 (88.5)
FC	Score	345	1,539	1,884	1,483	248	0-5	2.5 (0.8)
MC	Score	350	1,505	1,855	1,459	248	1-7	3.1 (0.7)
OSS	Score	354	1,601	1,955	1,518	246	104-201	150.3 (13.6)
RF	mm	354	1,615	1,969	1,532	247	0-17	5.4 (2.6)

RB = rebreeding; DtC2 = days to conception; MWT = mature live weight; MWT<sub>BCS</sub> = mature live weight adjusted for body condition score; MWT<sub>HIP</sub> = mature live weight adjusted for hip height; MBCS = body condition score of mature cows; MHIP = hip height of mature cows; WWT = weaning weight of calves; PWG = post-weaning gain; YWT = yearling weight; PYG = post-yearling gain; W18 = 18 month weight; YHIP = yearling hip height; EMA = eye-muscle area (ultrasound); IMF = intramuscular fat (ultrasound); FD<sub>P8</sub> = P8 fat depth (ultrasound); FD<sub>RIB</sub> = rib fat depth (ultrasound); CWT = hot carcass weight; CEMA = eye-muscle area (carcass); MB = marbling (carcass); FC = fat colour (carcass); MC = meat colour (carcass); OSS = ossification (carcass); RF = rib fat depth (carcass).

#### **5.3.4 Statistical analysis**

Data cleaning and formatting were conducted using R version 3.6.1 (R Core Team, 2019). Restricted maximum likelihood was used to estimate (co)variance components fitting various animal models in the ASREML 4.1 software package (Gilmour *et al.*, 2015).

Variance components were obtained for all growth and ultrasound traits using univariate animal models. For carcass traits, variance components were estimated using bivariate models including W18 to account for any selection that occurred prior to data recording due to drafting of animals in lighter and heavier slaughter mobs. Genetic and phenotypic correlations were obtained among all maternal and finishing traits for which heritability was greater than 0.05 by estimating (co)variance components from bivariate animal models, or trivariate models (when a carcass trait and W18 were included).

Models included various fixed effects which were not accounted for through pre-adjustments of the phenotypes. Those along with random effects fitted for each trait are shown in Table 5.3. The random effects included in each model were based primarily on relevance for each trait and data availability. Those traits measured in mature cows had repeated records over time (within and across years) such that a permanent environmental effect was included in the analysis to account for sustained data recording. Maternal grandsire and granddam information was available for progeny from naturally-mated heifers that were recorded up until weaning, allowing a maternal genetic effect to be included in the analysis for WWT. Additionally, a permanent environmental effect of the dam was included for WWT to account for dams with multiple calves across years.

**Table 5.3** Fixed effects and random effects for each trait included in the variance component analysis.

	Fixed Effects					Random Effects <sup>3</sup>			
	Age <sup>1</sup>	Age of Breed of Dam <sup>2</sup>	Animal <sup>1</sup>	Heterosis <sup>1</sup>	CG	a	m	me	pe
<b>Maternal traits</b>									
RB	✓	✓	✓	✓	✓	✓			
DtC2	✓	✓	✓	✓	✓	✓			
MWT/MWT <sub>BCS</sub> /MWT <sub>HIP</sub> / MBCS/MHIP			✓	✓	✓	✓			✓
WWT		✓	✓	✓	✓	✓	✓	✓	✓
<b>Growth traits</b>									
PWG/YWT/PYG/W18/YHIP		✓	✓	✓	✓	✓			
<b>Ultrasound traits</b>									
EMA/IMF/FD <sub>P8</sub> /FD <sub>RIB</sub>		✓	✓	✓	✓	✓			
<b>Carcass traits</b>									
CWT/CEMA/MB/FC/MC/ OSS/RF			✓	✓	✓	✓			

RB = rebreeding; DtC2 = days to conception; MWT = mature live weight; MWT<sub>BCS</sub> = mature live weight adjusted for body condition score; MWT<sub>HIP</sub> = mature live weight adjusted for hip height; MBCS = body condition score of mature cows; MHIP = hip height of mature cows; WWT = weaning weight of calves; PWG = post-weaning gain; YWT = yearling weight; PYG = post-yearling gain; W18 = 18 month weight; YHIP = yearling hip height; EMA = eye-muscle area (ultrasound); IMF = intramuscular fat (ultrasound); FD<sub>P8</sub> = P8 fat depth (ultrasound); FD<sub>RIB</sub> = rib fat depth (ultrasound); CWT = hot carcass weight; CEMA = eye-muscle area (carcass); MB = marbling (carcass); FC = fat colour (carcass); MC = meat colour (carcass); OSS = ossification (carcass); RF = rib fat depth (carcass)

<sup>1</sup>Covariate

<sup>2</sup>Class effect

<sup>3</sup>a = additive-genetic effect; m = maternal genetic effect; me = maternal permanent environmental effect; pe = permanent environmental effect

The general models used can be described as follows:

$$y_{\text{WWT}} = \mathbf{Xb} + \mathbf{Z}_1\mathbf{a} + \mathbf{Z}_2\mathbf{m} + \mathbf{Z}_3\mathbf{me} + \varepsilon \quad (5.1)$$

or

$$y_{\text{repeat}} = \mathbf{Xb} + \mathbf{Z}_1\mathbf{a} + \mathbf{Z}_2\mathbf{pe} + \varepsilon \quad (5.2)$$

or

$$y_{\text{single}} = \mathbf{Xb} + \mathbf{Z}_1\mathbf{a} + \varepsilon, \quad (5.3)$$

where  $y_{\text{WWT}}$  was the vector of pre-adjusted phenotypic records for maternally-influenced WWT,  $y_{\text{repeat}}$  was the vector of pre-adjusted phenotypic records for traits with repeated measures such as MWT and included a term for the permanent environmental effect (pe) of the animal to account for correlated residuals,  $y_{\text{single}}$  was the vector of pre-adjusted phenotypic records for traits that were not maternally-influenced and comprised only a single phenotypic observation such as PWG, the terms  $\mathbf{X}$  and  $\mathbf{Z}$  were incidence matrices relating vectors of fixed effects (b) and random direct additive-genetic (a), maternal genetic (m), maternal permanent environmental (me) and permanent environmental (pe) effects to each observation in  $y$  and  $\varepsilon$  was the vector of residual effects.

The expected values of  $y$  and (co)variance structures for the random effects among traits were assumed as follows:

$$E \begin{bmatrix} y \\ a \\ m \\ me \\ \varepsilon \end{bmatrix} = \begin{bmatrix} \mathbf{Xb} \\ 0 \\ 0 \\ 0 \\ 0 \end{bmatrix}; \text{var} \begin{bmatrix} a \\ m \\ me \\ \varepsilon \end{bmatrix} = \begin{bmatrix} \mathbf{A} \otimes \mathbf{G} & \mathbf{A} \otimes \mathbf{d} & 0 & 0 \\ \mathbf{A} \otimes \mathbf{d} & \mathbf{A} \sigma_m^2 & 0 & 0 \\ 0 & 0 & \mathbf{I} \sigma_{me}^2 & 0 \\ 0 & 0 & 0 & \mathbf{I} \otimes \mathbf{E} \end{bmatrix} \quad (5.4)$$

for bivariate or trivariate models with WWT (model Equation (5.1)) and one or two single observation traits (model Equation (5.3));

$$E \begin{bmatrix} y \\ a \\ pe \\ \varepsilon \end{bmatrix} = \begin{bmatrix} \mathbf{Xb} \\ 0 \\ 0 \\ 0 \end{bmatrix}; \text{var} \begin{bmatrix} a \\ pe \\ \varepsilon \end{bmatrix} = \begin{bmatrix} \mathbf{A} \otimes \mathbf{G} & 0 & 0 \\ 0 & \mathbf{I} \sigma_{pe}^2 & 0 \\ 0 & 0 & \mathbf{I} \otimes \mathbf{E} \end{bmatrix} \quad (5.5)$$

for bivariate or trivariate models with one trait containing a permanent environmental effect of the animal (model Equation (5.2)) and one or two single observation traits (model Equation (5.3)); and

$$E \begin{bmatrix} y \\ a \\ \varepsilon \end{bmatrix} = \begin{bmatrix} \mathbf{Xb} \\ 0 \\ 0 \end{bmatrix}; \text{var} \begin{bmatrix} a \\ \varepsilon \end{bmatrix} = \begin{bmatrix} \mathbf{A} \otimes \mathbf{G} & 0 \\ 0 & \mathbf{I} \otimes \mathbf{E} \end{bmatrix} \quad (5.6)$$

for bivariate or trivariate models with single observation traits (model Equation (5.3)). In these model descriptions,  $\mathbf{A}$  was the numerator relationship matrix,  $\mathbf{G}$  was the genetic (co)variance matrix ( $2 \times 2$  or  $3 \times 3$ ),  $\mathbf{d}$  was a vector of covariances between maternal effects for WWT and additive-genetic effects for other traits ( $2 \times 1$  or  $3 \times 1$ ),  $\sigma_m^2$  was the variance due to maternal genetic effects for WWT,  $\mathbf{I}$  was an identity matrix of the order equal to the number of animals with observations,  $\sigma_{me}^2$  was the variance

due to maternal permanent environmental effects for WWT,  $\sigma^2_{pe}$  was the variance due to permanent environmental effects of the animal,  $\mathbf{E}$  was a residual (co)variance matrix ( $2 \times 2$  or  $3 \times 3$ ; for traits not expressed within the same animal (maternal and carcass traits) no residual covariances were identifiable and residual covariances were constrained to be zero in the ASREML model), and  $\otimes$  denotes the Kronecker product operator.

Convergence was presumed according to the default value in ASREML when the log likelihood changed less than 0.002-fold the number of iterations and the change of individual variance parameter estimates was below 1%. The pedigree was traced back for up to two generations so that the numerator relationship matrix  $\mathbf{A}$  included a total of 14,240 individual animals including 424 sires and 4,473 dams. Ancestral pedigree was not available for founder cows or sires and the base population was assumed unrelated.

## 5.4 Results

### 5.4.1 Variance components and heritabilities

Results from univariate animal models for the estimation of variance components and heritabilities for growth and ultrasound traits as well as from bivariate analysis for carcass traits are presented in Table 5.4.

**Table 5.4** Variance components ( $\sigma^2_a$  = additive genetic;  $\sigma^2_\epsilon$  = residual), heritability estimates ( $h^2$ ) and their standard errors ( $\pm$  SE) from uni- and bivariate analysis for growth, ultrasound and carcass traits in New Zealand beef cattle.

Trait	$\sigma^2_a$	$\sigma^2_\epsilon$	$h^2$
<b>Growth traits</b>			
PWG	95.50	180.69	0.35 $\pm$ 0.04
YWT	339.81	301.71	0.53 $\pm$ 0.04
PYG	119.16	242.58	0.33 $\pm$ 0.05
W18	468.59	459.58	0.50 $\pm$ 0.06
YHIP	6.97	5.75	0.55 $\pm$ 0.04
<b>Ultrasound traits</b>			
EMA	5.84	10.26	0.36 $\pm$ 0.05
IMF	0.91	0.84	0.52 $\pm$ 0.05
FD <sub>P8</sub>	1.26	0.92	0.58 $\pm$ 0.05
FD <sub>RIB</sub>	0.53	0.45	0.54 $\pm$ 0.05
<b>Carcass traits</b>			
CWT	134.66	151.36	0.47 $\pm$ 0.07
CEMA	13.91	18.79	0.43 $\pm$ 0.11
MB	2,122.33	3,287.59	0.39 $\pm$ 0.08
FC	0.03	0.35	0.07 $\pm$ 0.06
MC <sup>1</sup>	0.00	0.51	0.00
OSS	24.21	178.87	0.12 $\pm$ 0.06
RF	2.01	5.18	0.28 $\pm$ 0.07

PWG = post-weaning gain; YWT = yearling weight; PYG = post-yearling gain; W18 = 18 month weight; YHIP = yearling hip height; EMA = eye-muscle area (ultrasound); IMF = intramuscular fat (ultrasound); FD<sub>P8</sub> = P8 fat depth (ultrasound); FD<sub>RIB</sub> = rib fat depth (ultrasound); CWT = hot carcass weight; CEMA = eye-muscle area (carcass); MB = marbling (carcass); FC = fat colour (carcass); MC = meat colour (carcass); OSS = ossification (carcass); RF = rib fat depth (carcass).

<sup>1</sup>Convergence was not achieved from bivariate model; results were obtained from univariate model.

Estimates for heritabilities were moderate for the growth traits PWG and PYG and ranged from 0.33 to 0.35. Heritabilities were higher for both weight-related traits YWT

and W18 with 0.53 and 0.50, respectively. Variance components increased for both additive-genetic and residual variances when estimated for the same trait in older compared to younger animals. The trait YHIP was the most heritable growth trait at 0.55.

Weight-constant ultrasound traits were moderately to highly heritable, and the lowest heritability estimate was for EMA (0.36). Estimates of heritability were generally greater among those traits related to fat deposition, namely IMF,  $FD_{P8}$  and  $FD_{RIB}$  (0.52–0.58), but variances were lower than for EMA.

Heritability estimates varied considerably across traits measured on the carcass at slaughter and were generally low to moderate. The most heritable carcass trait was CWT with 0.47 estimated at a constant age. Moderate heritabilities were also observed for the weight-constant traits CEMA (0.43) and MB (0.39). All other carcass traits were only lowly heritable and ranged from 0.07 to 0.28 for FC, OSS and RF. The trait MC was not heritable and variance components were low for both traits related to colour of the carcass (MC and FC).

### ***5.4.2 Correlations among finishing traits***

Genetic and phenotypic correlations among traits measured in finishing cattle are shown in Table 5.5.

**Table 5.5** Genetic (SE; below diagonal) and phenotypic correlations (SE; above diagonal) among finishing traits in New Zealand beef cattle.

	PWG	YWT	PYG	W18	YHIP	EMA	IMF	FD <sub>P8</sub>	FD <sub>RIB</sub>	CWT	CEMA	MB	FC	OSS	RF
PWG		0.46 (0.01)	-0.13 (0.02)	0.29 (0.02)	0.18 (0.02)	-0.03 (0.02)	0.04 (0.02)	0.07 (0.02)	0.03 (0.02)	0.18 (0.02)	-0.04 (0.03)	0.04 (0.03)	-0.01 (0.03)	0.02 (0.02)	0.00 (0.03)
YWT	0.16 (0.06)		-0.05 (0.02)	0.77 (0.01)	0.67 (0.01)	0.01 (0.02)	0.08 (0.02)	0.08 (0.02)	0.07 (0.02)	0.56 (0.02)	-0.09 (0.04)	-0.04 (0.03)	-0.01 (0.03)	0.01 (0.03)	0.01 (0.03)
PYG	0.10 (0.10)	0.21 (0.09)		0.60 (0.01)	0.15 (0.02)	-0.05 (0.02)	0.00 (0.02)	-0.06 (0.02)	-0.07 (0.02)	0.44 (0.02)	0.02 (0.03)	-0.07 (0.03)	-0.02 (0.03)	-0.03 (0.03)	-0.10 (0.03)
W18	0.18 (0.08)	0.88 (0.02)	0.68 (0.06)		0.60 (0.01)	-0.04 (0.02)	0.06 (0.02)	0.02 (0.02)	0.01 (0.02)	0.71 (0.01)	-0.03 (0.04)	-0.07 (0.03)	-0.02 (0.03)	-0.01 (0.03)	-0.06 (0.03)
YHIP	0.08 (0.07)	0.78 (0.03)	0.37 (0.09)	0.70 (0.04)		-0.09 (0.02)	-0.03 (0.02)	-0.05 (0.02)	-0.04 (0.02)	0.50 (0.02)	-0.09 (0.04)	-0.06 (0.03)	0.02 (0.03)	-0.02 (0.03)	-0.04 (0.03)
EMA	-0.28 (0.09)	-0.08 (0.09)	0.00 (0.11)	-0.12 (0.09)	-0.26 (0.08)		0.22 (0.02)	0.15 (0.02)	0.16 (0.02)	0.04 (0.02)	0.18 (0.03)	0.05 (0.02)	-0.01 (0.02)	0.04 (0.02)	0.07 (0.02)
IMF	0.00 (0.08)	0.14 (0.07)	-0.16 (0.09)	-0.03 (0.08)	-0.25 (0.07)	0.36 (0.08)		0.46 (0.01)	0.55 (0.01)	0.06 (0.02)	0.07 (0.03)	0.28 (0.02)	0.03 (0.03)	0.04 (0.03)	0.25 (0.02)
FD <sub>P8</sub>	0.06 (0.08)	0.09 (0.07)	-0.22 (0.09)	-0.11 (0.08)	-0.14 (0.07)	0.06 (0.09)	0.68 (0.05)		0.72 (0.01)	-0.07 (0.02)	-0.02 (0.03)	0.22 (0.02)	0.03 (0.02)	0.02 (0.02)	0.32 (0.02)
FD <sub>RIB</sub>	-0.01 (0.08)	0.06 (0.07)	-0.25 (0.09)	-0.07 (0.08)	-0.20 (0.07)	0.06 (0.09)	0.76 (0.04)	0.85 (0.03)		-0.05 (0.02)	-0.01 (0.03)	0.22 (0.02)	0.03 (0.02)	0.06 (0.02)	0.35 (0.02)
CWT	0.09 (0.10)	0.74 (0.05)	0.66 (0.08)	0.84 (0.04)	0.65 (0.06)	0.14 (0.11)	0.07 (0.09)	-0.06 (0.09)	-0.05 (0.09)		0.03 (0.03)	-0.04 (0.03)	-0.02 (0.03)	-0.02 (0.03)	-0.03 (0.03)
CEMA	-0.01 (0.15)	-0.32 (0.14)	0.06 (0.16)	-0.16 (0.15)	-0.39 (0.14)	0.53 (0.13)	0.17 (0.13)	-0.07 (0.13)	-0.07 (0.13)	-0.12 (0.16)		0.08 (0.03)	0.05 (0.03)	0.08 (0.03)	-0.06 (0.03)
MB	0.17 (0.12)	0.06 (0.11)	-0.21 (0.13)	-0.06 (0.12)	-0.08 (0.11)	-0.11 (0.12)	0.70 (0.08)	0.39 (0.10)	0.38 (0.10)	0.09 (0.13)	0.09 (0.17)		0.07 (0.02)	0.09 (0.02)	0.24 (0.02)
FC	0.11 (0.25)	-0.32 (0.27)	-0.04 (0.27)	-0.37 (0.27)	-0.35 (0.27)	-0.34 (0.26)	-0.07 (0.24)	-0.09 (0.24)	-0.19 (0.24)	-0.63 (0.34)	0.73 (0.49)	-0.01 (0.29)		0.05 (0.02)	0.09 (0.02)
OSS	-0.06 (0.20)	0.32 (0.17)	-0.20 (0.20)	-0.03 (0.19)	-0.08 (0.18)	0.23 (0.19)	0.10 (0.18)	-0.06 (0.18)	0.14 (0.17)	-0.06 (0.21)	-0.30 (0.26)	0.31 (0.22)	0.07 (0.45)		0.04 (0.02)
RF	0.10 (0.14)	0.18 (0.13)	-0.25 (0.15)	-0.07 (0.14)	0.02 (0.13)	0.12 (0.14)	0.72 (0.11)	0.66 (0.11)	0.95 (0.12)	0.03 (0.15)	-0.18 (0.19)	0.38 (0.15)	0.08 (0.33)	0.27 (0.26)	

PWG = post-weaning gain; YWT = yearling weight; PYG = post-yearling gain; W18 = 18 month weight; YHIP = yearling hip height; EMA = eye-muscle area (ultrasound); IMF = intramuscular fat (ultrasound); FD<sub>P8</sub> = P8 fat depth (ultrasound); FD<sub>RIB</sub> = rib fat depth (ultrasound); CWT = hot carcass weight; CEMA = eye-muscle area (carcass); MB = marbling (carcass); FC = fat colour (carcass); MC = meat colour (carcass); OSS = ossification (carcass); RF = rib fat depth (carcass).

Weight traits of growing animals generally had high genetic correlations (0.70–0.88) among themselves, but correlations with the growth-related traits PWG (0.08–0.18) and PYG (0.10–0.68) were overall lower. Those traits related to fat deposition measured at ultrasound scanning were highly correlated and ranged from 0.68 to 0.85 among IMF, FD<sub>P8</sub> and FD<sub>RIB</sub>. Both, FD<sub>P8</sub> and FD<sub>RIB</sub> were not correlated with EMA (0.06), but a moderate genetic correlation has been observed between EMA and IMF (0.36).

Genetic correlations among carcass traits ranged from a highly negative correlation between CWT and FC (-0.63) to a high positive correlation between CEMA and FC (0.73).

The trait CWT was only lowly genetically correlated with weight-constant ultrasound traits and ranged from -0.06 to 0.14. High genetic correlations were obtained among corresponding traits measured at either ultrasound scanning or at slaughter for EMA and CEMA (0.53), IMF and MB (0.70) and  $FD_{RIB}$  and RF (0.95). Overall, traits related to the fat content of live animals at ultrasound scanning (IMF,  $FD_{P8}$  and  $FD_{RIB}$ ) compared to carcass traits (MB and RF) were moderately to highly genetically correlated and ranged from 0.38 to 0.95. Low genetic correlations were generally obtained for OSS or FC with all traits measured in live animals at ultrasound scanning (-0.19–0.23), but a moderate genetic correlation was observed between FC and EMA (-0.34).

Generally, phenotypic correlations were lower compared to genetic correlations among all traits measured in finishing animals. The highest phenotypic correlations were estimated among weight traits such as YWT, W18 and CWT and ranged from 0.56 to 0.77. Low to high phenotypic correlations were observed among traits related to fat deposition in either live animals at ultrasound scanning or at slaughter and ranged from 0.22 to 0.72.

### ***5.4.3 Genetic correlations among maternal and finishing traits***

Genetic correlations among maternal performance and finishing traits are presented in Table 5.6.

**Table 5.6** Genetic correlations (SE) among maternal and finishing traits in New Zealand beef cattle.

	RB	DtC2	MWT	MWT <sub>BCS</sub>	MWT <sub>HIP</sub>	MBCS	MHIP	WWT <sub>D</sub>	WWT <sub>M</sub>
PWG	0.11 (0.22)	-0.31 (0.19)	0.45 (0.05)	0.39 (0.05)	0.43 (0.08)	0.25 (0.06)	0.13 (0.06)	0.04 (0.12)	-0.56 (0.11)
YWT	0.14 (0.20)	-0.26 (0.17)	0.64 (0.04)	0.66 (0.04)	0.26 (0.07)	0.12 (0.05)	0.43 (0.05)	0.86 (0.03)	0.78 (0.10)
PYG	0.22 (0.25)	0.12 (0.22)	0.86 (0.05)	0.84 (0.05)	0.64 (0.10)	0.36 (0.08)	0.57 (0.07)	0.56 (0.12)	-0.18 (0.12)
W18	0.32 (0.24)	-0.19 (0.19)	0.92 (0.04)	0.93 (0.03)	0.53 (0.09)	0.27 (0.06)	0.64 (0.05)	0.80 (0.05)	0.66 (0.15)
YHIP	0.18 (0.20)	-0.33 (0.17)	0.62 (0.04)	0.67 (0.04)	-0.04 (0.07)	0.02 (0.05)	0.80 (0.04)	0.67 (0.06)	0.77 (0.12)
EMA	0.11 (0.25)	-0.13 (0.20)	-0.29 (0.06)	-0.36 (0.05)	-0.22 (0.09)	0.20 (0.07)	-0.22 (0.07)	0.08 (0.13)	0.19 (0.11)
IMF	0.35 (0.25)	-0.42 (0.19)	-0.19 (0.05)	-0.24 (0.05)	-0.06 (0.08)	0.18 (0.06)	-0.25 (0.06)	0.22 (0.11)	0.14 (0.10)
FD <sub>P8</sub>	0.31 (0.25)	-0.35 (0.19)	-0.28 (0.05)	-0.39 (0.04)	-0.13 (0.08)	0.29 (0.06)	-0.31 (0.05)	-0.18 (0.12)	0.33 (0.10)
FD <sub>RIB</sub>	0.39 (0.25)	-0.37 (0.19)	-0.32 (0.05)	-0.41 (0.04)	-0.19 (0.08)	0.25 (0.06)	-0.32 (0.05)	-0.10 (0.12)	0.26 (0.10)
CWT	0.13 (0.26)	-0.08 (0.22)	0.82 (0.06)	0.82 (0.05)	0.40 (0.11)	0.24 (0.08)	0.65 (0.07)	0.85 (0.06)	0.42 (0.14)
CEMA	-0.46 (0.37)	0.21 (0.31)	-0.29 (0.10)	-0.23 (0.10)	-0.06 (0.16)	-0.07 (0.12)	-0.21 (0.12)	-0.29 (0.18)	-0.04 (0.20)
MB	0.22 (0.30)	-0.29 (0.26)	-0.35 (0.08)	-0.35 (0.08)	-0.34 (0.13)	-0.10 (0.10)	-0.17 (0.09)	0.01 (0.15)	-0.06 (0.16)
FC	-0.32 (0.59)	0.01 (0.50)	-0.52 (0.29)	-0.55 (0.28)	-0.48 (0.33)	0.13 (0.24)	-0.39 (0.27)	n.e.	n.e.
OSS	-0.50 (0.44)	0.19 (0.38)	-0.48 (0.16)	-0.45 (0.15)	-0.59 (0.23)	-0.30 (0.20)	-0.28 (0.16)	0.12 (0.22)	0.21 (0.27)
RF	0.36 (0.35)	-0.59 (0.29)	-0.40 (0.10)	-0.43 (0.09)	-0.49 (0.15)	0.02 (0.12)	-0.28 (0.10)	0.03 (0.16)	0.00 (0.19)

RB = rebreeding; DtC2 = days to conception; MWT = mature live weight; MWT<sub>BCS</sub> = mature live weight adjusted for body condition score; MWT<sub>HIP</sub> = mature live weight adjusted for hip height; MBCS = body condition score of mature cows; MHIP = hip height of mature cows; WWT = weaning weight of calves; PWG = post-weaning gain; YWT = yearling weight; PYG = post-yearling gain; W18 = 18 month weight; YHIP = yearling hip height; EMA = eye-muscle area (ultrasound); IMF = intramuscular fat (ultrasound); FD<sub>P8</sub> = P8 fat depth (ultrasound); FD<sub>RIB</sub> = rib fat depth (ultrasound); CWT = hot carcass weight; CEMA = eye-muscle area (carcass); MB = marbling (carcass); FC = fat colour (carcass); MC = meat colour (carcass); OSS = ossification (carcass) RF = rib fat depth (carcass)

n.e. = non-estimable

Genetic correlations of the reproductive traits RB and DtC2 with finishing traits were similar but with opposing signs except for PYG which was positively correlated with both reproduction traits. Traits related to growth in yearling animals (PWG, YWT and YHIP) were positively genetically correlated with RB in the current study but correlations were low (0.11–0.18). Estimates were slightly greater for growth traits measured in older animals (PYG and W18) and ranged from 0.22 to 0.32. Moderate genetic correlations were estimated among reproductive traits and ultrasound scan traits related to fat deposition such as IMF,  $FD_{P8}$  and  $FD_{RIB}$  and those correlations were positive for RB (0.31–0.39) and negative for DtC2 (-0.42 to -0.35). Correlations among fat-related traits measured on the carcass at slaughter (MB, RF) were slightly lower for RB (0.22–0.36) but in a similar range for DtC2 (-0.59 to -0.29). The trait RB was lowly positively (0.11) correlated with EMA at ultrasound scanning after the effect of weight has been accounted for but was moderately negatively correlated with the corresponding trait measured at slaughter (-0.46).

Generally, MWT was highly genetically correlated with most growth traits, ranging from 0.62 to 0.92, but only a moderate correlation was observed with PWG (0.45). Similarly, the genetic correlation with CWT was high (0.82). Genetic correlations of MWT with all ultrasound and carcass traits other than CWT and FC were low to moderate and negative and ranged from -0.48 to -0.19. Overall, estimates of genetic correlations with finishing traits were similar compared to those with MWT after the effect of BCS has been removed. Adjusting MWT to a constant HIP generally reduced all genetic correlations but estimates were slightly higher for the carcass traits OSS and RF. Correlations among MHIP and finishing traits were slightly lower but similar to those with MWT.

The trait MBCS was lowly genetically correlated with all finishing traits except for a moderate correlation with PYG (0.36) and OSS (-0.30). Body condition score was positively correlated with all ultrasound traits (0.18–0.29), but mainly negative genetic correlations were estimated with carcass traits other than CWT and those ranged from -0.30 to -0.07. No genetic correlation was observed between MBCS and RF.

No genetic correlation was observed between the direct genetic effect of WWT ( $WWT_D$ ) and PWG, but estimates were high with all other growth traits in the current study (0.56–0.86). Genetic correlations of  $WWT_D$  with ultrasound or carcass traits other than CWT (0.85) ranged from a low negative correlation with CEMA (-0.29) to a low positive

correlation with IMF (0.22). The maternal component of WWT ( $WWT_M$ ) was negatively correlated with both PWG and PYG (-0.56 and -0.18) but correlations with other growth traits were high and positive (0.66–0.78). Genetic correlations among  $WWT_M$  and ultrasound traits were low to moderate and positive, and the greatest estimate was observed with  $FD_{P8}$  (0.33). The genetic correlation for  $WWT_M$  was moderate only for CWT (0.42), whereas all other traits recorded at slaughter only showed low correlations with  $WWT_M$  (-0.06–0.21).

Phenotypic correlations among maternal performance traits and finishing traits are presented in Table 5.7. Similar to correlations among finishing traits, phenotypic correlations were lower compared to genetic correlations among traits measured in herd replacements and finishing cattle. The reproductive traits RB and DtC2 were only lowly correlated with all finishing traits and ranged from -0.13 to 0.09. The traits MWT,  $MWT_{BCS}$  and MHIP were moderately to highly phenotypically correlated with growth traits other than PWG but correlations with ultrasound traits were low and negative (-0.25– -0.07). Only low phenotypic correlations were observed among MBCS and all finishing traits (0.08–0.18). The trait WWT was generally highly correlated with growth traits (0.72–0.88), but estimates were low for PWG (-0.27) and PYG (0.05). Almost no correlations were observed among WWT with ultrasound and carcass traits (-0.08–0.09), but a high estimate was obtained with CWT (0.51).

**Table 5.7** Phenotypic correlations (SE) among maternal and finishing traits in New Zealand beef cattle.

	RB	DtC2	MWT	MWT <sub>BCS</sub>	MWT <sub>HIP</sub>	MBCS	MHIP	WWT
PWG	0.08 (0.03)	-0.11 (0.03)	0.19 (0.03)	0.18 (0.03)	0.11 (0.03)	0.08 (0.03)	0.20 (0.03)	-0.27 (0.02)
YWT	0.04 (0.03)	-0.07 (0.03)	0.35 (0.02)	0.41 (0.02)	0.28 (0.03)	0.09 (0.03)	0.42 (0.03)	0.88 (0.01)
PYG	0.06 (0.03)	-0.04 (0.03)	0.39 (0.03)	0.43 (0.03)	0.31 (0.03)	0.14 (0.04)	0.35 (0.03)	0.05 (0.02)
W18	0.05 (0.03)	-0.05 (0.03)	0.57 (0.02)	0.64 (0.02)	0.40 (0.03)	0.18 (0.03)	0.53 (0.02)	0.72 (0.02)
YHIP	0.01 (0.03)	-0.03 (0.03)	0.37 (0.02)	0.43 (0.02)	0.07 (0.03)	0.09 (0.03)	0.61 (0.02)	0.72 (0.02)
EMA	0.03 (0.03)	-0.05 (0.03)	-0.11 (0.03)	-0.19 (0.03)	-0.09 (0.04)	0.08 (0.04)	-0.11 (0.04)	0.06 (0.02)
IMF	0.08 (0.03)	-0.08 (0.03)	-0.07 (0.03)	-0.13 (0.03)	0.04 (0.04)	0.08 (0.03)	-0.08 (0.03)	0.08 (0.02)
FD <sub>P8</sub>	0.09 (0.03)	-0.11 (0.03)	-0.14 (0.03)	-0.25 (0.03)	0.03 (0.04)	0.16 (0.03)	-0.18 (0.03)	0.09 (0.02)
FD <sub>RIB</sub>	0.08 (0.03)	-0.13 (0.03)	-0.16 (0.03)	-0.25 (0.03)	-0.02 (0.04)	0.09 (0.04)	-0.18 (0.03)	0.08 (0.02)
CWT	-	-	-	-	-	-	-	0.51 (0.03)
CEMA	-	-	-	-	-	-	-	-0.06 (0.04)
MB	-	-	-	-	-	-	-	-0.08 (0.03)
FC	-	-	-	-	-	-	-	n.e.
OSS	-	-	-	-	-	-	-	-0.01 (0.03)
RF	-	-	-	-	-	-	-	-0.01 (0.03)

RB = rebreeding; DtC2 = days to conception; MWT = mature live weight; MWT<sub>BCS</sub> = mature live weight adjusted for body condition score; MWT<sub>HIP</sub> = mature live weight adjusted for hip height; MBCS = body condition score of mature cows; MHIP = hip height of mature cows; WWT = weaning weight of calves; PWG = post-weaning gain; YWT = yearling weight; PYG = post-yearling gain; W18 = 18 month weight; YHIP = yearling hip height; EMA = eye-muscle area (ultrasound); IMF = intramuscular fat (ultrasound); FD<sub>P8</sub> = P8 fat depth (ultrasound); FD<sub>RIB</sub> = rib fat depth (ultrasound); CWT = hot carcass weight; CEMA = eye-muscle area (carcass); MB = marbling (carcass); FC = fat colour (carcass); MC = meat colour (carcass); OSS = ossification (carcass); RF = rib fat depth (carcass)

No phenotypic covariance exists for those correlations indicated by "-" as traits were not measured within the same animal

n.e. = non-estimable

## 5.5 Discussion

### 5.5.1 Inheritance of finishing traits

Heritabilities for the growth traits YWT and W18 were high compared with published values (Meyer, 1992, Koots *et al.*, 1994a). The implementation of data collection as part of the BPT and the limited number of years in which data has been recorded did not allow the estimation of maternal effects on progeny performance for either YWT or W18, thus part of the variation that would be attributable to maternal genetic effects may have been partitioned into the additive-genetic component. This may explain the greater heritability for those traits compared to literature values (Meyer, 1992, Eler *et al.*, 1995) and this is especially relevant for YWT where the maternal impact is likely to be considerably larger compared to W18 (Meyer, 1992, Meyer *et al.*, 1993). Estimating genetic parameters for growth rates rather than absolute weights is a way to account for the carry over effect of the maternal contribution to the corresponding LWT. Thus, variance components were estimated for PWG and PYG in addition to the LWT traits to avoid the requirement of fitting a maternal effect in the model. Heritability estimates for both traits agree with values presented in the literature (Koots *et al.*, 1994a, Boligon *et al.*, 2011). All variance components increased with an increase in the mean LWT as animals grow, and this has been expected (Robinson, 1996, Splan *et al.*, 1998). Previous research in beef cattle has shown that HIP traits are generally more heritable than weight traits (Koots *et al.*, 1994a, Vargas *et al.*, 2000, Afolayan *et al.*, 2007, Donoghue *et al.*, 2016) and the same effect has been shown in the current study for YHIP compared to either YWT or W18. Results indicate that a large proportion of the phenotype for growth traits is attributable to differences in the genotype, thus selecting animals with higher genetic merit in those traits is likely to improve growth in the next generation.

Ultrasound traits recorded on the live animal in the current study were generally heritable and variable, thus direct selection for higher genetic merit in live animal scan traits is feasible. Most previous research has evaluated live animal ultrasound scan traits primarily on an age- rather than weight-constant basis and this needs to be considered when comparing results presented in this study with literature values. Generally, heritability estimates for ultrasound traits presented here were slightly greater compared to those values presented in the literature and the adjustment factors may explain part of the discrepancy. After adjustment of the animals to a constant weight at 18 months of age, differences in EMA are likely to be primarily due to differences in muscling rather than size. Traits related to size of the animals are likely

to be more heritable than those traits related to muscling ability, and this may explain the lower estimates obtained in the current study when comparing the results to an age-constant EMA without accounting for differences in weight (Kemp *et al.*, 2002). Copping *et al.* (2016), however, found that results were similar with and without adjustments to a constant weight. Arnold *et al.* (1991) estimated heritabilities for weight-constant ultrasound traits in Hereford steers of 0.26 for backfat measures and 0.25 for EMA, both of which were lower compared to values obtained in the current analysis. Similarly, the pooled heritability for a weight-constant EMA obtained by Robinson *et al.* (1993) for Australian Angus and Hereford cattle was lower (0.21) compared to the estimate in the current study (0.36). Overall, fat-related traits in the current study had greater heritabilities compared to EMA at ultrasound scanning and this agrees with the estimates presented by Kemp *et al.* (2002) in United States Angus steers.

The current study evaluated all carcass traits other than CWT on a weight-constant basis, whereas CWT was adjusted to a constant age. A similar approach has been presented by Reverter *et al.* (2000) for genetic evaluations within BREEDPLAN (Graser *et al.*, 2005). They reported heritabilities in Australian Hereford cattle for CWT (0.54), CEMA (0.38), MB (0.36) and RF (0.27) generally in the same range compared to estimates observed in the current study. Similarly, Benyshek (1981) reported estimates for CWT on an age-constant basis of 0.48 for commercially farmed Hereford cattle and this is consistent with the result reported in the current study. All other carcass traits in their study have been obtained on an age- and weight-constant basis. The heritability estimate of CEMA in the current study agrees with the estimate obtained by Benyshek (1981) of 0.41 but both estimates for RF (0.51) and MB (0.46) were greater compared with the results from the current analysis. Both heritability estimates for MB (0.35) and CEMA (0.46) presented by Arnold *et al.* (1991) on a weight-constant basis are consistent with current estimates. A study conducted by Cundiff *et al.* (1971) indicates that heritabilities of carcass traits obtained on a weight-constant basis differ only slightly from those adjusted to a constant age. Heritabilities were, however, slightly lower for the longissimus dorsi area (CEMA) following weight adjustments and this is also reflected in the phenotypic variance. A similar trend has been reported by Kemp *et al.* (2002). Those results support the assertion that weight adjustments remove part of the variation that is explained through size of the animal as previously highlighted for ultrasound traits, and this is reflected in the lower

heritability. Börner *et al.* (2013), however, found similar heritabilities for CEMA adjusted to a constant age. No heritability was estimable for MC in the current study and estimates were low for FC and OSS and this may be attributable to low variation of the observed carcass quality traits. Research, however, has generally shown higher values for FC of 0.33 (Pitchford *et al.*, 2001).

### ***5.5.2 Correlations among traits measured in finishing cattle***

Generally, genetic correlations among all growth traits were high, indicating that animals with favourable genotypes for one trait also have favourable genotypes for the other traits and this has also been observed by previous researchers (Koots *et al.*, 1994b, Eler *et al.*, 1995, Vargas *et al.*, 2000). Similarly, the fat-related ultrasound scan traits IMF,  $FD_{P8}$  and  $FD_{RIB}$  were highly correlated amongst themselves. Thus, genetic progress in one trait can lead to a correlated response in other scan traits in the same direction, and this is in agreement with the literature (Robinson *et al.*, 1993, Kemp *et al.*, 2002). However, almost no genetic relationship existed between EMA and  $FD_{RIB}$  (0.06) or between EMA and  $FD_{P8}$  (0.06) at ultrasound scanning, which was in contrast with the moderate genetic correlation between backfat and longissimus muscle area (0.39) presented by Arnold *et al.* (1991). Genetic correlations among weight-constant carcass traits were generally low to moderate. The trait CEMA was only lowly correlated to both fat-related carcass traits MB and RF in the current study, and this aligns with the observation in ultrasound scan traits. Thus, breeders wanting to improve muscling ability in finishing cattle can achieve this without reducing marbling of the carcass. Börner *et al.* (2013) found equally low correlations among the age-constant carcass traits CEMA and MB (0.18) as well as CEMA and RF (-0.14). They, however, reported no correlation among MB and RF and this is in contrast to the moderate genetic correlation (0.38) found in this study.

Several researchers have examined genetic relationships between ultrasound traits and the corresponding traits recorded on the carcass at slaughter. Carcass traits measured via ultrasound scanning in live animals are used as indicator traits for carcass merit, allowing an early, more simplified prediction compared to measuring the actual economically relevant traits at slaughter (MacNeil & Northcutt, 2008). Kemp *et al.* (2002) studied the relationship at both a constant age and weight. Aligning with the results found in the current study, their results have shown that the genetic correlation among the muscling traits EMA and CEMA (0.58) was lower compared to the correlations among corresponding fat-related traits. The estimated correlation

between  $FD_{RIB}$  and RF of 0.86 reported by Kemp *et al.* (2002) was consistent with the value obtained in the current analysis (0.95). The correlation among the intra-muscular fat traits IMF and MB by Kemp *et al.* (2002) of 0.94, however, was higher compared to the value in the current analysis (0.70), whereas MacNeil & Northcutt (2008) presented results for the genetic correlation among IMF and MB in United States Angus cattle in the same range (0.52–0.84). Generally, correlations were high among corresponding traits measured at ultrasound scanning and at slaughter, such that particularly  $FD_{RIB}$  is likely to be an accurate predictor of RF recorded on the carcass at slaughter and can be used as a selection tool for genetic improvement (Robinson *et al.*, 1993, Kemp *et al.*, 2002). Similarly, genetic gain in MB is likely to be achieved when improving the genotype for finishing cattle via IMF measured at ultrasound scanning. However, at a genetic correlation of 0.70, there are limits on the accuracy in identifying animals with superior genetics for MB on the carcass when using IMF as a correlated predictor and the same is true for EMA and CEMA with a genetic correlation of 0.53.

### **5.5.3 Associations among maternal and finishing performance**

Results from this study indicate that RB in female herd replacements has only limited genetic correlations with growth and weight traits in finishing cattle. The same has been observed for DtC2 which describes a similar trait to RB using a continuous as opposed to binary measure of reproductive success. Increased reproductive performance in female herd replacements in terms of first-calving heifers getting back in calf early in their second mating season had a positive genetic correlation with fat traits in finishing animals at either live animal ultrasound scanning or at slaughter. Thus, genetic progress in the fat content of finishing cattle is likely to move the average of the replacement herd towards animals with higher pregnancy outcomes. Wolcott *et al.* (2013) examined the genetic relationship among reproductive traits in females and finishing performance in steers. This research was conducted for the Australian Brahman and Tropical Composite breeds and those are likely to differ from estimates obtained for British breeds such as Hereford and Angus particularly in terms of reproduction. Genetic correlations presented in their research, however, tend to align with estimates from the current study. Wolcott *et al.* (2013) reported a positive genetic correlation between MB and pregnancy rate of 0.20 and between MB and days to calving from -0.13 to -0.11 and this is consistent with the correlations of 0.22 between MB and RB and -0.29 between MB and DtC2 found in the current study. The moderate negative genetic correlation among RB and CEMA indicates that a reduction in

pregnancy outcomes in 2-year-old cows is likely when improving the genetic merit for muscling ability in finishing cattle. The large standard error for this correlation, however, implies that further research is required to confirm this assertion. The same applies to correlations with FC and OSS and this may be attributable to low heritabilities of both carcass quality traits.

Mature live weight was highly genetically correlated with growth and other weight traits such as YWT, W18 and CWT and this has been previously reported in the literature (Bullock *et al.*, 1993, Nephawe *et al.*, 2004). Thus, balancing selection strategies is required to improve growth and carcass traits in finishing cattle while at the same time reducing the size of mature cows to minimise energy requirements for maintenance. High genetic correlations, however, may limit the opportunity to identify animals with high growth but moderate mature size genotypes. The negative genetic correlations of MWT with either EMA or CEMA indicates that improving the genetic merit of muscularity in finishing animals at the same slaughter endpoint is likely to move the average of the replacement herd towards cow that exhibit overall lower MWT. Similarly, moderate and negative genetic correlations were observed for MWT with fat traits measured either via ultrasound on live animals or at slaughter. Thus, selection for higher fat content in finishing animals is likely to reduce MWT. Overall, relationships were consistent to those with MWT after the phenotypic association with BCS or HIP has been removed. Similarly, MHIP behaved in a similar manner when comparing among genetic correlations with all finishing traits.

Body condition score was only lowly genetically correlated to all finishing traits in the current study. Contrary to common belief among breeders, the results have shown that the fat content in finishing animals at either ultrasound scanning or on the carcass is not strongly related to the energy reserves in mature cows as indicated by MBCS. This indicates that if breeders want to increase the MBCS of their cows by using fat traits in finishing cattle as a selection tool, a large increase in the genetic merit of ultrasound and carcass fat traits would be required for only a small change in MBCS. Generally, a greater response in MBCS is likely when including a direct measure of MBCS in the selection program and breeders may improve MBCS in their cows without greatly impacting the fattening potential of the finishing herd. Practical application may, however, be limited by the time delay in measuring mature cows and/or the number of cows available for selection.

Genetic correlations among  $WWT_D$  and growth traits were generally high, and this agrees with literature values (Koots *et al.*, 1994b, Vargas *et al.*, 2000). All ultrasound and carcass traits other than CWT were only lowly genetically correlated with  $WWT_D$  and this indicates only a limited impact on fat content and muscularity for finishing cattle at a constant weight when aiming for genetic progress in  $WWT_D$ . Improving maternal genetic ability in terms of  $WWT$  tends to lead to a correlated response in LWT traits and YHIP of finishing animals in the same direction but those animals are less likely to exhibit greater genetic merit for growth rates until W18. Overall,  $WWT_M$  was only lowly genetically correlated with carcass traits other than CWT and correlations were only slightly higher with those traits measured at ultrasound scanning. Thus, antagonistic effects on any traits related to performance in finishing cattle are unlikely when improving the genetic merit for  $WWT_M$ . The genetic correlations among  $WWT_M$  and the carcass traits CWT, RF and MB agree with the estimates presented by Crews *et al.* (2004) in Canadian Charolais cattle of 0.27, -0.02 and -0.07, respectively. Estimates presented by Splan *et al.* (2002) were, however, larger for all carcass traits and this may be attributable to the adjustment method of carcass traits to a constant age rather than weight.

### 5.6 Conclusions

To optimise the efficiency of the entire beef herd, knowledge of the relationships among traits that affect the maternal and the finishing operation is required. Generally, results indicate that genetic correlations exist among key maternal performance traits and finishing traits and those need to be taken into account to avoid potential antagonisms when developing selection programs and for genetic evaluations. Balanced selection is required to enhance production in both systems without compromising performance in correlated traits. Genetic correlations indicate that there is potential to reduce the fat content in either live animals at ultrasound scanning or at slaughter with only minor changes in body energy reserves in mature cows, but this may have a detrimental effect on the genetic merit for reproductive performance in 2-year-old cows. Thus, it is important to consider traits in a multi-trait context to achieve genetic gain in the entire system. Results indicate that it is possible to identify animals with favourable genotypes for finishing and maternal performance when measures are available for both trait groups.

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**Chapter 6** – Development of a bio-economic model to compare the productivity of cows of defined genotype under distinct feed availability scenarios

## **6.1 Abstract**

A stochastic model was built to simulate the performance of beef breeding cows in response to a consistent annual feed supply curve versus a feed supply that varied across years and to evaluate the impact of variability in feed supply on the profitability of the cow-calf production system under New Zealand hill country farming conditions. The model was constructed by incorporating information from Chapter 2 to 5 as well as from the literature on the phenotypic and genetic performance of the herd, nutritional requirements, management practices and economic factors. The model creates phenotypic performance of beef cows and their progeny for key production traits until weaning based on individual breeding values and environmental factors. The model runs simulations on an individual animal basis and creates average herd performance outcomes to demonstrate the impact of variable feed allocation on overall productivity of the breeding herd. Key drivers in the model are the way cows respond to the available feed in terms of depleting or replenishing body energy reserves over time and how the resulting body condition score impacts on the reproductive performance of the herd. Results from this model have shown that the total gross margin of beef cows under a consistent feed supply curve was 1.3% greater on a per head basis and 3.9% greater on a herd level compared to a system where variability in feed allocation occurred. The much larger standard deviations for all key production and economic outcomes under a variable system, however, reflected the higher risk associated with inconsistent environmental conditions across years. A consistent environment is not an adequate representation of New Zealand hill country conditions, therefore, variability in feed supply should be accounted for when evaluating the profitability of beef cows under New Zealand hill country farming systems.

## 6.2 Introduction

Beef breeding cows within New Zealand farming systems are often farmed on hill country (Carter, 1975, Morris, 2013b) jointly with other enterprises such as sheep (McCall, 1994). Their contribution to the farming system is realised primarily through production of calves that are either retained as herd replacements or finished for beef production. Cows are often a lower priority on farms due to their low profitability relative to other stock classes. Thus, they are often managed in a way to complement other enterprises on farm through their role in maintaining pasture quality and/or quantity (Pleasants *et al.*, 1991, McCall, 1994).

In New Zealand beef breeding herds, feed allocation to cows is driven primarily by availability due to seasonal fluctuations in pasture growth as a response to climatic conditions and management strategies rather than by the nutritional requirements of the animals (Morris & Smeaton, 2009, Morris & Hickson, 2016). Cows are thereby required to buffer themselves in times of feed shortage by utilising surplus body condition as energy reserves to retain production but need to be able to regain condition following periods of restricted feeding when pasture is in ample supply (Pleasants *et al.*, 1994, Morris & Smeaton, 2009). As a response, cows can fluctuate significantly in their live weight (LWT) and body condition score (BCS) profiles throughout annual production cycles.

The productivity of cows depends on the genetic potential of the animals in the herd, individual feed intake, environmental conditions and management decisions (Jenkins & Ferrell, 1994, Berry & Evans, 2014). With the calf being the sole production output from the breeding herd, the overall productivity and efficiency of the production system is reliant on cows maintaining high reproductive performance while adjusting energy intake to fit seasonal fluctuations in pasture growth (Morris & Smeaton, 2009, Diskin & Kenny, 2016). Optimising the interactions between feeding and management strategies and selecting beef cows that complement such strategies is based on identifying breeding cows that perform under variable environments but also controlling the environment in a way to maximise cow performance.

Models often consider the impact of consistent annual feed allocation to the cow herd but rarely account for the long-term impact of variable feed supply across multiple years on the performance and resulting profitability of the cow-calf production system. Especially under hill country conditions where cows are required to use body energy

reserves as a nutritional buffer throughout the seasons and across years, including variability of feed supply in the simulation may result in substantial changes in BCS and consequently reproductive outcomes with impact on future production compared to circumstances under a controlled environment. Furthermore, accounting for variability within the farming system is likely to reflect reality much more closely compared to consistent conditions across years. Thus, it is useful to know how cows are likely to respond to variability in feed availability and to what extent this differs to situations where the environment is consistent across years. A model that incorporates genetic, biological and environmental aspects simultaneously will allow cow herds and management strategies to be evaluated under different environments. Within- and between-year variation in environmental conditions require a model to cover multiple production cycles to evaluate the flexibility of beef cows while allowing for favourable and unfavourable events.

The aim of this chapter was to develop a bio-economic model that allows the simulation of a beef breeding cow herd and to quantify cow performance under a consistent and a variable feed supply across multiple years and to determine the impact of variability on the profitability of the cow herd.

## 6.3 Materials and methods

### 6.3.1 Model overview and key production parameters

A stochastic simulation model was built using R version 3.6.1 (R Core Team, 2019). The model simulates cow-calf production for spring-calving beef cows under commercial New Zealand hill country conditions on a central North Island sheep and beef farm. The model simulates cows from the time they enter the breeding herd as in-calf 18-month-old heifers throughout their productive life until culling, and their progeny until weaning. The unit of measurement for time was set to one day with five consecutive years being modelled in each run. The model runs simulations at an individual animal level and, through replicates, creates average cow and herd performance outputs such as daily LWT and BCS as well as reproduction parameters and economic performance indicators typically considered by farmers.

The model aimed to quantify how cows that differ in their breeding values for key production traits respond to the available feed resources through LWT and BCS change and to what extent this impacts on the future production of the herd in terms of reproductive performance and calf output. Breeding values and environmental parameters, nutritional requirements, management strategies and their interactions were considered within the model to determine the productivity of the breeding herd under a given feed allocation scenario across the annual production cycle. These aspects were structured in seven modules (Figure 6.1) to describe the functioning of the model, and these are outlined in more detail in the following subsections:

- Module 1: Distributions of breeding values and random environmental effects were used as model inputs to determine the phenotypic performance of cows within the breeding herd for key production traits with impact on the reproductive performance of the herd.
- Module 2: The amount of feed available to the cow herd varied within and across years, reflecting both environmental conditions and management strategies. The variation was driven by input parameters.
- Module 3: Phenotypes for key production traits were determined based on the individual breeding values and environmental effects as determined in Module 1. Those provided the basis for the performance and

productivity of cows throughout the annual production cycle. Key features of the annual production cycle included:

- Cows calve annually in late spring (end of October until December) aligning with the pasture growth curve to benefit from the pasture flush over lactation
- Mating occurs in spring with bulls joining the breeding herd in early January for a total of 63 days (three oestrus cycles)
- Calves were weaned at a fixed date in April each year and sold to a finishing farm
- At weaning cull cows were removed from the breeding herd and replacements were purchased as in-calf 18-month-old heifers to maintain herd size
- Winter was relatively long with minimal pasture growth between April and August

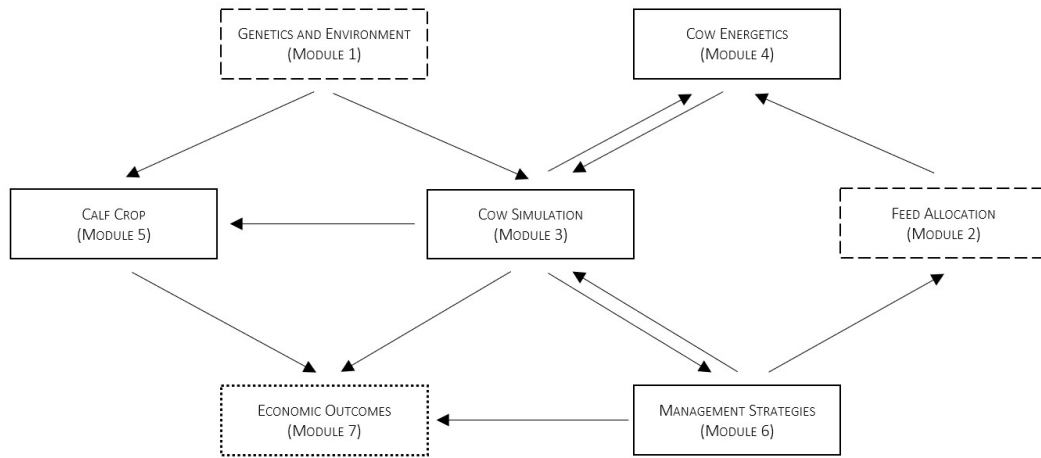
**Module 4:** The model allowed for individual cows to respond to the available feed resources determined in Module 2 which was reflected through fluctuations in BCS as a response to LWT change (refer to Chapter 2). The BCS of cows was a key parameter in the model; BCS changed in response to feed allocation and drove reproductive performance in terms of conception rate (refer to Chapter 3) and, consequently, future production of the cows within the herd. This meant that the amount of feed supplied to the cow herd ultimately determined whether cows were able to replenish or deteriorate body energy reserves.

**Module 5:** The performance of calves was a direct product of the genetic merit of the dam and sire as well as random and systematic (i.e., feed supply) environmental effects. Direct and maternal growth, weight traits and feed intake of calves were simulated until weaning.

**Module 6:** Management strategies on farm were implemented to reflect the decision rules of the farmer in regard to culling policies, replacement strategies and supplementation provided to the cow herd as a response to feed availability.

Module 7: The total gross margin of the cow-calf production system was determined based on the amount of supplementation required to retain an acceptable level of BCS throughout the annual production cycle and replacement costs and revenue from weaned calves and cull cows.

The key drivers in the model were the interaction of Module 3 and Module 4 (cow performance and energetics), in response to the input parameters of genetics, feed and imposed management rules.



**Figure 6.1** Schematic presentation of input (---), reactive (---) and output (.....) modules used within the beef cow simulation model.

The current model is based on an existing simulation model (Archer *et al.*, 2018 (unpublished), Wenham, 2019) which was developed to compare the performance of cows of different genetic merit under distinct feeding scenarios. Some basic assumptions were taken from the previous model; however, the model has been substantially revised from the original version and re-parametrised to answer the research question under consideration and to allow performance of animals to be evaluated across multiple years.

### 6.3.2 Module 1: Genetics and environment

This module defines the underlying genetic and environmental variation of the breeding herd. The base cows representing the initial herd at the beginning of the simulation, the herd replacements and their progeny were organised in a pedigree structure covering one generation. Breeding values and environmental parameters

defined in this module were used to simulate the performance of cows within the breeding herd for key production traits. The traits used in the simulation model were selected as important drivers of maternal productivity with focus on New Zealand hill country farming environments. The actual phenotypes of the base cows, herd replacements and calves were generated from a phenotypic base, individual breeding values as well as permanent and temporary environmental effects and this is further outlined in Module 3. The genetic and environmental parameters for each trait used within the simulation model are listed in Table 6.1 with estimates predominantly originating from a progeny test study conducted on New Zealand hill country farms (Chapter 4 and 5) and from literature values.

**Table 6.1** Phenotypic base ( $\mu$ ), heritabilities ( $h^2$ ), phenotypic ( $\sigma_p$ ), genetic ( $\sigma_a$ ), permanent environmental ( $\sigma_{pe}$ ) and temporary environmental ( $\sigma_e$ ) standard deviations for relevant beef cow traits (refer to Chapter 4 and 5, Short *et al.*, 1990, Morris *et al.*, 2000, Crews, 2006, Tait *et al.*, 2017, Angus New Zealand, 2022).

Trait	Abb.	Unit	Phenotypic					
			base ( $\mu$ )	$h^2$	$\sigma_p$	$\sigma_a$	$\sigma_{pe}$	$\sigma_e$
Mature live weight	MWT	kg	562.00	0.48	47.20	32.70	28.12	19.18
Gestation length	GL	days	282.00	0.62	4.50	3.54	0.00	2.77
Calf weaning weight (direct)	WWT <sub>D</sub>	kg	227.00	0.14	25.00	9.35	0.00	23.18
Calf weaning weight (maternal)	WWT <sub>M</sub>	kg	0.00	0.20	25.00	11.18	13.71	17.66
Calf birth weight	BWT	kg	37.90	0.32	3.80	2.15	0.00	3.13
Postpartum anoestrus interval	PPAI	days	30.00	0.11	11.10	3.68	3.00	10.03

Trait genetic variances ( $\sigma_a^2$ ) were calculated within the model from phenotypic variances ( $\sigma_p^2$ ) and heritabilities ( $h^2$ ) which were both inputs to the model:

$$\sigma_a^2 = \sigma_p^2 * h^2 \quad (6.1)$$

Genetic correlations were model inputs and are outlined in Table 6.2. Genetic correlations were set to zero in case of unknown relationships between traits. A genetic variance-covariance matrix ( $S_G$ ) was calculated from the genetic variances and the (6×6) genetic correlation matrix G within the model as follows:

$$S_G = D_G^{0.5} G D_G^{0.5} \quad (6.2)$$

where  $D_G$  was a diagonal matrix holding the diagonal elements of  $G$ .

**Table 6.2** Genetic correlations between traits included in the model (refer to Chapter 4 and 5, Bourdon & Brinks, 1982, Bullock *et al.*, 1993, Meyer *et al.*, 1993, Kaps *et al.*, 1999, Mialon *et al.*, 2000).

	MWT	GL	WWT <sub>D</sub>	WWT <sub>M</sub>	BWT	PPAI
MWT	1.00					
GL	0.00	1.00				
WWT <sub>D</sub>	0.85	0.11	1.00			
WWT <sub>M</sub>	-0.28	-0.14	-0.53	1.00		
BWT	0.64	0.34	0.65	0.00	1.00	
PPAI	-0.19	0.00	0.00	0.50	0.00	1.00

MWT=mature live weight; GL=gestation length; WWT<sub>D</sub>=calf weaning weight (direct), WWT<sub>M</sub>=calf weaning weight (maternal); BWT=calf birth weight; PPAI=postpartum anoestrus interval

Environmental variances were divided into permanent (pe) and temporary ( $\epsilon$ ) environment. Variances for the permanent environmental effects ( $\sigma_{pe}^2$ ) were inputs to the model for traits with repeated measures on the same animal such as LWT. Temporary environmental/residual variances ( $\sigma_{\epsilon}^2$ ) were then calculated as follows:

$$\sigma_{\epsilon}^2 = \sigma_p^2 - (\sigma_a^2 + \sigma_{pe}^2) \quad (6.3)$$

such that the environmental variance ( $\sigma_e^2$ ) was calculated from the sum of the permanent and temporary environment:

$$\sigma_e^2 = \sigma_p^2 * (1 - h^2) \quad (6.4)$$

Environmental correlations for the permanent and temporary environment were also inputs to the model (Table 6.3). Environmental correlations were set to zero if relationships between traits were unknown or for permanent environmental correlations between single observation traits. Permanent and temporary environmental variance-covariance matrices ( $S_{pe/\epsilon}$ ) were generated from environmental variances and (6×6) correlation matrices ( $E_{pe/\epsilon}$ ) using:

$$S_{pe/\epsilon} = D_{pe/\epsilon}^{0.5} E_{pe/\epsilon} D_{pe/\epsilon}^{0.5} \quad (6.5)$$

where  $D_{pe/\epsilon}$  was a diagonal matrix with the diagonal elements of  $E_{pe/\epsilon}$ .

**Table 6.3** Permanent environmental (above diagonal) and temporary environmental/residual (below diagonal) correlations between traits included in the model (refer to Chapter 4 and 5, Bourdon & Brinks, 1982, Bullock *et al.*, 1993, Kaps *et al.*, 1999, Mialon *et al.*, 2000).

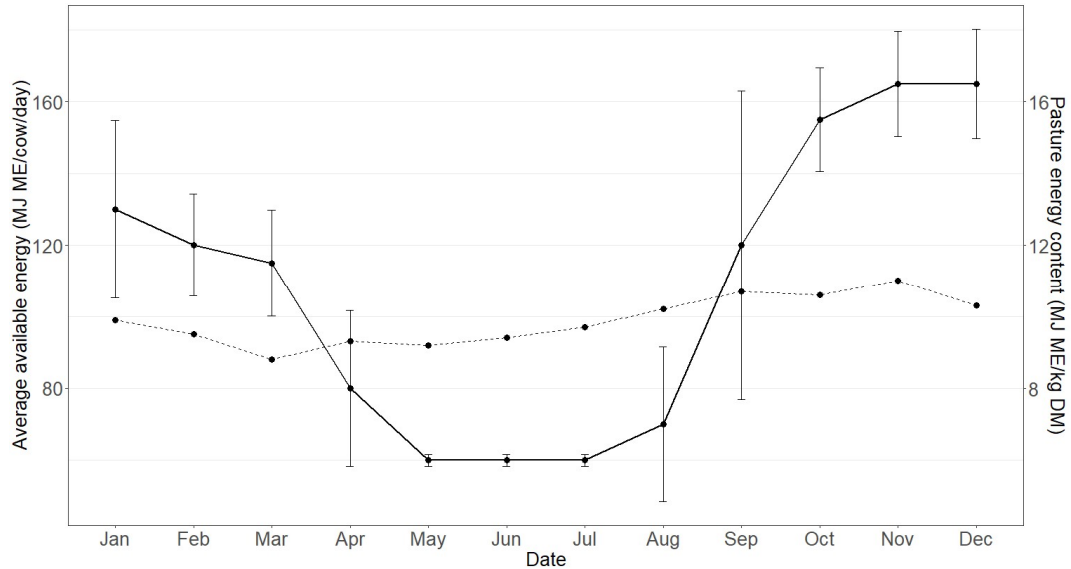
	MWT	GL	WWT <sub>D</sub>	WWT <sub>M</sub>	BWT	PPAI
MWT	1.00	0.00	0.00	0.00	0.00	-0.07
GL	0.00	1.00	0.00	0.00	0.00	0.00
WWT <sub>D</sub>	-0.09	0.13	1.00	0.00	0.00	0.00
WWT <sub>M</sub>	0.00	0.00	0.00	1.00	0.00	0.00
BWT	0.15	0.36	0.00	0.00	1.00	0.00
PPAI	-0.07	0.00	0.00	0.00	0.00	1.00

MWT=mature live weight; GL=gestation length; WWT<sub>D</sub>=calf weaning weight (direct), WWT<sub>M</sub>=calf weaning weight (maternal); BWT=calf birth weight; PPAI=postpartum anoestrus interval

### 6.3.3 Module 2: Feed allocation

The feed allocated to the cow herd was a relevant input parameter into the model, reflecting both climatic conditions and management strategies. The mean quantity of metabolisable energy (ME) available to the cow herd was specified for each month. Although pasture growth rates generally vary on a daily basis, a constant daily energy supply dictated by pasture allowance was applied for each day within the month. The input parameters for ME available per month were derived via back calculations from animal requirements determined by productivity as per Chapter 2. Live weight profiles and production parameters (pregnancy and lactation) across years were used to calculate the intake of a cow with an average mature live weight of 562 kg for each month of each year on Farm B from Chapter 2 as the reference herd. This farm was chosen as the reference herd to demonstrate the feasibility of the model results and to allow simulation outcomes to be compared to real-life conditions. Equations used to inform the energy intake of the average cow were those described in Module 4. Variability of energy supply was achieved by introducing a standard deviation (SD) in monthly energy supply as an input parameter for each month. Consequently, the energy allocated to the cow herd may fluctuate for the same month in different years but is constant within any of the days within any individual month. The SD for each month was derived from Chapter 2 across five years of records. The monthly energy content of pasture was derived from Litherland & Lambert (2007) for a central North Island hill country farm and adjusted to reflect the lower average energy allocated to beef cows compared to other livestock enterprises on farm according to Morris & Smeaton

(2009). The mean monthly energy supply with corresponding SD and the energy content of dry matter are displayed in Figure 6.2.

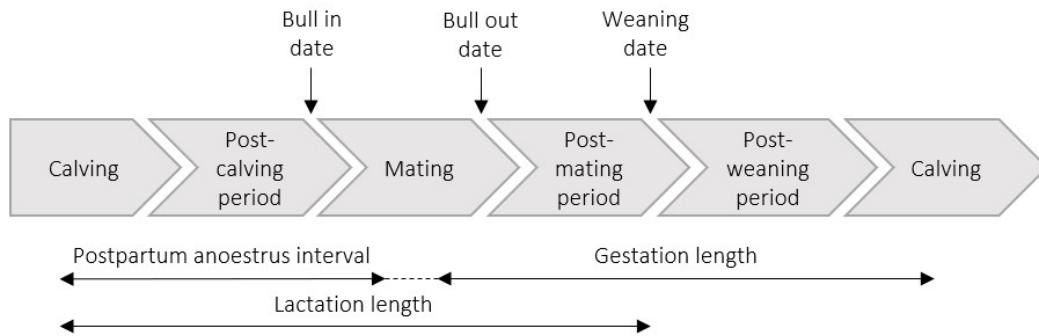


**Figure 6.2** Average energy supply (MJ ME/cow and day; solid line) with corresponding standard deviation for each month throughout the annual production cycle and pasture energy content (MJ ME/kg DM, dashed line).

The actual feed in terms of ME available to the entire cow herd ( $Feed_{total}$ ) was derived as the daily feed (ME) available for the average cow in the herd ( $Feed_i$ ; with or without SD) as per the distribution above and multiplied by the stocking rate.

### 6.3.4 Module 3: Cow simulation

This module simulates the performance of cows in the breeding herd at initiation of the simulation and defines herd parameters and key events throughout the annual production cycle. A schematic representation of the production cycle defined by various fixed events and variable periods typical for spring-calving beef cows in New Zealand is presented in Figure 6.3.



**Figure 6.3** Schematic representation of the annual production cycle of the beef cow herd.

*Herd parameterisation*

Non-genetic parameters used to describe a typical seasonal New Zealand pastoral farming system in the central North Island are listed in Table 6.4. The age structure of the herd at initiation of the model was determined by the culling policy on farm, and this is further outlined in Module 6. Thus, the probability of survival from one parity to the next was determined by management decisions to remove cows from the herd due to failure to conceive or wean a live calf and involuntary culls as well as random cow death. Remaining cows were removed from the breeding herd following their ninth parity at approximately ten years of age.

**Table 6.4** Non-genetic input parameters used to parameterise a beef cow herd in the central North Island in New Zealand (refer to Chapter 2).

Non-genetic input parameters	Unit of measure	Value	Reference
<b>Herd management<sup>4</sup></b>			
Bull in date (Mating start date)	Day of the year <sup>1</sup>	15	Beef progeny test data
Mating season	Days	63	McFadden <i>et al.</i> (2005)
Weaning date	Day of the year <sup>1</sup>	105	Beef progeny test data
<b>Herd performance<sup>5</sup></b>			
Calf peri-natal mortality <sup>2</sup>	%	3.9	Morris <i>et al.</i> (1986)
Pre-weaning mortality <sup>3</sup>	%	1.8	Morris <i>et al.</i> (1986)
Involuntary culls	%	4.6	Thomas (2008)
Cow death	%	2.4	Thomas (2008)
Survival			
Parity 1–2	%	87.0	
Parity 2–9	%	78.0	
Parity >9	%	0.0	

<sup>1</sup>Days from 1 January<sup>2</sup>Calves dead within 48 hours of calving as a percentage of total number of calves born<sup>3</sup>Calves dead between 48 hours and weaning as a percentage of total number of calves born<sup>4</sup>Constants<sup>5</sup>Expected values

Parity effects were applied for gestation length (GL), maternal weaning weight ( $WWT_M$ ) and postpartum anoestrus interval (PPAI). Cow age effects were not applied because in the New Zealand production system where cows are required to calve each year in order to be retained, age and parity are essentially the same. Those effects are outlined in Table 6.5 and represent the difference in trait expression for different parities relative to parities 4–10.

**Table 6.5** Age (parity) effects on gestation length (GL), maternal weaning weight ( $WWT_M$ ) and postpartum anoestrus interval (PPAI) (Bourdon & Brinks, 1982, Doornbos *et al.*, 1984, Lubritz *et al.*, 1989).

Parity	GL (days) <sup>1</sup>	$WWT_M$ <sup>2</sup>	PPAI <sup>2</sup>
1	-2.00	0.74	1.41
2	0.00	0.86	1.00
3	0.00	0.96	1.00
4–10	0.00	1.00	1.00

<sup>1</sup>Values compared to mean<sup>2</sup>Expressed as a relative proportion (of mature equivalent)

*Cow phenotypes*

Genetic and environmental parameters described in Module 1 were used to simulate phenotypes for each cow in the herd for certain traits. True breeding values for each cow and trait were randomly sampled from a multivariate normal distribution using a mean of zero and the genetic variance-covariance matrix ( $S_G$ ) created from the genetic effects as specified above. Similarly, permanent and temporary environmental effects were randomly allocated to each cow in the herd from multivariate normal distributions with a mean of zero and either the permanent ( $S_{pe}$ ) or temporary ( $S_{te}$ ) environmental variance-covariance matrix described above.

Phenotypic base ( $\mu_i$ ), true breeding values ( $TBV_{ij}$ ), permanent ( $pe_i$ ) and temporary ( $\varepsilon_{ijt}$ ) environmental effects were then combined to generate phenotypes (Trait) for trait  $i$  and animal  $j$  at time  $t$  according to:

$$\text{Trait}_{ij,a} = \mu_i + TBV_{ij} \quad (6.6)$$

for single observation traits not containing temporary environmental effects that are constant over time ( $\text{Trait}_{ij,a}$ ),

$$\text{Trait}_{ij,pe} = \mu_i + TBV_{ij} + pe_{ij} \quad (6.7)$$

for traits containing a permanent environmental effect but no temporary environmental effect that are constant over time ( $\text{Trait}_{ij,pe}$ ),

$$\text{Trait}_{ijt,\varepsilon} = \mu_i + TBV_{ij} + \varepsilon_{ijt} \quad (6.8)$$

for single observation traits containing a temporary environmental effect that vary over time ( $\text{Trait}_{ijt,\varepsilon}$ ), or

$$\text{Trait}_{ijt} = \mu_i + TBV_{ij} + pe_{ij} + \varepsilon_{ijt} \quad (6.9)$$

for traits containing both permanent and temporary environmental effects that vary over time ( $\text{Trait}_{ijt}$ ).

*Simulating the base cow herd*

This section defines the base cow herd representing the original population of cows at the start of the simulation. At initiation of the model, every animal in the herd had phenotypes calculated for the traits LWT, BCS and GL as well as conception date, calving date and total lactation potential were determined for each animal.

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### Step 1: Cow calving date

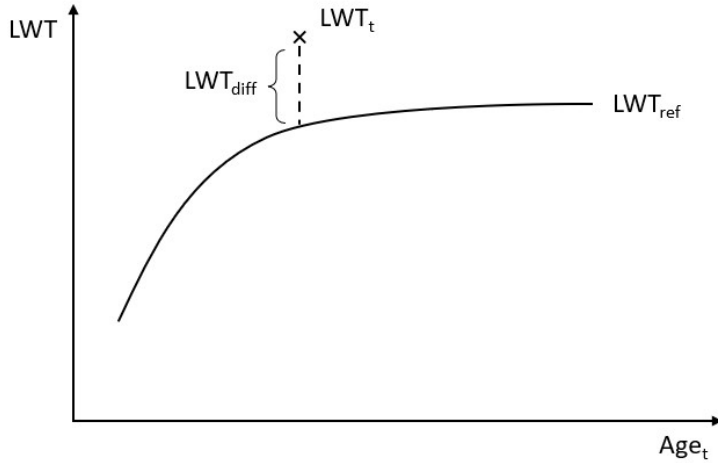
The model starts on the first day of the calving season (start date: 24 October). Age of the base cows in terms of parity number was randomly assigned to each cow based on the age structure described previously. The birth date of cows and replacement heifers was not known but a reference birth date was assumed for all animals in the breeding herd and set to align with the planned start of calving to approximate the age in days at any given day of the production cycle. Cows were randomly assigned a calving date in respect to mating start date, conception date and gestation length. An initial mating period of 63 days was assumed (McFadden *et al.*, 2005) with an initial conception rate of 60% for the first cycle (assuming a 21-day cycle; Morris, 2007, Beef + Lamb New Zealand, 2017i). This predicted the number of cows conceiving at each cycle given a certain probability of conception and each cow had a conception date randomly allocated. An individual GL sampled from a normal distribution (mean=282 days; SD=4.7 days; Bourdon & Brinks, 1982) was assigned to each cow and added to each conception date to determine calving dates.

### Step 2: Initial performance parameters at calving

For each cow in the herd, a true live weight at a reference BCS of 6 ( $LWT_{ref}$ ) was calculated and this was assumed to be independent of temporary environmental effects and the body condition of the animal. The  $LWT_{ref}$  was estimated using individual growth curves based on the Brody curve (Brody, 1945). The Brody curve was updated using parameters for skeletal development according to Taylor (1986) as implemented by Freer *et al.* (2007). Individual growth curves were determined for each cow in the breeding herd with respect to their age at time  $t$  ( $Age_t$ ; Figure 6.4):

$$LWT_{ref} = MWT - ((MWT - BWT) \times e^{-0.35 \times Age_t \times MWT^{-0.27}}) \quad (6.10)$$

where BWT and MWT were the phenotypes for birth weight and mature live weight calculated from Equation (6.6) and Equation (6.7), respectively, for each cow.



**Figure 6.4** Difference in live weight ( $LWT_{diff}$ ) between the live weight at time  $t$  ( $LWT_t$ ) and the live weight at a body condition score of 6 ( $LWT_{ref}$ ) with respect to the age of the animal at time  $t$ .

The  $LWT_{ref}$  was used to derive initial phenotypes for each cow in the herd for LWT ( $LWT_{calv}$ ) and BCS ( $BCS_{calv}$ ) at calving. The  $LWT_{calv}$  was determined as a function of  $LWT_{ref}$ , the deviation of the average herd BCS at calving (assumed to be 5.7; Chapter 2) from the reference BCS of 6 and a temporary environmental effect on mature live weight ( $te_{MWT}$ ) as follows:

$$LWT_{calv} = LWT_{ref} + te_{MWT} + (5.7 - 6) \times \Delta BCS \quad (6.11)$$

where  $\Delta BCS$  was the change in LWT that relates to one unit change in BCS. The  $\Delta BCS$  was a relevant parameter used in the simulation model, regulating mobilisation and accumulation of body energy reserves as cow live weight fluctuates according to feed supply and physiological status. The current input assumed a linear  $\Delta BCS$  of 28.5 kg throughout the annual production cycle such that each animal had the same conversion of the number of kg to gain/lose a BCS score unit, irrespective of the mature weight and/or size of the cow (refer to Chapter 2). The BCS was based on a 1–10 scale commonly used for evaluating stored body energy reserves in New Zealand beef cattle (Hickson *et al.*, 2017).

The difference between  $LWT_{calv}$  and  $LWT_{ref}$  ( $LWT_{diff}$ , Figure 6.3) was used to calculate  $BCS_{calv}$  using:

$$BCS_{calv} = 6 + \frac{LWT_{diff}}{\Delta BCS} \quad (6.12)$$

As cows cycle throughout the year the model simulates daily LWT and its resulting BCS for each individual animal in the breeding herd in response to individual energy requirements and pasture availability on each day and those are important drivers of reproductive performance of the animals. Calculations for both traits on a daily basis are further outlined in Module 4.

#### *Cow lactation curves*

Lactation curves were determined for each cow for each lactation. The total lactation potential of each cow from calving until weaning was simulated from breeding values, environmental (temporary and permanent) and parity effects that impact on milk production and varied with stage of lactation. Assumptions on milk production and the shape of the lactation curve for New Zealand beef cows were derived from Roca Fraga (2013) to inform the proportion of milk yield on each day of lactation from the total lactation potential of each individual.

The model calculated the total milk yield expressed by the dam until weaning from her maternal weaning weight potential ( $WWT_M$ ) using Equation (6.9). Based on Roca Fraga (2013), 12 kg of milk were required to produce an extra kg of calf weaning weight and this was used as a multiplier with  $WWT_M$  so as to express the maternal weaning weight potential of the dam in kilogram milk yield. The following equation was used to determine the total lactation potential, i.e. milk yield (LAC; kg) for each dam for 200 days of lactation:

$$LAC = (\text{base}_{lac} + 12 \times WWT_M) \times MILK_{parity} \quad (6.13)$$

where  $\text{base}_{lac}$  was the base lactation potential of each cow in the herd of 1,492.25 kg for 200 days of lactation (Roca Fraga, 2013) and  $MILK_{parity}$  the effect of parity on the total milk production potential.

The total length of lactation was determined as the difference in days between calving date of each individual cow until weaning at a fixed date each year (Table 6.4).

#### *Defining key events throughout the annual production cycle*

##### Post-calving period (calving until start of mating)

The length of the PPAI determined the first cycling day of each cow in the herd and may vary according to the breeding values of the cows, their calving date, parity and  $BCS_{calv}$  (Hansen & Hauser, 1983, Short *et al.*, 1990, Blanc & Agabriel, 2008). The phenotype for

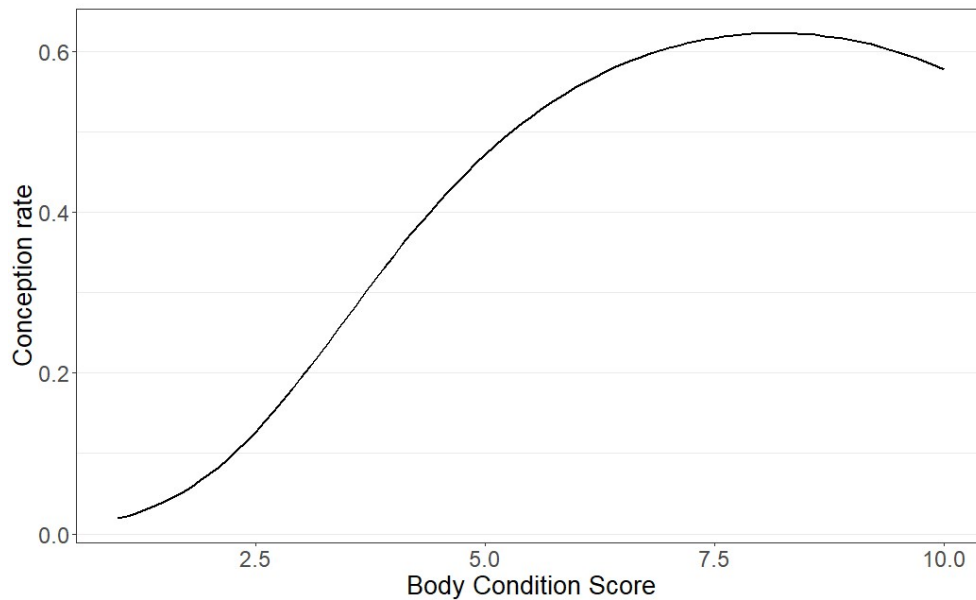
PPAI for each cow was calculated using Equation (6.9) and a parity effect on the duration of the PPAI was added (Table 6.5). An average 0.22 day shorter PPAI was assumed for each additional day later the cow calved relative to the start of the calving season (Hansen & Hauser, 1983). The impact of  $BCS_{calv}$  on PPAI was derived from values presented by Short *et al.* (1990). It was assumed that a decrease in BCS resulted in an extended PPAI. The PPAI for cows at or above a BCS of 7 was expected to increase by one day whereas the duration of the PPAI increased exponentially such that an additional 80 day longer PPAI was expected for cows at or below a BCS of 3. The effects for both the calving date and  $BCS_{calv}$  were added to the phenotypic base of PPAI (Table 6.1) for each individual cow to calculate the actual PPAI for each animal in the breeding herd and, thus, the day each cow resumed regular cycling activity.

Post-mating period (mating season until weaning)

Bulls were introduced to the herd for a total of 63 days, allowing cows to cycle up to three times (based on a 21-day cycle) over the course of the mating season. The likelihood of a cow conceiving was dependent on her cycling day. A constant 21 days were assumed between the day cows resumed regular cycling activity and any subsequent cycling day until conception. If cows were cycling at the current day under consideration, the main driver of probability of conception was assumed to be BCS at the start of mating and this was used to generate the underlying conception rate of the model. The relationship between conception rate and BCS was taken from Chapter 3. The probability of conception (CR) for each cow was derived from the total pregnancy rate following AI and 49-days of natural mating (PR) via back calculation using the approach presented by McFadden *et al.* (2005):

$$PR = 3CR - 3CR^2 + CR^3 \quad (6.14)$$

Figure 6.5 shows the probability of conception in each cycle at different mating BCS.



**Figure 6.5** Probability of conception in each cycle at different mating body condition scores with values derived from Chapter 3.

The probability of conception was derived for cows from their second mating season onwards. Herd replacements entered the breeding herd as in-calf 18-month-old heifers and the rebreeding conception rate of first calving heifers was assumed be the equivalent to mature cows (Chapter 4).

The gestation length (GL) for each cow was determined based on the breeding value of the animal and environmental effects using Equation (6.8) and adding a parity effect (Table 6.5). Progeny were assumed to be 50% male and 50% female (Morris *et al.*, 1986) such that no distinction for sex of the calf was considered as a determinant of GL and this is further outlined in Module 5.

#### Post-weaning period (weaning day until calving)

Weaning of the calves was conducted at a fixed day each year (Table 6.4). At this time the number and weight of calves weaned was established and this is described in Module 5. Cull cows were removed from the breeding herd at weaning and, additionally, a cow death rate of 2.4% (Thomas, 2008) was applied randomly across the herd.

Herd replacements were introduced to the breeding herd at weaning to replace cull and dead cows. All females used as herd replacements were introduced to the herd as in-

calf 18-month-old heifers. The replacement strategy is further outlined in Module 6. Phenotypes for herd replacements were calculated at that point for  $LWT_{ref}$  according to Equation (6.10) used for the base cow population. The initial live weight at weaning ( $LWT_{wean}$ ) was calculated similarly to  $LWT_{calv}$  (Equation (6.11)) with the distinction that the initial BCS for replacements at weaning was assumed to be one BCS unit above the average herd BCS at that time to account for the generally higher body energy reserves of first-calving heifers compared to cows (Chapter 4) but also allow for seasonal variation in nutritional levels over summer.

The following calving date for each animal was calculated from the individual conception date and GL. Calving dates for herd replacements were calculated in the same way than for the cows in the original year and aligning with the preceding mating start date of the herd.

### **6.3.5 Module 4: Cow energetics**

This module describes the cow herd in terms of its resulting LWT and BCS performance in front of the feed availability of the environment on a daily basis. The amount of energy supplied to the cow herd has been described in Module 2. Here it was determined how much energy was required for each cow based on the physiological state and whether those requirements were met through individual feed intake. The difference in energy balance provided the basis for daily LWT fluctuations throughout the annual cycle and the resulting BCS. The BCS of cows was a key driver in the model impacting on cow performance and production at certain times of the year as outlined in Module 3.

#### *Cow energy requirements*

The energy requirements for each individual animal were derived for each day, and varied with age, LWT, BCS and physiological state. Calculation of energy requirements used within this section were based primarily on equations from Freer *et al.* (2007) and Nicol & Brookes (2007).

#### Maintenance

Maintenance requirements ( $ME_{maint}$ ; MJ ME/day) were calculated as follows:

$$ME_{maint} = LWT_t^{0.75} \times k_m \quad (6.15)$$

where  $LWT_t$  was the actual live weight of each animal on any given day and  $k_m$  the efficiency of ME used for maintenance, calculated as  $k_m = 0.02 \times \text{Feed}_{ME} + 0.5$  with  $\text{Feed}_{ME}$  being the energy content of pasture for the corresponding month (MJ ME/kg DM; Figure 6.2).

### Pregnancy

The energy retention for each day of pregnancy ( $ME_{preg}$ ; MJ ME/day) was determined using the Gompertz model and this was used to calculate the daily ME requirements for gestation as follows:

$$ME_{preg} = \frac{BWT_{Calf} \times 0.025 \times 0.02011 \times e^{349.22 - 349.16 \times e^{-0.0000576 \times Age_f - (0.0000576 \times Age_f)}}}{0.133} \quad (6.16)$$

where  $BWT_{Calf}$  was the birth weight of the calf in utero (kg; calculations further outlined in Module 5),  $Age_f$  the age of the fetus at any given day of the cycle.

### Lactation

Using the information from the individual lactation curves for each cow, daily milk production was derived for each day of the cycle, and this was used to approximate the energy requirements during lactation ( $ME_{lact}$ ; MJ ME/day) as follows:

$$ME_{lact} = \text{Milk}_{kg} \times \frac{EVL}{k_l} \quad (6.17)$$

Where  $k_l$  was the efficiency of energy used for milk production, calculated as  $k_l = 0.02 \times \text{Feed}_{ME} + 0.4$ , and  $EVL$  the energy content of milk (3.4659 MJ ME/kg milk yield).

### Total energy requirements

The total energy requirement for maintenance and production excluding growth ( $ME_{total}$ ) was calculated as the sum of energy required for maintenance, pregnancy and lactation:

$$ME_{total} = ME_{maint} + ME_{preg} + ME_{lact} \quad (6.18)$$

### Cow energy intake

The live weight of the cow at each day of the year along with age and physiological state was used to determine voluntary feed intake (VFI; MJ ME/day) of each cow, which reflects the upper limit of feed consumption. Calculations for VFI were based on

equations from Freer *et al.* (2007) and scaled to achieve a maximum intake for mature cows of 2.5% of live weight (Archer *et al.*, 2002):

$$VFI = 0.0358 \times MWT \times Z \times (1.7 - Z) \times C \times \text{Feed}_{ME} \quad (6.19)$$

$$\text{with } Z = \frac{LWT_{ref}}{MWT} \text{ if } Z < 1 \text{ and } Z = 1 \text{ if } Z \geq 1, \quad (6.20)$$

$$LWT_{cond} = \frac{LWT_t}{LWT_{ref}} \text{ where} \quad (6.21)$$

$$C = \frac{LWT_{cond} \times (1.5 - LWT_{cond})}{0.5} \text{ if } LWT_{cond} > 1 \text{ and } C = 1 \text{ if } LWT_{cond} \leq 1. \quad (6.22)$$

No additional adjustments for intake were made during pregnancy. However, there is evidence that potential intake of the cows increases during lactation. The peak intake generally lags behind the peak in milk production but can be assumed to be of similar shape to the lactation curve (Freer *et al.*, 2007). Thus, an intake factor ( $m_{lac}$ ) was used as a multiplier with Equation (6.19) for lactating cows dependent on the day of lactation (lacday):

$$m_{lac} = 1.0 + 0.42 \times \left(\frac{\text{lacday}}{62}\right)^{1.7} \times e^{1.7 \times \left(1 - \frac{\text{lacday}}{62}\right)} \times \left(0.5 + 0.5 \times \frac{BCS_{calv}}{BCS_{Herd}}\right) \quad (6.23)$$

where  $BCS_{Herd}$  was the average herd BCS at calving.

If sufficient feed was provided to the entire herd, the actual total energy intake of each animal on each day ( $I_{total}$ ) was equivalent to VFI. In a feed shortage situation, however, where VFI cannot be met, it was assumed that  $I_{total}$  was a proportion of the VFI potential of each animal:

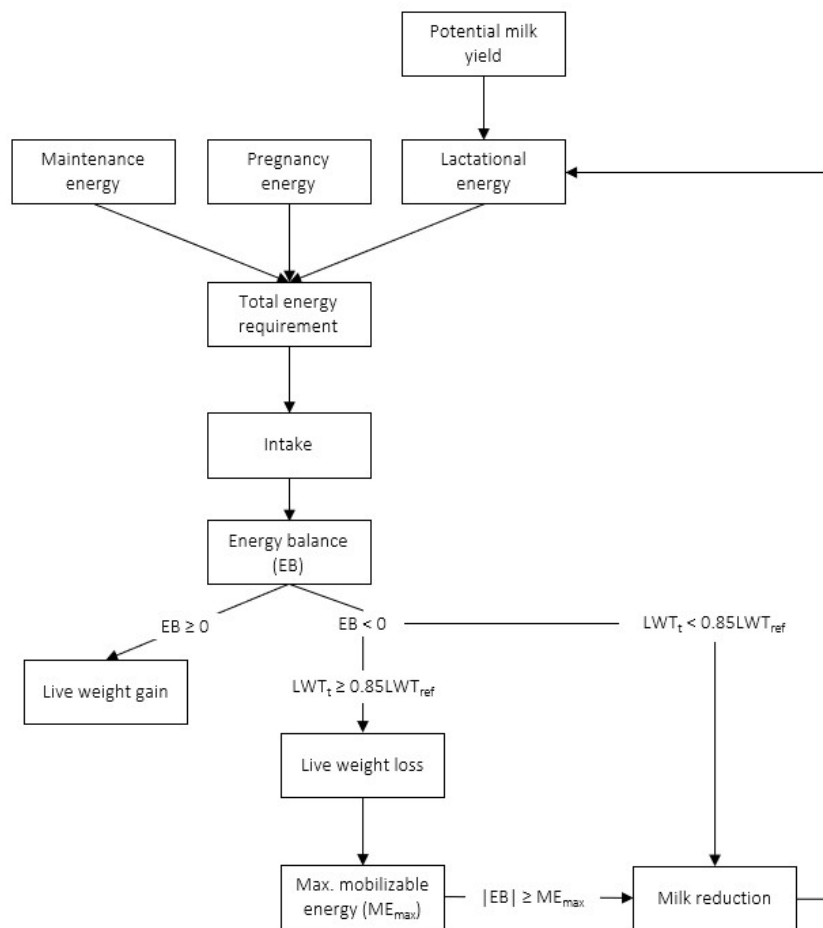
$$I_{total} = VFI \text{ if } \text{Feed}_{total} \geq \sum VFI \quad (6.24)$$

$$\text{or } I_{total} = VFI \times \frac{\text{Feed}_{total}}{\sum VFI} \text{ if } \text{Feed}_{total} < \sum VFI \quad (6.25)$$

where  $\sum VFI$  was the sum of the VFI of each animal across the herd.

*Energy balance and growth*

Daily live weight gain and/or loss of each individual cow depended on the energy balance (EB), i.e. the difference between  $I_{\text{total}}$  and  $ME_{\text{total}}$ . When the energy intake of an individual animal exceeded  $ME_{\text{total}}$  ( $EB \geq 0$ ), the surplus energy consumed was used for live weight gain. In case of a negative energy balance ( $EB < 0$ ), additional energy was required for maintenance and production, and this was realised primarily through mobilisation of body energy reserves and secondly through compromised milk production. The energetics of mobilisable energy and milk energy are presented in a flow chart in Figure 6.6.



**Figure 6.6** Schematic presentation of energy balance and the corresponding response in performance and production parameters (adapted from Hirooka & Yamada (1990)).

If cows were in a negative energy balance ( $EB < 0$ ), there was assumed to be a maximum amount of energy that can be mobilised from stored energy ( $ME_{max}$ ; MJ ME/day) on a single day (Brockington *et al.*, 1983) and this was a function of the animal's live weight on the day:

$$ME_{max} = 0.2 \times LWT_t^{0.75} \quad (6.26)$$

It was assumed that a reduction in milk yield would only occur if animals did not have sufficient energy reserves to spare ( $LWT_t < 0.85 \times LWT_{ref}$ ) or once the deficit in energy was larger than the amount mobilisable through body tissue such that if the absolute EB ( $|EB|$ ) was larger than  $ME_{max}$ , the reduction of milk energy may be calculated as follows:

$$ME_{lact}' = 0.84 \times \left( \frac{ME_{lact}}{0.84} + ME_{max} - |EB| \right) \quad (6.27)$$

where  $ME_{lact}'$  was the energy required for compromised milk production.

The energy required for live weight gain or mobilised from live weight loss was calculated differently for growing heifers and for mature cows and varied across the annual production cycle (lactating and non-lactating period).

For growing animals (up to parity 4), the following equation was used to estimate the energy content of 1 kg live weight change ( $ME_{growing}$ ; MJ ME/ kg live weight):

$$ME_{growing} = \frac{((6.7 + 1.0 \times R) + (20.3 - 1.0 \times R))}{(1 + e^{-6 \times (Z-0.4)}) \times 0.92} \quad (6.28)$$

$$\text{with } R = \left( \frac{ME_{total}}{ME_{maint}} - 2 \right) \quad (6.29)$$

For mature cows the energy content of 1 kg live weight change ( $ME_{mature}$ ; MJ ME/kg live weight) was a function of the BCS at each day of the production cycle ( $BCS_t$ ):

$$ME_{mature} = \frac{(20.8 + 2.07 \times BCS_t)}{0.92} \quad (6.30)$$

For growing animals or mature cows where  $EB \geq 0$ , the energy required to gain 1 kg of live weight ( $ME_{gain}$ ; MJ ME/kg live weight) was calculated as follows:

$$ME_{gain} = ME_{growing/mature} \times \frac{1}{k_g} \quad (6.31)$$

where  $k_g$  was the efficiency of ME used for live weight gain and varied with the lactation status of the cow ( $k_g$  for lactating cows=0.60;  $k_g$  for non-lactating cows=0.43).

The gain and subsequent loss of LWT is generally associated with a cost, such that not all dietary ME is stored as energy reserves and can be mobilised. Thus, the energy gained from 1 kg live weight loss (for  $EB < 0$ ) was calculated differently dependent on the lactation status, and can be determined for non-lactating females using:

$$ME_{\text{loss,maint}} = ME_{\text{growing/mature}} \times \frac{0.80}{k_m} \quad (6.32)$$

and during lactation using:

$$ME_{\text{loss,lact}} = ME_{\text{growing/mature}} \times \frac{0.84}{k_l} \quad (6.33)$$

where  $ME_{\text{loss,maint}}$  was the dietary ME spared for maintenance from live weight loss (MJ ME/kg live weight) in non-lactating cows and  $ME_{\text{loss,lact}}$  the dietary ME spared for milk production (MJ ME/kg milk yield) in lactating cows.

#### *Cow live weight and body condition score*

Individual LWT and BCS were then calculated for each cow for every day of the cycle. Daily LWT was dependent on the LWT of the previous day ( $LWT_{t-1}$ ) and either increased if surplus energy was available for growth of the animal ( $EB \geq 0$ ) or decreased if requirements for maintenance and production were not met ( $EB < 0$ ). The actual LWT of each animal on any given day of the cycle was therefore calculated as follows:

$$LWT_t = LWT_{t-1} + \frac{EB}{ME_{\text{growth}}} \quad (6.34)$$

where  $ME_{\text{growth}}$  was equivalent to  $ME_{\text{gain}}$  (Equation (6.31)) when  $EB \geq 0$ , or equivalent to  $ME_{\text{loss}}$  (Equation (6.32) or Equation (6.33)) when  $EB < 0$ .

The  $BCS_t$  was then determined from the difference between  $LWT_t$  and  $LWT_{\text{ref}}$  using the same approach previously outlined for  $BCS_{\text{calv}}$  (Equation (6.12)).

### **6.3.6 Module 5: Calf crop**

#### *Calf genetics*

The model produced calves that were a reflection of the genetic merit of the cow and bull. Calf breeding values were calculated based on half the additive genetic variance of

both sire and dam and a mendelian sampling component. Breeding values of bulls were assumed to be the same as the average breeding values of the cow herd (equal to the herd mean of zero; refer to Module 3), with the same bull (or bulls of equal genetic merit) used as the sire for all calves. The mendelian sampling component was randomly allocated to each calf in the herd and sampled from a multivariate normal distribution with a mean of zero and half of the genetic variance-covariance matrix ( $S_G$ ) defined in Module 1 to maintain trait correlations. Similar to the approach used for the base cow herd, permanent and temporary environmental effects were randomly allocated to all calves using multivariate normal distributions with a mean of zero and the environmental variance-covariance matrices ( $S_{pe}$  or  $S_{te}$ ) defined above.

*Modelling the calf crop until weaning*

The calf traits predicted in the model were birth date (from dam's conception date and GL), birth weight, weaning weight, 200-day weight, total energy required per weaned calf and total feed intake per weaned calf.

The calving date calculated for each cow within the breeding herd was used as the birth date for each calf. The  $BWT_{Calf}$  was generated using Equation (6.8) and accounting for the ratio between BWT of the calf and MWT of the dam to allow for the effect of bigger cows generating bigger calves. It was expected that approximately 50% of progeny were male calves (Morris *et al.*, 1986) such that no distinction was made for sex of the calf in the model, and this has also been accounted for in Module 7 with calves being sold on a per kg live weight basis at weaning.

The age of the calf at weaning ( $Age_{wean}$ ) was calculated as the time difference in days from birth until weaning. A binomial distribution was used to randomly allocate probability of peri-natal or overall pre-weaning mortality to each calf in the herd (Table 6.4). This was used to assign loss of calves to a proportion of cows at any day between birth and weaning and this shortened the lactation length accordingly in the corresponding dams.

Calf weaning weights (WWT) were generated from  $BWT_{Calf}$  and 200-day weight ( $WWT_{200}$ ) of the calf as follows:

$$WWT = BWT_{Calf} + \frac{WWT_{200} - BWT_{Calf}}{200} \times Age_{wean} \quad (6.35)$$

$$\text{with } WWT_{200} = WWT_D + WWT_M \quad (6.36)$$

where  $WWT_D$  was the direct and  $WWT_M$  the maternal effect on calf weaning weight (effect of the dams' milk potential on the WWT of the calf) calculated using Equation (6.8) and Equation (6.9), respectively.

The total amount of energy required to wean a calf ( $ME_{\text{Wean}}$ ) was a function of the amount of energy required for maintenance and for live weight gain from birth to weaning. In this simulation, the energy required for 1 kg live weight gain of calves was assumed to be 30 MJ ME/kg DM (Nicol & Brookes, 2007), thus:

$$ME_{\text{Wean}} = 0.70 \times (\text{Age}_{\text{WWT}} \times \left( \text{BWT}_{\text{Calf}} + \frac{\text{WWT} - \text{BWT}_{\text{Calf}}}{2} \right))^{0.75} + 30 \times (\text{WWT} - \text{BWT}_{\text{Calf}}) \quad (6.37)$$

The energy required to wean a calf was partly covered by the total potential milk production of each dam during lactation ( $ME_{\text{lact}}$ ), and the remaining energy supply was covered by pasture intake of the calf before weaning. Thus, the total amount of pasture required for the calf until weaning ( $ME_{\text{Pasture}}$ ) was calculated as follows:

$$ME_{\text{Pasture}} = ME_{\text{Wean}} - ME_{\text{lact}} \quad (6.38)$$

Weaning weights of the calves were corrected if the dam was not able to spare sufficient body energy reserves in times of feed shortage, resulting in a reduction in milk available for the calf. Furthermore, if pasture allowance for the dams varied from that in an average year ( $SD \neq 0$ ), it was assumed that the difference in pasture allowance for the calf was proportional to the pasture allowance of the dam, indicating that both cows and calves missed out on or received an equal percentage of the feed difference. Thus, the actual amount of pasture available to the calf until weaning ( $ME_{\text{Pasture}}'$ ) was calculated as follows:

$$ME_{\text{Pasture}}' = ME_{\text{Pasture}} \times \frac{\text{Feed}_t}{\text{Feed}_{\text{av}}} \quad (6.39)$$

where  $\text{Feed}_{\text{av}}$  was the amount of feed available at SD of zero, averaged across the lactation period.

The actual WWT of each calf was then determined via back calculations of Equation (6.37) and Equation (6.38) using the adjusted  $ME_{\text{Wean}}$  due to differences in milk production of the dam ( $ME_{\text{lact}}'$ ) and pasture availability for the calf ( $ME_{\text{Pasture}}'$ ).

### **6.3.7 Module 6: Management strategies**

This module describes the decision rules of the farmer in terms of management strategies as a response to herd replacements, climatic conditions and feed availability.

#### *Culling policy*

Aged and cull cows were removed from the herd at weaning of the calf. Culling decisions were based on management decisions including involuntary and voluntary culls.

The primary reasons for culling of cows were due to failure to conceive or failure to wean a live calf. Cows that were not pregnant at the time of weaning were culled following weaning of their calf. Secondly, animals were culled for age following their 9<sup>th</sup> parity such that no animals older than 10 years of age remained in the herd. An additional 4.6% of animals were chosen randomly from the herd and considered involuntary culls (Thomas, 2008) and this may be due to poor structure (feet, legs or udder) or any reasons for cows leaving the herd other than reproduction, calf death or age.

The annual replacement rate was 20% of the herd (Beef + Lamb New Zealand, 2017f) and voluntary culling was conducted only when the replacement rate was below this percentage after involuntary cull cows had been removed from the herd. Those additional voluntary culls were conducted mainly based on body condition. When cows were below a BCS of 5, animals were removed due to not having sufficient energy reserves required for the start of winter or otherwise were chosen at random from the remaining cows in the breeding herd. If, however, the number of involuntary culls exceeded 20%, additional replacement heifers were purchased to maintain the initial stocking rate.

#### *Supplementation strategy*

Supplementation was not usually offered to the breeding herd. If, however, the BCS of animals was below a defined threshold, supplementation in form of increased pasture allowance was provided to maintain productivity and an acceptable level of BCS for animal welfare reasons. Supplementation was offered to 20% of the herd with the lowest BCS only when 5% of animals in the herd were below a BCS of 4.5. This threshold was chosen to ensure that the average of the herd would not deplete BCS over time. The total amount of supplementation provided was assumed to be 3 kg DM per head with an average energy content of 10 MJ ME/kg DM (Beef + Lamb New Zealand, 2017d).

### 6.3.8 Module 7: Economic outcomes

This module derived the profitability of the breeding herd in terms of feed and replacement costs and revenue from weaned calves and cull cows. The primary outcomes were based on the total number and weight of calves weaned and replacements needed to maintain the size of the breeding herd. The economic inputs included basic price reference components of revenue and expenditure, considering the only cost components assumed were feed and replacement costs.

#### *Revenue stream*

At calf weaning cull cows as well as weaner calves were removed from the breeding herd and sold. Cull cows were valued on a \$/kg LWT basis at the day of sales which was assumed to be weaning day. Weaner calf prices were derived from sales reports from a central North Island saleyard and valued based on \$/kg WWT at the day of weaning, independent of sex and age of the calf (Table 6.6).

**Table 6.6** Prices for sold cattle and for herd replacements.

	Unit	Value	Reference
Weaner calf price <sup>1</sup>	\$/kg LWT	3.40	Interest New Zealand (2022b); Interest New Zealand (2022c)
Cull cow price	\$/kg LWT	2.25 <sup>2</sup>	Interest New Zealand (2022a)

<sup>1</sup>Assumed to be sold to another farmer for finishing; average price for male and female calves.

<sup>2</sup>Assuming a dressing out percentage of 50%.

#### *Cost components*

##### *Feed costs*

The pasture availability on farm and effectively the actual feed eaten by the cow herd was assumed to be a fixed cost such that the cost of pasture itself was not included in the analysis. The only feed cost considered were those for supplementation and pasture intake of the calf from birth until weaning which was evaluated separately to the pasture supply provided to the cow herd.

Supplementation was realised through increased pasture allowance. The total value of pasture was assumed to vary throughout the year due to availability (Table 6.7) and was highest in July (Beef + Lamb New Zealand, 2017e). Supplementation of the herd is

generally required over winter when the value of pasture is at its highest. Thus, the cost of supplementation was equivalent to the value of pasture at the most expensive time of the production year, multiplied with an average pasture price of \$0.10/kg DM (Beef + Lamb New Zealand, 2020) to derive a fixed price of \$0.53/kg DM, and this was independent of the month the supplementation was required.

**Table 6.7** Monthly feed value and supplement feed price (\$/kg DM) for North Island hill country pasture (Litherland & Lambert, 2007, Beef + Lamb New Zealand, 2017f, Beef + Lamb New Zealand, 2020).

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Feed value <sup>1</sup>	0.7	1.0	1.1	0.9	1.0	2.6	5.3	3.3	1.4	0.8	0.6	0.6
Supplement price	0.53	0.53	0.53	0.53	0.53	0.53	0.53	0.53	0.53	0.53	0.53	0.53

<sup>1</sup>Relative value of pasture dry matter per month (annual average daily growth divided by average daily growth in each month; Beef + Lamb New Zealand, 2017f).

The pasture used by the calves until weaning was accounted for separately to feed consumed by the cow herd and valued at an average feed value over the lactation period from birth to weaning (Table 6.7) and assuming an average pasture price of \$0.10/kg DM (Beef + Lamb New Zealand, 2020). Calculating the pasture cost in relation to the calf excluded the first 30 days of a calf's life as animals were assumed to have only minimal pasture intake at that time with feed requirements primarily satisfied through milk supply of the dam.

#### Herd replacements

The model did not simulate a self-replacing herd. Instead, weaner calves were sold at weaning and the value of herd replacements was determined as the opportunity cost of the animal being sold at weaning and the amount of pasture ME required to raise heifers from weaning until the time animals entered the breeding herd. For each replacement heifer entering the breeding herd, a WWT was calculated aligning with Equation (6.35) outlined in Module 5. The  $LWT_{\text{wean}}$  of each heifer at weaning was used to determine the amount of ME required for maintenance and growth of each animal according to the number of days between weaning and the day heifers entered the breeding herd ( $\text{Age}_{\text{days}}$ ):

$$\begin{aligned} \text{ME}_{\text{wean}} = k_m \times (\text{Age}_{\text{days}} \times \left( \text{WWT} + \frac{\text{LWT}_{\text{repl}} - \text{WWT}}{2} \right))^{0.75} \\ + 40 \times (\text{LWT}_{\text{wean}} - \text{WWT}) \end{aligned} \quad (6.40)$$

Similar to pasture costs calculated for calves until weaning, the total ME consumed by replacement heifers was valued based on the average pasture value from weaning until the day replacements entered the breeding herd (Table 6.7) and multiplied with an average pasture price of \$0.10/kg DM (Beef + Lamb New Zealand, 2020).

The total cost of each replacement was determined based on its WWT and corresponding value at weaning, the feed costs associated with maintenance and growth from weaning until heifers would enter the breeding herd and an additional premium of \$100 was added due to heifers being in calf when joining the breeding herd.

#### *Gross margin*

The model adjusts economic values to a steady state system by putting a value on the difference in LWT at the start and end of each year ( $\Delta\text{LWT}_{\text{year}}$ ). Thus, if on average cows lost or gained LWT over the year, this was assumed to affect the reference price ( $\text{Weight}_{\text{adj}}$ ) of the animal as follows:

$$\text{Weight}_{\text{adj}} = \Delta\text{LWT}_{\text{year}} \times \text{herd size} \times \text{Rev}_{\text{Culls}} \quad (6.41)$$

where  $\text{Rev}_{\text{Culls}}$  was the cull cow price per kg LWT as outlined in Table 6.6.

The gross margin (GM, i.e. profitability) of the cow-calf production system was then valued based on expenditure (Exp), revenue (Rev) and the live weight adjustment as follows:

$$\text{GM} = \text{Rev} - \text{Exp} + \text{Weight}_{\text{adj}} \quad (6.42)$$

### **6.3.9 Application of the simulation model**

To demonstrate the application of the simulation a reference herd size of 200 cows was assumed based on which the feed allocated to the cow herd was calculated (see Module 2). For the purpose of demonstrating the model, two feeding scenarios were considered in this chapter, one of which assumed a consistent amount of pasture allocated to the cow herd across years (SD=0; **Scenario C**) and a second one where variable pasture allowance was accounted for across years with the corresponding SD according to Figure 6.2 (SD≠0; **Scenario V**).

A total of 50 replicates were simulated for each model scenario, each for a period of six years. The first year was regarded as a burn-in period and, thus, discarded from the final analysis. Key results were extracted from the model for each replicate, and results were averaged across replicates to determine average herd performance and profitability parameters.

To ensure scenarios that were consistent with farming practices, it was required that the average BCS of the cow herd would neither increase nor deplete across multiple years. The model itself has built in mechanisms that ensure the feasibility of the system such that a constant BCS over time was realised. The upper limit of BCS was driven by the VFI of cows which was lower for animals with higher body energy reserves compared to low conditioned cows, whereas supplementation was provided in situations where the average herd BCS dropped below a certain threshold, and this was reflected in the gross margin. The reference herd size was used as a starting point and increased or decreased in increments of five cows ensuring that BCS neither decreased nor increased over time, respectively, indicating that the stocking rate was infeasible. A stocking rate where the average herd BCS dropped below a threshold of 4 over winter was considered unsuitable with potential welfare implications (Hickson *et al.*, 2017). Within the feasible stocking rate, the stocking rate that generated the greatest profit was selected as the most appropriate for each feeding scenario. This stocking rate was used for comparison among feeding scenarios.

### *Statistical analysis*

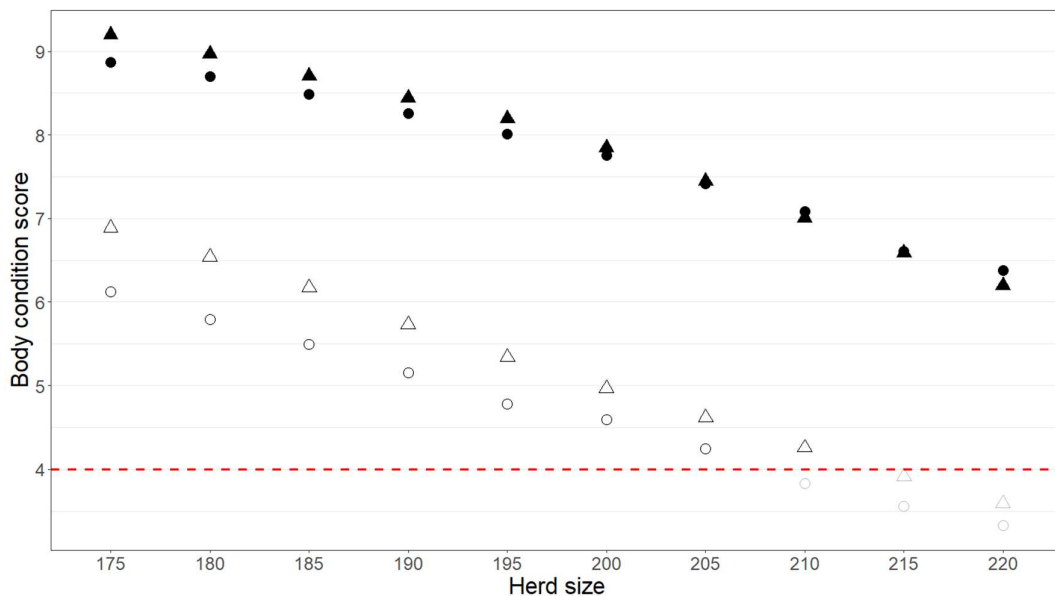
To compare the significance of performance and profitability parameters between the different feed availability scenarios, linear regression models were fitted with the feeding system (Scenario C vs Scenario V) as a factor in the model and using analyses of variance (ANOVA; F-statistic on type-III sums of squares). Least-square means were calculated from the model to compare outcomes for each scenario.

## 6.4 Results

Through replicates the model creates a large number of outputs such that the results will focus on describing the most relevant outcomes to demonstrate the validity of the model results. Annual production parameters, LWT and BCS profiles, cull cow and replacement numbers, weaner calf crop and profitability parameters are outlined and discussed in the following paragraphs.

### 6.4.1 Herd size

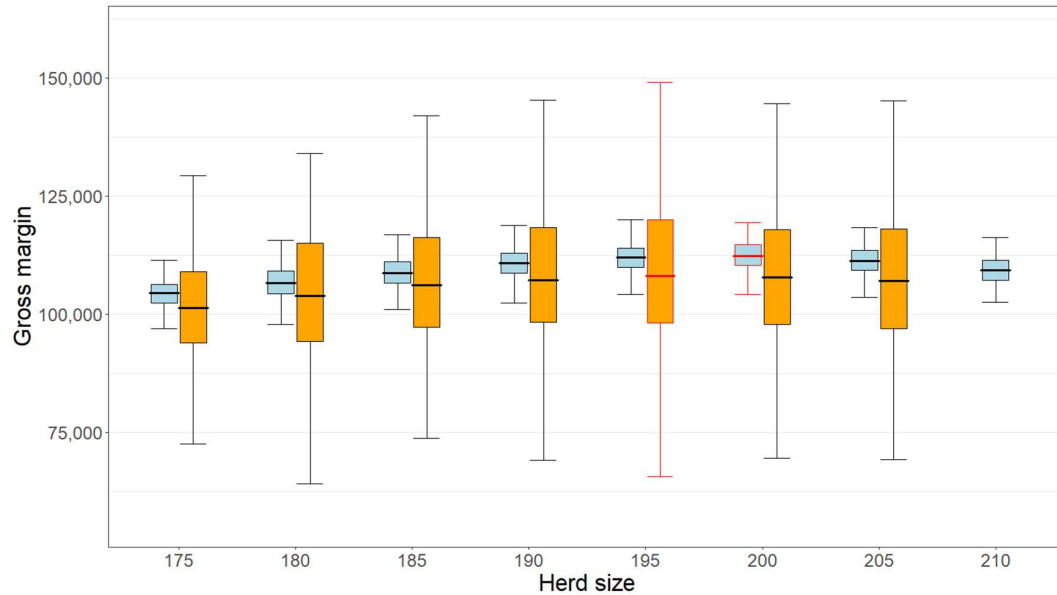
A range of herd sizes were considered to determine the most suitable stocking rate for each scenario. Figure 6.7 displays the minimum and maximum annual BCS for each herd size under consideration, averaged across five years and 50 model replicates for both systems. The lower the herd size the higher was the BCS on average whereas BCS decreased with an increase in herd size. Overall, the range in BCS was larger for Scenario V compared to Scenario C and increased with increasing herd size.



**Figure 6.7** Minimum (no fill) and maximum (filled) herd mean body condition score for each herd size, averaged across years and model replicates for Scenario C (triangle) and Scenario V (dot); dashed line=lower herd body condition score threshold below which potential implications in terms of welfare may occur.

The gross margin for Scenario C and Scenario V across years and model replicates is outlined in Figure 6.8. A total of 195 and 200 animals were considered most suitable

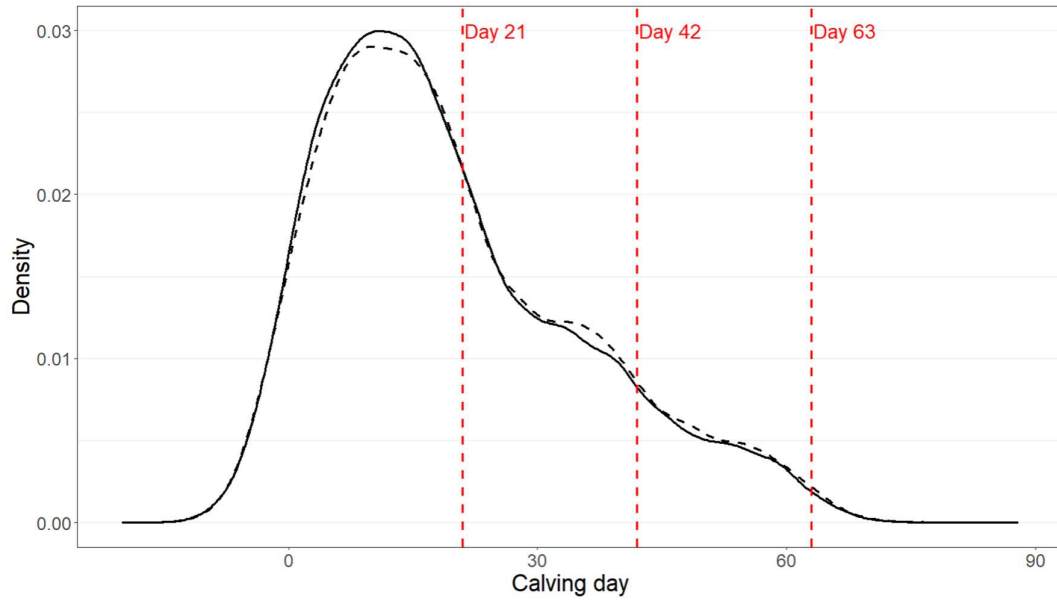
for the variable and the consistent feeding system, respectively, based on the criteria outlined in the 'Material and methods' section such that these were used as the stocking rates for further analysis. At each stocking rate, Scenario V showed a considerable larger confidence interval compared to Scenario C.



**Figure 6.8** Gross margin for Scenario C (blue) and Scenario V (orange) for different herd sizes considered in the analysis; the stocking rate highlighted in red was considered the most profitable for each scenario; box = inter-quantile range; error bars = 95% confidence interval.

### 6.4.2 Annual production cycle

The model produced production outcomes typical for central North Island commercial hill country farming conditions in New Zealand. The model started with the calving season in spring. Averaged across five years, the calving spread for both model scenarios is displayed in Figure 6.9. A total of 63.0% and 61.7% of calves were born within the first 21 days from the planned start of calving for Scenario C and Scenario V, respectively.



**Figure 6.9** Calving spread for Scenario C (solid line) and Scenario V (dashed line).

Key parameters that reflect the reproductive performance of the breeding herd are summarised in Table 6.8. Compared to Scenario C, cows in Scenario V had an on average four day longer PPAI, conceived approximately one day later and had a 1.2% lower pregnancy rate. The SD indicated overall higher variability of the reproductive performance of the herd for Scenario V compared to Scenario C.

**Table 6.8** Least-square means (lsmean) and standard deviation (SD) of key reproductive performance parameters for a beef cow herd under consistent (Scenario C) and variable (Scenario V) annual feed supply, averaged across a five-year production period and 50 model replicates.

Parameter	Unit	Scenario C		Scenario V		Significance
		lsmean	SD	lsmean	SD	
Postpartum anoestrus interval	Days	32.7	12.0	36.5	18.1	P<0.05
Days to conception	Days	19.2	15.0	19.7	15.3	P<0.05
Pregnancy rate	%	94.0	1.6	92.8	3.7	P<0.05
Gestation length	Days	281.2	10.3	281.0	13.1	P<0.05
First-calvers	%	21.4	1.8	22.0	3.2	P<0.05

### 6.4.3 Cow live weight and body condition score

Least-square means for LWT and BCS across years and model replicates were predicted from the model to compare outcomes with the LWT and BCS profiles of Farm B from Chapter 2 on which the feed system was based. Table 6.9 shows the results from the simulated LWT and resulting BCS performance in the model to compare within-year fluctuations for both scenarios at three different time points: prior to mating (defined at two weeks prior to the start of mating to align with the time LWT and BCS was recorded on Farm B from Chapter 2), at weaning (at the actual weaning day) and prior to calving (two weeks prior to the start of calving).

**Table 6.9** Least-square means ( $\pm$  standard deviation) for simulated live weight (LWT; kg) and body condition score (BCS; score 1-10) fluctuations within-year compared to least-square means for Farm B from Chapter 2 for a beef cow herd under consistent (Scenario C) and variable (Scenario V) annual feed supply, averaged across individuals, a five-year production period and 50 model replicates.

	Herd size	Mating		Weaning		Calving	
		LWT	BCS	LWT	BCS	LWT	BCS
Farm B		576.2	7.6	559.2	7.0	511.7	5.7
Scenario C	200	579.2 ( $\pm$ 59.6)	7.8 ( $\pm$ 0.7)	567.6 ( $\pm$ 59.7)	7.2 ( $\pm$ 0.9)	512.5 ( $\pm$ 57.8)	5.7 ( $\pm$ 0.5)
Scenario V	195	573.9 ( $\pm$ 62.1)	7.6 ( $\pm$ 0.9)	569.6 ( $\pm$ 62.5)	7.2 ( $\pm$ 1.1)	510.0 ( $\pm$ 64.4)	5.6 ( $\pm$ 1.0)
Significance		P<0.05	P<0.05	P<0.05	P<0.05	P<0.05	P<0.05

Live weight and BCS were significantly ( $P < 0.05$ ) different between both scenarios. The LWT and BCS values were always lowest at calving time, and this aligns with the least-square estimates for the original cow herd on Farm B. However, the SD indicated a larger variability for both LWT and BCS profiles for the cow herd with a variable (Scenario V) compared to the cow herd with a consistent (Scenario C) annual feed supply and the difference in SD was generally more prominent at calving time.

### 6.4.4 Weaning time

#### *Calf performance*

Energy intake, birth weight and actual WWT of the calves were significantly ( $P < 0.05$ ) different between model scenarios (Table 6.10). Calves gained LWT at a rate of 1.0 kg a day to reach WWT at approximately 154 days of age at 180.5 kg and 178.0 kg for

Scenario C and Scenario V, respectively. Energy intake for growth was obtained predominantly through milk intake and secondly through pasture consumption.

**Table 6.10** Least-square means (lsmean) and standard deviations (SD) of average performance parameters of the calf crop until weaning, including energy required for maintenance and live weight gain and growth traits from birth to weaning, for a beef cow herd under consistent (Scenario C) and variable (Scenario V) annual feed supply across multiple years and model replicates.

Parameter	Unit	Scenario C		Scenario V		Significance
		lsmean	SD	lsmean	SD	
<b>Energy intake - birth until weaning</b>						
Mean daily pasture intake <sup>1</sup>	MJ ME	13.0	6.2	13.2	6.3	P<0.05
Mean daily milk intake	MJ ME	24.6	5.6	24.1	5.5	P<0.05
<b>Weaning time</b>						
Birth weight	kg	35.3	5.6	35.0	5.9	P<0.05
Live weight gain <sup>2</sup>	kg/day	1.0	0.2	1.0	0.2	n.s.
Weaning weight <sup>3</sup>	kg	180.5	29.8	178.0	30.4	P<0.05
200-day weight <sup>4</sup>	kg	227.0	34.2	226.7	34.2	n.s.

<sup>1</sup>Excluding the first 30 days where no pasture intake was assumed.

<sup>2</sup>Daily live weight gain from birth to weaning.

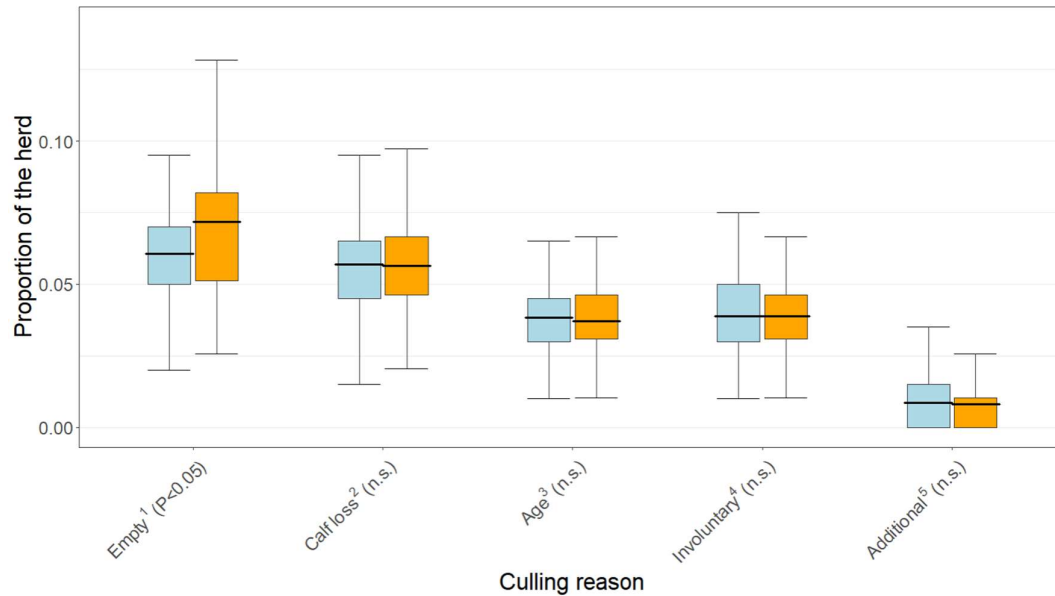
<sup>3</sup>Calf weaning weights at weaning day at approximately 153 days of age.

<sup>4</sup>Calf weaning weights at 200 days of age (aligning with BREEDPLAN EBV).

n.s.=not significant

### *Culling policy*

At weaning time cull cows were removed and replacement animals introduced to the breeding herd to maintain the herd size. Reasons for culling were based on management strategies allowing for voluntary and involuntary culls and those may be due to reproductive performance of the animal, calf loss until weaning or any reason other than production. Compared to Scenario C, Scenario V showed an on average significantly ( $P < 0.05$ ) higher empty rate of cows with larger variability across replicates (Figure 6.10) whereas all other reasons for culling were similar for both scenarios.



**Figure 6.10** Reasons for culling of beef breeding cows at weaning under a consistent (Scenario C; blue) and variable (Scenario V; orange) annual feed supply; box = inter-quartile range; error bars = 95% confidence interval; n.s. = not significant; <sup>1</sup>cows that failed to conceive during the mating season; <sup>2</sup>failure to wean a live calf due to perinatal calf loss or calves lost between birth and weaning; <sup>3</sup>cows older than 10 years of age; <sup>4</sup>cows leaving the herd for reasons other than reproduction, calf loss and age; <sup>5</sup>additional cows culled to maintain an annual replacement rate of 20% of the herd.

#### 6.4.5 Profitability of the cow-calf production system

The profitability of the cow herd for each scenario was determined based on revenue and expenditure and accounting for the average LWT change of cows at the start and end of each production year to determine the gross margin for the cow-calf production system and outcomes are shown in Table 6.11. Total expenses were significantly ( $P < 0.05$ ) different across scenarios, resulting in a significantly ( $P < 0.05$ ) lower total gross margin for Scenario V.

**Table 6.11** Least-square means (lsmean) and corresponding standard deviations (SD) for economic values derived from the simulation model for a cow herd under consistent (Scenario C) or variable (Scenario V) annual feed supply.

Parameter	Unit	Scenario C		Scenario V		Significance
		lsmean	SD	lsmean	SD	
<b>Biology</b>						
Herd size	Count	200		195		
Weaning percentage <sup>1</sup>	%	94.3	1.7	94.4	1.7	n.s.
Culling percentage	%	19.4	1.8	20.3	3.3	P<0.05
Pasture intake cow	MJ ME/cow/year	39,294.1	85.5	39,320.2	1,755.7	n.s.
Supplements	MJ ME/cow/year	209.8	32.5	252.9	254.1	P<0.05
Pasture intake calf	MJ ME/calf/year	1,617.0	813.4	1,631.0	823.4	P<0.05
<b>Economics</b>						
Cull cow revenue	\$/head	1,285.1	22.8	1,289.3	50.1	n.s.
Replacement cost	\$/head	1,081.7	15.5	1,081.5	19.0	n.s.
<b>Revenue</b>						
Weaning value <sup>2</sup>	\$/cow/year	567.0	12.4	558.8	25.0	P<0.05
Cull cow value <sup>2</sup>	\$/cow/year	249.4	23.8	261.0	39.8	P<0.05
Revenue <sup>2</sup>	\$/cow/year	816.4	22.2	819.9	45.7	n.s.
<b>Expenses</b>						
Supplement costs <sup>2</sup>	\$/cow/year	11.0	1.7	13.6	13.6	P<0.05
Weaning feed costs <sup>2</sup>	\$/cow/year	12.9	0.4	13.0	1.0	n.s.
Replacement costs <sup>2</sup>	\$/cow/year	230.5	18.0	239.4	35.0	P<0.05
Expenditure <sup>2</sup>	\$/cow/year	254.4	17.9	266.0	41.1	P<0.05
<b>Weight adjustments<sup>4</sup></b>						
Weight adjustment <sup>2</sup>	\$/cow/year	-0.4	5.9	0.7	72.6	n.s.
<b>Gross margin</b>						
Gross margin <sup>2</sup>	\$/cow/year	561.6	16.4	554.6	87.9	n.s.
Total gross margin <sup>3</sup>	\$/herd/year	112,325.5	3,283.1	108,148.6	17,148.8	P<0.05

n.s. = not significant (P&gt;0.05)

<sup>1</sup>Number of calves weaned per cows wintered.<sup>2</sup>Average value per cow in the herd.<sup>3</sup>Average value of the herd.<sup>4</sup>Parameter used to adjust economic values for the difference in average live weight of cows at the start and end of each year.

## 6.5 Discussion

### 6.5.1 Validity of model results

#### *Annual production cycle*

The model simulated annual cow-calf production for a central North Island hill country farm where beef breeding cows are calved in spring. The calving spread generally reflects the duration of the mating season (Wiltbank, 1970, Mossman & Hanly, 1977). According to Beef + Lamb New Zealand (2017i) and Mossman & Hanly (1977) at least 60% of mature beef cows calving within the first 21 days of the calving season should be a production target. This was realised in the current model where 61.7–63.0% of cows calved within the first three weeks from the planned start of calving (282 days after start of mating) for both scenarios (Figure 6.9).

At the initiation of mating, cows in higher BCS were more likely to conceive (refer to Chapter 3, Selk *et al.*, 1988, Morris *et al.*, 2006, Renquist *et al.*, 2006) such that the pregnancy rate increased with increasing BCS of the herd. In the current study an average pregnancy rate of 92.8–94.0% was achieved for mature beef cows and this was slightly above the 90% pregnancy rate presented by McFadden *et al.* (2005) for mature beef cows in New Zealand following a 63-day mating season. Outcomes from the current study only reflected the pregnancy rate of mature beef cows as replacement animals were entering the herd as in-calf 18-month-old heifers. Accounting for the conception rate of heifers would likely result in reduced pregnancy outcomes due to generally lower in-calf rates from heifer matings compared to mature cows (Morris *et al.*, 2000).

At weaning time, cull cows were removed from the herd and replacement heifers introduced to maintain the same herd size across years. The proportion of cows culled due to failure to conceive or wean a live calf ranged from 6.1–7.2% and 5.6–5.7%, respectively, between years in the current study and this was consistent with hill country systems in New Zealand (Morris *et al.*, 1986, Beef + Lamb New Zealand, 2017a). The total number of herd replacements required was primarily dependent on the proportion of empty cows in the breeding herd and was higher in years where feed supply was below average.

### *Calf performance*

The BWT of calves in the current study generally agreed with results from previous research for the New Zealand Angus breed (Meyer, 1995a, Tait *et al.*, 2017). Following birth, the target pre-weaning live weight gain for beef breed calves is approximately 1.0 kg per day (Morris, 2013a, Morris & Kenyon, 2014), however, this is rarely achieved under extensive hill country conditions. The live weight gain of 1.0 kg per day in the current model aligned with the industry target and was similar compared to the average daily gain from birth to weaning of 0.97 kg/day presented by Hickson *et al.* (2014) for purebred Angus calves.

Calves were weaned at approximately 154 days of age, and this aligned with management practices on Farm B from Chapter 2 which was used as the reference farm for this simulation. The average WWT of calves at that time ranged from 178.0 to 180.5 kg ( $\pm$  29.8 and 30.4 kg) and those were consistent with literature values when calves were weaned at a similar age and pre-weaning live weight gain (Morris *et al.*, 2006, Beef + Lamb New Zealand, 2017a, Tait *et al.*, 2017). The weaning percentage (number of calves weaned per cows wintered) for mature cows in the current model ranged from 94.3–94.4% for both feeding systems, which was slightly above the reproduction target outlined by Beef + Lamb New Zealand (2017i) of at least 90% in adult cows.

### *Simulated live weight and body condition score profiles*

Live weight and BCS profiles showed significant variation within years across measured time points and fluctuations throughout the annual production cycle have been described by several researchers for New Zealand hill country farming systems (Pleasant *et al.*, 1994, Morris *et al.*, 2006, Muir & Thomson, 2011). Under seasonal calving conditions cows are used for pasture management (McCall, 1994) where animals are required to accumulate body energy reserves in times of surplus feed such that the stored energy reserves can then be mobilised when feed is in short supply (Pleasant *et al.*, 1994) resulting in LWT and BCS fluctuations across the year.

Following weaning and until approximately two months prior to calving, cows are generally used as a nutritional buffer throughout times of feed shortage so as to overcome feed deficits over winter by mobilising stored energy reserves (Pleasant *et al.*, 1991, McCall, 1994, Pleasant *et al.*, 1994). As a result, cows are usually at their lowest LWT and BCS during this time (Chapter 2, Morris, 2007) and this has been

demonstrated in the current model with a range of 510.0–512.5 kg and 5.6–5.7, respectively, across both scenarios. This is within the range of values presented in the literature where the LWT of cows ranged from 505–511 kg and BCS from 5.2–5.3 (Morris *et al.*, 2006, Law *et al.*, 2013, Hickson *et al.*, 2017, Tait *et al.*, 2017). The aim is to ensure cows are in a sufficiently high BCS of preferably 7 or higher prior to mating (Chapter 3, Hickson *et al.*, 2017) to optimise the reproductive performance of the herd. In the current study, the average herd BCS ranged from 7.6 ( $\pm 0.9$ ) to 7.8 ( $\pm 0.7$ ) prior to mating and this was similar to or above the industry target (Hickson *et al.*, 2017) and literature values (Law *et al.*, 2013, Tait *et al.*, 2017). Throughout the mating season and up until weaning cows are generally able to retain body energy reserves, however, this may be subject to environmental conditions such as droughts throughout summer or management strategies on farm which can lead to BCS loss in some years (Morris *et al.*, 2006, Hickson *et al.*, 2017). The simulated LWT and BCS within the model were generally highest at mating time and decreased through to weaning, likely reflecting management strategies and variable environmental conditions on Farm B as the reference herd (refer to Chapter 2). Similarly, Morris *et al.* (2006) and Law *et al.* (2013) reported overall lower BCS at weaning compared to mating. However, taking the SD of both traits into account indicated that in some years nutritional resources were above average such that cows were heavier and in higher condition around weaning time compared to the period leading up to mating.

Comparing the results with outcomes for Farm B as the reference Central North Island herd from Chapter 2 indicated similar profiles across annual production points. Especially outcomes for Scenario C where the stocking rate aligned with the reference herd size of 200 cows which was used to derive the feed that was allocated to the cow herd closely match the LWT and BCS profiles of Farm B for the measured production events calving, mating and weaning (Table 6.9). The close match of simulated LWT and BCS profiles with both literature values and outcomes from Chapter 2, indicate that the model provides a good representation of LWT and BCS fluctuations and may be used to model scenarios under real life conditions.

### **6.5.2 Comparison consistent vs variable annual feed supply**

#### *Stocking rate*

The decrease in BCS with increasing stocking rate was consistent with previous studies in dairy (Roche *et al.*, 2007a, Macdonald *et al.*, 2008) and beef cows (Long *et al.*, 1975,

Doye & Lalman, 2011, Beck *et al.*, 2016) and can be explained by cows having a lower per-cow feed allowance when more cows are present for the same total feed allowance. Results indicated that the appropriate stocking rate under a variable feed supply was slightly lower compared to the consistent scenario which aligned with the reference herd size based on which the feed allocated to the cow herd was calculated. A more conservative approach in terms of adjustments in stocking rate provides an opportunity to respond to variable feed resources within the farming system (Beef + Lamb New Zealand, 2017e) and this has been demonstrated in the current model.

It needs to be considered that for all herd sizes included in the initial calculations, the consistent scenario always resulted in a higher gross margin compared to the variable system. Ultimately, given the absolute values for the gross margin for both scenarios while also taking the SD into account indicated that under real life conditions small changes in the herd size may not have a considerable impact on the profitability of the system.

#### *Performance parameters*

Generally, results have shown that Scenario C and Scenario V were similar for most traits considered in the simulation. Variable feeding, however, affected the amount of supplementation provided to the cow herd more than any other trait. The amount of supplementation required under variable feed supply was overall higher compared to the consistent environment. Due to the supplementation strategy differences in LWT and BCS performance of cows were likely smaller compared to systems where no supplementation was provided. There is a cost associated with losing and regaining condition in terms of energy required for production (Nicol & Brookes, 2007), such that the same level of performance may not be achieved when cows need to respond to nutritional fluctuations in feed supply compared to animals that are kept on the same amount of pasture across annual production cycles in situations where no additional feed was provided to overcome those times of feed shortage. The requirement of the model to supplement low-conditioned cows and BCS as the main driver of reproductive performance of the herd meant that the pregnancy rate of cows, WWT of calves and reasons for culling did not deviate too far from the consistent environment. Thus, a much more prominent impact on the performance of the cow-calf herd might be expected if no supplementation would have been provided to the lowest conditioned proportion of the herd.

The main differences between the consistent and variable feeding system in terms of BCS were visible when feed was in short supply. While the upper limit of BCS was similar for both scenarios, cows in the variable scenario tended to lose more condition in times of feed shortage, thus had an overall lower BCS limit (Figure 6.7), irrespective of higher proportion of supplementation provided to the herd compared to the cow herd under a consistent feed supply. Research in dairy cows has demonstrated similar outcomes where cows under a more controlled environment fed with a total mixed ration lost a smaller proportion of their body energy reserves compared to grazing cows (Washburn *et al.*, 2002, Roche *et al.*, 2007a). Although supplementation was provided as part of the model, this was only realised for the lowest 20 percent of the herd and may not be sufficient when considerable overstocking occurred under a variable environment.

Supplementation is rare under New Zealand hill country conditions for the cow herd and is merely provided to retain an acceptable level of production to overcome feed deficits over winter or throughout droughts (McCall & Scott, 1988, De Ruiter *et al.*, 2007, Morris, 2013b). Although supplementation was provided to the lowest-conditioned 20 percent of cows in the herd, the reproductive performance of cows under a variable feed supply was slightly inferior compared to the cow herd under a consistent environment highlighting the impact of a year with low feed availability on the reproductive performance of the herd. Overall, cows in Scenario C were more likely to get in calf early in the breeding season and this may also be due to the shorter PPAI (Table 6.8). The higher pregnancy rate may be attributable to the fact that cows generally require less energy to regain sufficient body energy reserves following winter when managed in a consistent way compared to systems where animals need to respond to more variable environmental conditions. The model accounted for the relationship between BCS and pregnancy rate which entailed a downside risk where cows in below-target BCS of 7 at mating time (Chapter 3, Hickson *et al.*, 2017) were more likely to be empty whereas the upside risk was only limited such that the occurrence of a good year resulting in above-target BCS of cows did not translate into more pregnancies. The differences between both model scenarios on the reproductive performance of the herd were, however, small and may be compensated through appropriate management strategies where supplementation is provided to meet the nutritional requirements of the animals and through adjustments in stocking rate.

### *Economic outcomes*

Economic price references in the current study accounted for revenue from sales of cull cows and weaner calves and expenditure in terms of supplementation provided to the cow herd, pasture feed costs for the calves from birth until weaning and purchase of replacement heifers to retain a constant herd size across years.

The amount of supplementation required and the productivity of the herd as a response to LWT and BCS fluctuations were the primary factors determining the difference between consistent and variable feed supply, resulting in a significantly higher gross margin for cows under a consistent environment compared to those under a variable feed supply. Evaluating cow performance under a consistent feed supply may, therefore, be likely to overestimate the long-term profitability of the cow-calf system. Although the absolute value for the gross margin of Scenario V was not considerably lower compared to Scenario C, the much larger SD indicated that this outcome was not consistent across years and/or model replicates. Thus, while some years may be more profitable on average, Scenario V also accounted for the risk associated with the occurrence of adverse events during the annual production cycle where cows may not be able to reach their optimum production potential without providing an adequate level of supplementation to overcome feed deficits. Risk is a factor that is present in day-to-day farming practices and should be accounted for when aiming to model farming systems that closely reflect reality. A variable feed supply tends to better reflect reality where breeding cows may be required to sustain production when feed supply is restricted (Pleasant *et al.*, 1991, Pleasant *et al.*, 1994), sometimes over extended periods. Accounting for the variability in feed supply allows the possibility of risk associated with New Zealand hill country farming systems to be evaluated while demonstrating the impact of fluctuations in nutritional resources on the ability of cows to retain a desirable level of production. A consistent environment across years is not an adequate representation of reality, especially under New Zealand hill country conditions and merely provides a simplified version of real-life conditions. Thus, across-year variation should best be included as a factor when evaluating the profitability of beef breeding cows under New Zealand farming systems.

### ***6.5.3 Limitations of the simulation model***

The aim of this model was to examine the impact of variability in feed supply on the profitability of the cow-calf production system. Results have shown that the simulated

performance within the model is representative of real-life conditions under hill country farming systems in New Zealand. However, some additional questions may be considered for future research.

The current model did not account for adjustments in stocking rate across years as a response to annual production. Instead, the herd size was kept constant across years and future research may consider adjusting the stocking rate on an annual basis to better align the available feed resources with the nutritional requirements of the herd (Beef + Lamb New Zealand, 2017g) over multiple cycles.

The VFI of cows has been accounted for in the current model which was driving the upper limit of feed consumed by the cow. The VFI of cows is driven by multiple factors such as rumen capacity (physical limit), metabolisable energy (metabolical limit) and pasture quality and quantity (Ingvarlsen, 1994, Freer *et al.*, 2007). Most factors that determine total intake interact with each other and should best be accounted for when evaluating the impact on pasture intake of each individual. However, the multitude of effects controlling actual intake contribute to the complex nature of the trait such that several approaches may exist to address the research question under consideration (Forbes, 2003). For the purpose of this study, a more simplistic approach was taken where VFI was controlled primarily by the upper limit of BCS and rate of maturity of the animals. Especially in times of feed deficit the actual intake of cows is likely impacted by changes in MWT, BCS or other key production parameters. It may be considered that cows in low BCS have a higher drive to eat compared to obese cows, resulting in a greater VFI. Furthermore, VFI may be compromised, particularly under a variable environment, due to overall lower pasture cover and, consequently, reduced intake efficiency and increased locomotion and grazing activity, and this may likely vary with other parameters such as sward height. As opposed to this in months where pasture growth surpasses the intake capacity of the herd, a deterioration in ME is likely to occur. The current model accounted for typical fluctuations in ME throughout the annual production cycle as demonstrated by Litherland & Lambert (2007) and Morris & Smeaton (2009). However, no further adjustments have been made due to a above or below average year as a result of the variable environment. No research has been conducted to confirm those assumptions under extensive farming conditions similar to those in New Zealand, such that the current approach was considered appropriate to answer the research question.

Social hierarchy can impact on the grazing distribution (Sowell *et al.*, 1999) and, thus, the feed intake of the individual and is of relevance especially when cows are competing for available feed resources (Ingrand, 2000, Hubbard *et al.*, 2021). Larger, older cows may be less likely to miss out on feed in a feed shortage situation and this may be attributable to the social dominance of older animals (Hubbard *et al.*, 2021). However, the current model did not include social hierarchy as a parameter in the simulation and this was primarily due to the limited information and lack of knowledge on beef cow behaviour under New Zealand hill country farming conditions. To the authors knowledge, no evidence was available from the literature under comparable farming systems where stocking rates are generally low, and cows are required to occasionally cover large distances to access suitable feed resources. A more detailed understanding of the social factors influencing grazing behaviour would be required to be incorporated as a factor in the model simulation (Sowell *et al.*, 1999).

The current model did not include seasonal variation in calving spread of first calving heifers. The variation in calving dates of herd replacements followed the same distribution across years, however, a larger variance or later average calving dates may be expected if animals were in lower condition at the preceding mating season. Future research may consider accounting for the impact of BCS in the period leading up to mating on subsequent calving dates in first-calving heifers. This was, however, not applicable within the current simulation model due to insufficient knowledge about this relationship.

Common farm practices often draft off low conditioned cows within the breeding herd for preferential treatment over a certain time period to ensure cows are accumulating sufficient energy reserves for the upcoming mating season (De Ruiter *et al.*, 2007, Morris, 2013b). The model aimed to reflect this approach as closely as possible. It should, however, be considered that the supplementation strategy used within the model may be more efficient than it would likely be the case in real life where body energy reserves would not be evaluated on a daily basis to determine whether cows should re-enter the breeding herd or be kept on supplements for an extended period. Such supplementation strategies are likely associated with additional costs due to labour requirements for yarding, drafting, separating paddocks and feeding mechanisms, however, those have not been accounted for in the current model. Under commercial farming conditions calves are not usually identified to the cow which is

limiting the ability to implement such management strategies between calving and weaning.

Fluctuations in feed costs and cattle prices in response to variable feed supply were not accounted for in the current model. Under real-life conditions there may be considerable volatility in both prices, and this may partly be driven by the available feed resources. This means that in years of high pasture growth, feed prices would likely be below average whereas cattle prices are high, while in years of low pasture availability, feed prices are likely higher than usual, and cattle prices are more likely to drop. Accounting for variable cost components as well as co-variances between costs, prices and production factors might exacerbate the variability in economic outcomes under the variable feeding system. This is likely to lead to greater downside risk rather than upside risk as the lower feed costs in an above average year will not be realised as the cows are unlikely to need supplementary feed. Knowledge of the interrelationships between feed availability, beef price and supplement price is, however, limited such that future research may consider further exploring these interactions.

### **6.6 Conclusions**

This chapter examined the impact of variability in feed supply on the performance and profitability of cows of defined genotype compared to a beef cow herd under a consistent feeding system. The model created closely matched simulated performance to performance observed within a central North Island hill country farming system. Outcomes from the model have demonstrated that including variability in the simulation has the potential to closely reflect real-life conditions of a cow herd and this was significantly different compared to a cow herd managed under a consistent feed supply. Accounting for variability can be a useful tool to determine the impact of risk associated with the flexible role beef breeding cows provide to the sector in terms of accumulation of body energy reserves in times of surplus feed and mobilisation of BCS when feed is in short supply. Evaluating the profitability of cows under a consistent feed availability scenario is likely to overestimate the performance and profitability of the herd such that including fluctuations in feed supply in the model may reflect reality much more closely and this should be considered when developing models under hill country farming systems such as in New Zealand.

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**Chapter 7** – Productivity of beef cow herds of different mature live weight type: a stochastic simulation study

## 7.1 Abstract

Beef breeding cows in New Zealand are usually farmed to complement other livestock enterprises. This is realised through pasture management and the resulting increase in productivity of those other livestock classes. Although larger mature cow size is associated with a heavier calf at weaning and consequently higher return per calf weaned, large cows also require higher energy intake compared to smaller sized cows and this may impact on the performance and profitability of cows within the system. The simulation model developed in Chapter 6 was used to examine the impact of cows of different mature live weight (MWT) type (small vs moderate vs large MWT type) on the performance and resulting profitability of the cow-calf production system when farmed under seasonal pasture supplies that vary from year to year. Results from this study have shown that across the current New Zealand Angus population cows of large MWT type were on average 5.9% and 14.1% more profitable on a per head basis and 3.2% and 5.7% more profitable on a herd level compared to moderate and small MWT types, respectively, provided the stocking rate was adjusted to accommodate the different feed requirements of varying cow sizes. Due to body condition score (BCS) driving the reproductive performance of the herd in the current model, the main differences between cow types were expressed in the amount of supplementation required rather than the production level achieved. The greatest amount of supplementation was required by the larger cow type to retain an acceptable level of BCS across the herd. The impact of MWT on the profitability of the cow-calf production system may be minimal so long as the change in MWT is associated with change in other correlated traits, particularly calf size, and cows are managed according to their nutritional requirements to reduce the number of low conditioned cows in the herd. This would allow for selection on higher weights in finishing animals without the risk of compromising profitability due to a correlated increase in MWT of cows.

## 7.2 Introduction

Beef breeding cows in New Zealand compete for pasture with other livestock classes on farm (Morris, 2013) and are often managed in a way to benefit the performance of other enterprises such as sheep or deer (McCall, 1994). As a result, cows are required to cope with variable feed supply throughout the annual production cycle and across years as a response to climatic conditions and management strategies. Feed allocation to cows is often driven by availability rather than their individual energy requirements (Morris & Hickson, 2016) and this is reflected through their variable live weight (LWT) and body condition score (BCS) profiles. The variability in cow BCS within and across years due to fluctuations in feed availability may impact on the reproductive performance of the herd (refer to Chapter 3) and consequently on the overall profitability of the cow-calf production system as demonstrated in Chapter 6. Extensive pasture-based farming systems require cows to be robust in terms of mobilising or depositing body energy reserves in response to environmental challenges while maintaining production (Pleasant *et al.*, 1991, Pleasant *et al.*, 1994).

Increased selection for growth performance in finishing cattle and imported genetics from overseas (particularly from the United States) has led to an increase in mature live weight (MWT) and size over the last 50 years (Carter, 1975, Morris *et al.*, 1987, Law *et al.*, 2013, Hickson *et al.*, 2014, Morris & Hickson, 2016). The correlation between weight traits in both finishing beef cattle and mature cows (refer to Chapter 5) indicates that farming of larger cow types would be advantageous due to the higher revenue from the carcass at culling (Brinks *et al.*, 1964, Kaps *et al.*, 1999). In spite of that there is a range of 98 kg in MWT estimated breeding values (EBV) from the top to bottom one percentile for 2021 born calves within the New Zealand Angus population (Angus New Zealand, 2022b). Producers often avoid cows with larger MWT that are becoming more prevalent every year due to the belief that these cows are less resilient to variation in feed supply due to overall higher maintenance requirements and feed intake compared to cows with smaller MWT (Smeaton *et al.*, 2000, Arthur *et al.*, 2004, Morris, 2008). Furthermore, research has shown that the weaning weight ratio (WWR; calf weaning weight (WWT) as a proportion of the dams live weight) is likely to decrease with increasing MWT (Dinkel & Brown, 1978, Farrell *et al.*, 2021). The WWR is often a function of milking ability as an increase in milk yield will both increase the WWT of the calf and decrease the LWT of the dam. However, this is not always a desirable scenario if this leads to compromised cow BCS (Arthur *et al.*, 1997, Law *et al.*, 2013).

The optimum MWT is likely to differ for varying production systems, management strategies, environmental conditions and current economic demands. To determine the most suitable cow type for each farming system in respect to their MWT the entire lifetime production cycle of the animal and its interaction with the environment and other correlated traits need to be taken into account. The MWT of an animal is determined by its genotype as well as non-genetic factors that impact on growth through the environment such as climatic conditions, nutritional resources and management strategies (Arango & Van Vleck, 2002), all of which contribute to the profitability of the herd under a given environment. Smeaton *et al.* (2000) suggested the optimum cow for New Zealand hill country farming systems to be a medium framed animal of around 440 kg. The average MWT of cows has increased since then (Chapter 2, Law *et al.*, 2013) and likely production potential also differs. Therefore, it is useful to know how beef cows of different MWT type respond to variability within the farming system and which factors determine whether particular cow types are better equipped to respond to variability in feed supply compared to others and, thus, may be considered more resilient when it comes to coping with environmental challenges within a particular environment (Amer, 2012, Friggens *et al.*, 2017).

In this chapter a stochastic simulation model was used to compare key performance parameters and profitability of small, moderate and large MWT cow types within the New Zealand Angus population in response to variability in feed supply.

## **7.3 Materials and methods**

### ***7.3.1 Simulation model***

A stochastic simulation model was developed to describe the performance of beef cows and their progeny until weaning on a typical New Zealand Central North Island hill country sheep and beef farm (refer to Chapter 6). This model considered the beef breeding herd as a subsystem of the sheep and beef farm. The simulation model was constructed using R version 3.6.1 (R Core Team, 2019) and has been described in detail in Chapter 6 such that this chapter will only include additional information relevant to the functioning of the model in addressing this research question. Model parameters described in Chapter 6 were updated to allow evaluation of cow herds of differing MWT types, and details on the scenarios under consideration are given in the following subsections.

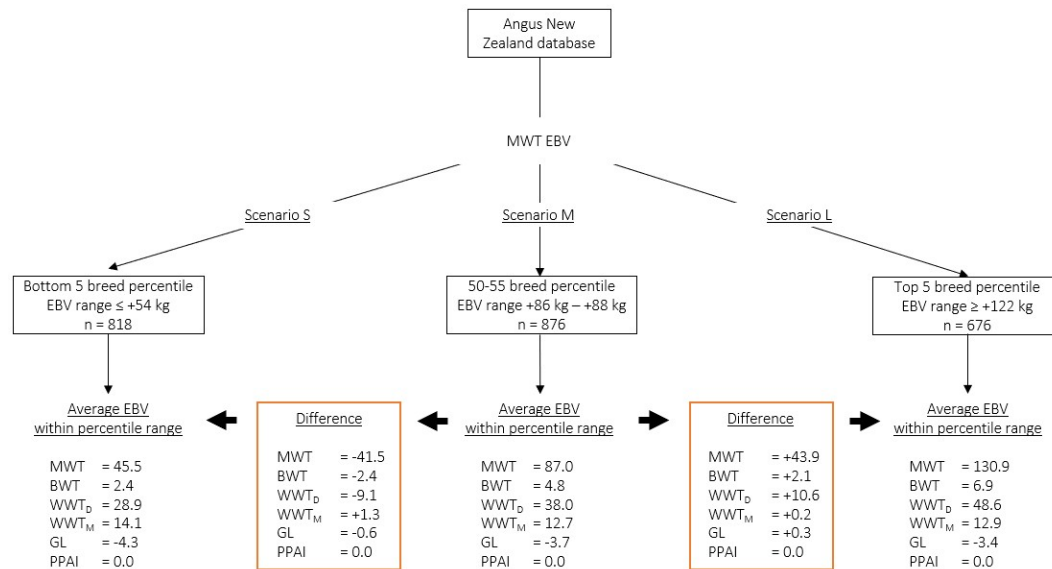
Briefly, data on farm and herd characteristics were derived from literature as well as industry data as part of a central beef progeny test for Central North Island hill country farms across a total of five production years. Cows calved annually in late spring (end of October until December) and were managed on extensive hill country pasture year-round. The herd age structure and timing of mating and weaning were the same as for Chapter 6. The feed supply available for the cows was that simulated using the parameters for the variable scenario in Chapter 6 for a reference herd size of 200 breeding cows.

### ***7.3.2 Model scenarios and mature live weight types***

A total of three different scenarios were modelled covering cow herds of different MWT type and those comprised: small (Scenario S), moderate (Scenario M) and large (Scenario L) MWT types. The Scenario M herd was defined using the same parameters as the herd in Chapter 6 (equivalent to Scenario V).

As described in Chapter 6, the model simulated a herd distribution of breeding values for the traits MWT, birth weight (BWT), direct (WWT<sub>D</sub>) and maternal weaning weight (WWT<sub>M</sub>), gestation length (GL) and postpartum anoestrus interval (PPAI) based on inputs for the mean breeding values for each trait. The herd mean breeding values (HBV) for each cow MWT type, i.e., each scenario, were inputs into the model and were determined from the Angus New Zealand BREEDPLAN (Angus New Zealand, 2022b) database with the Angus breed representing the majority of the maternal herd within the New Zealand beef cow population (Beef + Lamb New Zealand, 2021). The HBV for

MWT were taken to be the mean values for 2017-born calves and were used to reflect the current range of MWT genotypes within the New Zealand Angus breed. The HBV for MWT were a reflection of the current 50–55 percentile range (moderate cow size; Scenario M), the top five percentile range (large cow size; Scenario L) or the bottom five percentile range (small cow size; Scenario S) for MWT EBV in 2017-born New Zealand Angus cattle (Figure 7.1). As the aim of this study was to investigate differences in types of cows within the Angus breed (rather than estimating the economic value of MWT in isolation from other correlated traits), HBV for all other traits considered in the current study were assumed to be the average EBV for those traits within the animals selected in each MWT EBV percentile range. Thus, EBV used in this chapter were a reflection of previous selection policies.



**Figure 7.1** Definition of mature live weight (MWT) types (small = Scenario S, moderate = Scenario M and large = Scenario L) derived from Angus New Zealand (Angus New Zealand, 2022a); BWT = birth weight, WWT<sub>D</sub> = direct weaning weight, WWT<sub>M</sub> = maternal weaning weight, GL = gestation length, PPAI = postpartum anoestrus interval.

The HBV for Scenario M were used as a reference such that Scenario S and Scenario L were expressed as deviations from the moderate MWT type (Figure 7.1). Thus, for example the BWT for the small MWT cow type (Scenario S) was on average 2.4 kg lighter compared to the moderate MWT type (Scenario M), whereas the large MWT type (Scenario L) was 2.1 kg heavier at birth. The HBV were used as the mean breeding

values for each scenario and trait and a herd distribution of breeding values was simulated based on the method described in Chapter 6.

### 7.3.3 Feeding system

The feeding system was constructed based on a central North Island hill country farm in New Zealand with typically long, cold winter months and has been described in detail in Chapter 6. Key features include:

- Cows calve in late spring (end of October until December) aligning with the annual pasture growth curve to take advantage of the spring pasture flush over lactation
- Mating occurred during summer (from early January)
- Pasture availability varies over summer dependent on droughts throughout summer
- Winter is relatively long with little pasture growth from April through to August
- Cows generally lose LWT from the start of winter through to early spring, effectively utilising body energy reserves laid down earlier in the year

The feeding system was based on a variable environment, assuming a mean monthly pasture allocation but accounting for variability across years through introduction of a standard deviation (SD) in monthly feed supply as an input parameter for each month (Table 7.1). Thus, the feed availability in a particular month may vary across years but is assumed to be constant for each day within a month.

**Table 7.1** Average pasture supply (MJ ME/cow and day) with corresponding standard deviation ( $\pm$ SD) for each month throughout the annual production cycle and the monthly pasture energy content (MJ ME/kg DM) (Litherland & Lambert, 2007, Morris & Smeaton, 2009).

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Pasture supply	130 (24.8)	120 (14.3)	115 (14.9)	80 (21.7)	60 (1.6)	60 (1.6)	60 (1.7)	70 (21.5)	120 (43.1)	155 (14.5)	165 (14.7)	165 (15.3)
Energy content	9.9	9.5	8.8	9.3	9.2	9.4	9.7	10.2	10.7	10.6	11.0	10.3

The total amount of feed available to the cow herd was derived from the daily pasture available for the average cow in the herd (pasture allowance  $\pm$  SD) as per the distribution in Table 7.1 and multiplied by the reference herd size of 200 animals.

Cows received supplements as per the method outlined in Chapter 6, such that supplementation was provided to the lowest 20 percent of the herd only when more than five percent of the herd were below a BCS of 4.5 on each day of the production cycle.

### **7.3.4 Economics**

Price references used for revenue and expenditure aligned with the values presented in Chapter 6 to evaluate the overall gross margin for each model scenario. Revenue was obtained within the model through either sale of weaner calves or cull cows. Fixed farm expenses were not considered in this model and only expenses influenced by the differences in MWT types were compared. Expenses were divided into those related to feed intake in terms of supplementation required for the breeding herd and pasture intake of the calves. Furthermore, the acquisition of replacement heifers was required each year at weaning to maintain the herd size throughout the duration of the simulation and this was realised through purchase of in-calf 18-months-old heifers.

### **7.3.5 Herd size adjustments and model application**

A total of 50 replicates were simulated for each of the three model scenarios, each for a period of five years. For each replicate, key results were extracted from the model and averaged across replicates to determine the mean and SD for herd performance and profitability for cows of different MWT type.

Aligning with Chapter 6, the appropriate stocking rate for each model scenario was determined based on the BCS of the herd and overall profitability. A herd size where the average herd BCS dropped below a threshold of 4 over winter was considered unsuitable due to potential impact on animal welfare (Hickson *et al.*, 2017). Within the feasible herd size and provided that cows neither accumulated nor depleted body energy reserves over multiple years (built in mechanisms in the model ensure the feasibility of the system by realising a constant BCS across multiple years due to voluntary feed intake and supplementation strategy; refer to Chapter 6), the herd size yielding the highest gross margin was assumed to be the most appropriate for each MWT type. Thus, this herd size was used as the stocking rate for further analysis and comparison among model scenarios.

### ***7.3.6 Statistical analysis***

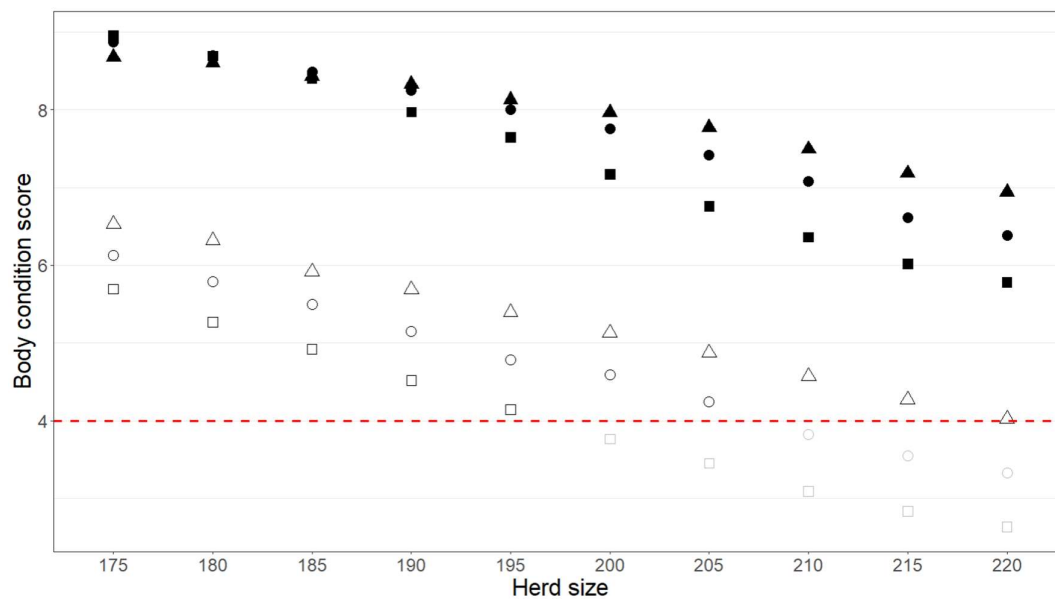
To compare the significance of performance and profitability parameters across cows of different MWT type, linear regression models were fitted with MWT type (Scenario S vs Scenario M vs Scenario L) as a factor in the model and using analyses of variance (ANOVA; F-statistic on type-III sums of squares) to compare model outcomes. Least-square means were calculated from the model to compare outcomes for each scenario.

## 7.4 Results

Key performance parameters of cows and calves within the breeding herd, feed requirements and resulting profitability across the three MWT types considered in the analysis are outlined and discussed in the following subsections.

### 7.4.1 Herd size

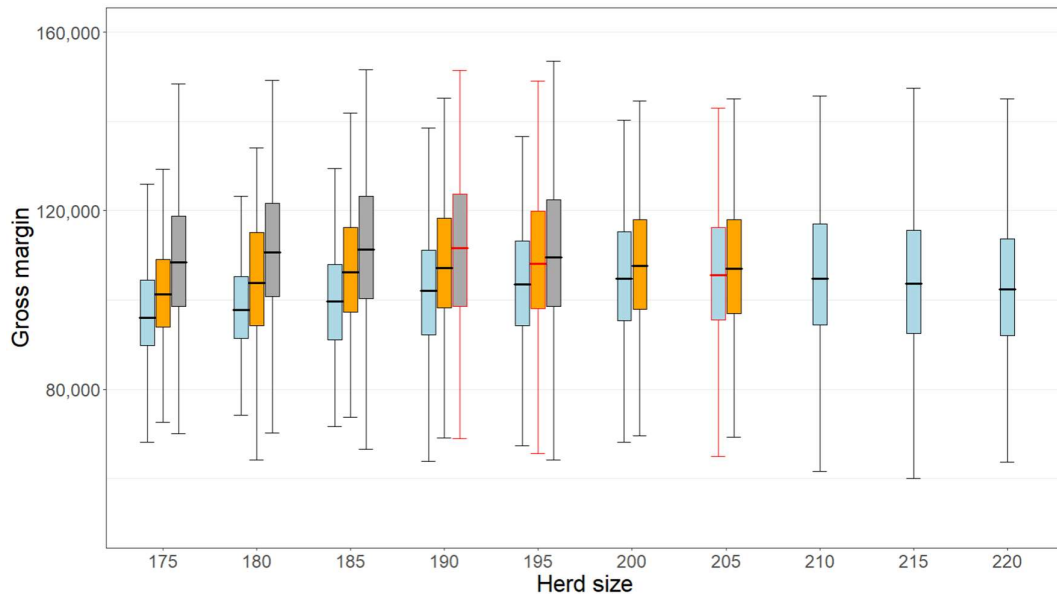
Generally, an increase in herd size was associated with a decrease in BCS for all MWT types (Figure 7.2). The difference between model scenarios increased for both the lower and upper BCS limit with an increase in herd size.



**Figure 7.2** Minimum (no fill) and maximum (filled) herd mean body condition score for each herd size, averaged across years and model replicates for small (triangle), moderate (dot) and large (square) mature live weight types; dashed line=lower herd body condition score threshold below which potential implications in terms of welfare may occur (Hickson *et al.*, 2017).

The difference in the total gross margin across model scenarios was larger for smaller herd sizes and profitability approached a similar level when the number of animals increased within the herd (Figure 7.3). An increase in herd size generally entailed a larger SD for each scenario. The most profitable herd size differed across scenarios and was smallest for the herd with cows of large MWT type at 190 animals, slightly larger at 195 animals for the moderate MWT type and highest for small MWT types at 205.

Thus, these stocking rates were used as the basis for all subsequent comparisons between the different MWT types.



**Figure 7.3** Gross margin for small (blue), moderate (orange) and large (grey) mature live weight types for different herd sizes considered in the analysis; the herd size highlighted in red was considered the most profitable for each scenario; box = inter-quartile range; error bars = 95% confidence interval.

#### **7.4.2 Live weight and body condition score**

Both LWT and BCS were least at calving time and greatest at mating, and this was the same across all scenarios (Table 7.2). The SD of LWT was greater for the large (64.7–66.6 kg) compared to the small (60.2–61.8 kg) and moderate (62.1–64.4 kg) MWT types for each time point but the SD of BCS (0.9–1.2) was similar for all time points throughout the annual production cycle.

**Table 7.2** Least-square means ( $\pm$  standard deviation) for simulated live weight (LWT; kg) and body condition score (BCS; score 1–10) fluctuations within-year for small (Scenario S), moderate (Scenario M) and large (Scenario L) mature live weight types, averaged across a five-year production period and 50 model replicates.

	Scenario S	Scenario M	Scenario L
<b>LWT</b>			
Mating	531.9 <sup>a</sup> ( $\pm$ 60.2)	573.9 <sup>b</sup> ( $\pm$ 62.1)	610.9 <sup>c</sup> ( $\pm$ 64.9)
Weaning	525.0 <sup>a</sup> ( $\pm$ 61.8)	569.6 <sup>b</sup> ( $\pm$ 62.5)	605.2 <sup>c</sup> ( $\pm$ 64.7)
Calving	473.4 <sup>a</sup> ( $\pm$ 60.9)	510.0 <sup>b</sup> ( $\pm$ 64.4)	540.7 <sup>c</sup> ( $\pm$ 66.6)
<b>BCS</b>			
Mating	7.5 <sup>a</sup> ( $\pm$ 0.9)	7.6 <sup>c</sup> ( $\pm$ 0.9)	7.6 <sup>b</sup> ( $\pm$ 1.0)
Weaning	7.0 <sup>a</sup> ( $\pm$ 1.1)	7.2 <sup>c</sup> ( $\pm$ 1.1)	7.1 <sup>b</sup> ( $\pm$ 1.2)
Calving	5.6 <sup>b</sup> ( $\pm$ 0.9)	5.6 <sup>b</sup> ( $\pm$ 1.0)	5.4 <sup>a</sup> ( $\pm$ 1.0)

<sup>a,b,c</sup>Means within each row with different superscripts are significantly different ( $P < 0.05$ ).

### 7.4.3 Cow reproductive performance

The reproductive performance of the cow herd differed significantly ( $P < 0.05$ ) for the traits PPAI, days to conception, pregnancy rate and GL (Table 7.3). Overall, cows of smaller MWT type tended to reach regular cycling activity earlier compared to the other cow types, resulting in earlier conception dates and, consequently, higher pregnancy rates.

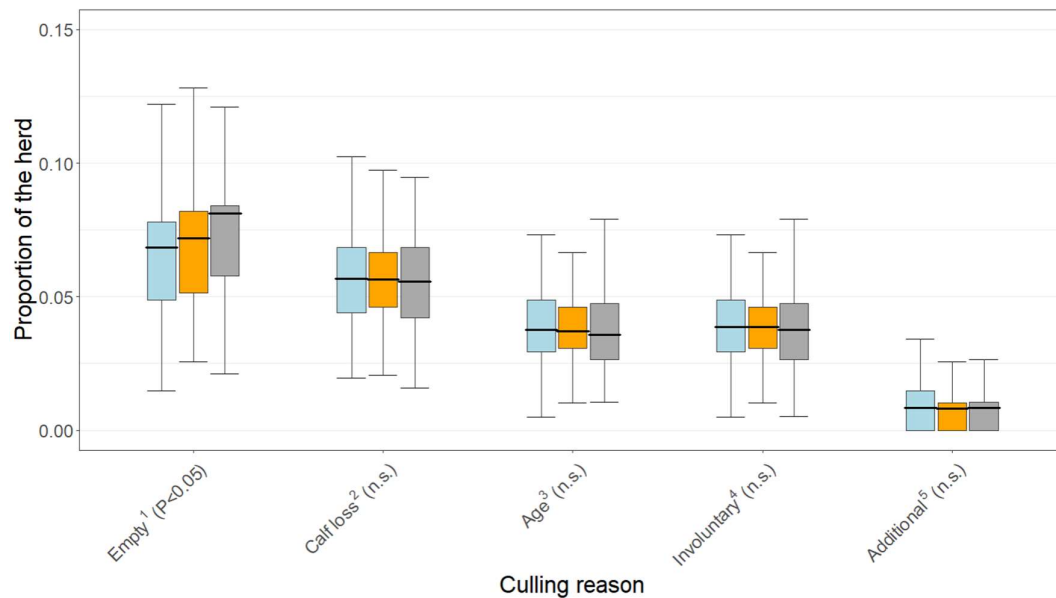
**Table 7.3** Least-square means (lsmeans) and standard deviation (SD) of key reproductive performance parameters for small (Scenario S), moderate (Scenario M) and large (Scenario L) mature live weight types, averaged across a five-year production period and 50 model replicates.

Parameter	Unit	Scenario S		Scenario M		Scenario L	
		lsmeans	SD	lsmeans	SD	lsmeans	SD
Postpartum anoestrus interval	Days	35.7 <sup>a</sup>	17.1	36.5 <sup>b</sup>	18.1	39.3 <sup>c</sup>	21.5
Days to conception	Days	19.7 <sup>a</sup>	15.3	19.7 <sup>a</sup>	15.3	20.2 <sup>b</sup>	15.5
Pregnancy rate	%	93.2 <sup>b</sup>	3.6	92.8 <sup>b</sup>	3.7	91.9 <sup>a</sup>	5.1
Gestation length	Days	280.5 <sup>a</sup>	12.1	281.0 <sup>b</sup>	13.1	281.0 <sup>b</sup>	15.5
First-calvers	%	22.1 <sup>a</sup>	3.2	22.0 <sup>a</sup>	3.2	22.5 <sup>a</sup>	4.3

<sup>a,b,c</sup>means within each row with different superscripts are significantly different ( $P < 0.05$ ).

#### 7.4.4 Calf weaning

At weaning time, calves and cull cows were sold and replacement heifers added to the breeding herd. The majority of reasons for culling were not different ( $P > 0.05$ ) across scenarios and were only significant ( $P < 0.05$ ) for the number of empty cows in the herd due to failure to conceive during the mating season (Figure 7.4).



**Figure 7.4** Reasons for culling for small (blue), moderate (orange) and large (black) mature live weight types at weaning; box = inter-quantile range; error bars = 95% confidence interval; n.s. = not significant ( $P > 0.05$ ); <sup>1</sup>cows that failed to conceive during the mating season; <sup>2</sup>failure to wean a live calf due to perinatal calf loss or calves lost between birth and weaning; <sup>3</sup>cows older than 10 years of age; <sup>4</sup>cows leaving the herd for reasons other than reproduction, calf loss and age; <sup>5</sup>additional cows culled to maintain an annual replacement rate of 20% of the herd.

Calves were weaned at a fixed date each year, and this aligned with the day cull cows were sold. With higher MWT types the absolute values for both BWT and WWT of calves increased significantly ( $P < 0.05$ ) whereas the WWT to MWT ratio decreased (Table 7.4). Overall, the pasture intake of calves under Scenario L was significantly larger compared to the other scenarios whereas milk intake was the opposite, resulting in similar calf growth rates (0.9–1.0 kg/day) across model scenarios.

**Table 7.4** Least-square means (lsmeans) and corresponding standard deviation (SD) of performance parameters of the calf crop until weaning, including energy required for growth as well as weight and growth traits from birth to weaning for small (Scenario S), moderate (Scenario M) and large (Scenario L) mature live weight types, averaged across a five-year production period and 50 model replicates.

Parameter	Unit	Scenario S		Scenario M		Scenario L	
		lsmeans	SD	lsmeans	SD	lsmeans	SD
<b>Energy intake – birth until weaning</b>							
Mean daily pasture intake <sup>1</sup>	MJ ME	12.2 <sup>a</sup>	6.2	13.2 <sup>b</sup>	6.3	14.6 <sup>c</sup>	6.6
Mean daily milk intake	MJ ME	24.4 <sup>b</sup>	5.5	24.1 <sup>a</sup>	5.5	24.1 <sup>a</sup>	5.5
<b>Weaning time</b>							
Birth weight	kg	30.2 <sup>a</sup>	5.8	35.0 <sup>b</sup>	5.9	39.2 <sup>c</sup>	6.0
Live weight gain <sup>2</sup>	kg/day	0.9 <sup>a</sup>	0.2	1.0 <sup>b</sup>	0.2	1.0 <sup>c</sup>	0.2
Weaning weight <sup>3</sup>	kg	172.5 <sup>a</sup>	30.3	178.0 <sup>b</sup>	30.4	186.4 <sup>c</sup>	30.6
200-day weight <sup>4</sup>	kg	218.9 <sup>a</sup>	34.3	226.7 <sup>b</sup>	34.2	237.9 <sup>c</sup>	34.3
Weaning weight ratio <sup>5</sup>		0.33 <sup>c</sup>	0.1	0.32 <sup>b</sup>	0.1	0.31 <sup>a</sup>	0.1
200-day weight ratio <sup>6</sup>		0.42 <sup>c</sup>	0.1	0.40 <sup>b</sup>	0.1	0.40 <sup>a</sup>	0.1

<sup>1</sup>Excluding the first 30 days where no pasture intake was assumed.

<sup>2</sup>Daily live weight gain from birth to weaning.

<sup>3</sup>Calf weaning weights at weaning day at approximately 153 days of age.

<sup>4</sup>Calf weaning weights at 200 days of age (aligning with BREEDPLAN EBV).

<sup>5</sup>Calf weaning weight as a proportion of the dams' live weight at weaning.

<sup>6</sup>200-day weight of the calf as a proportion of the dams' live weight at weaning.

<sup>a,b,c</sup>means within each row with different superscripts are significantly different ( $P < 0.05$ ).

#### 7.4.5 Economics

The income from large compared to small and moderate MWT types was larger due to the greater weight of calves and cull cows at weaning time (Table 7.5). Although the expenses were significantly ( $P < 0.05$ ) higher for greater MWT types, the higher revenue compensated for this such that, on average, the most profitable herd in terms of total gross margin on a \$ per cow per year basis was the herd under Scenario L.

**Table 7.5** Least-square means (lsmeans) and corresponding standard deviation (SD) for economic values derived from the simulation model for a cow herd of small (Scenario S), moderate (Scenario M) and large (Scenario L) mature live weight type, averaged across a five-year production period and 50 model replicates.

Parameter	Unit	Scenario S		Scenario M		Scenario L	
		lsmeans	SD	lsmeans	SD	lsmeans	SD
<b>Biology</b>							
Herd size	Count	205		195		190	
Weaning percentage <sup>1</sup>	%	94.3 <sup>a</sup>	1.7	94.4 <sup>a</sup>	1.7	94.4 <sup>a</sup>	1.6
Culling percentage	%	20.1 <sup>a</sup>	3.2	20.3 <sup>a</sup>	3.3	20.8 <sup>a</sup>	4.4
Pasture intake cow	MJME/cow/year	37,197.7 <sup>a</sup>	1,589.1	39,320.2 <sup>b</sup>	1,755.7	40,923.2 <sup>c</sup>	1,810.1
Supplements	MJME/cow/year	260.7 <sup>a</sup>	281.2	256.2 <sup>a</sup>	257.4	397.4 <sup>b</sup>	327.9
Pasture intake calf	MJME/calf/year	1,520.2 <sup>a</sup>	811.7	1,631.0 <sup>b</sup>	823.4	1,799.1 <sup>c</sup>	854.6
<b>Economics</b>							
Cull cow revenue	\$/head	1,187.6 <sup>a</sup>	50.8	1,289.3 <sup>b</sup>	50.1	1,369.7 <sup>c</sup>	58.4
Replacement cost	\$/head	1,041.0 <sup>a</sup>	20.1	1,081.5 <sup>b</sup>	19.0	1,127.2 <sup>c</sup>	20.8
<b>Revenue</b>							
Weaning value <sup>2</sup>	\$/cow/year	534.4 <sup>a</sup>	21.4	558.8 <sup>b</sup>	25.0	592.5 <sup>c</sup>	26.8
Cull cow value <sup>2</sup>	\$/cow/year	238.0 <sup>a</sup>	35.7	261.0 <sup>b</sup>	39.8	284.4 <sup>c</sup>	54.0
Revenue <sup>2</sup>	\$/cow/year	772.4 <sup>a</sup>	41.1	819.9 <sup>b</sup>	45.7	876.8 <sup>c</sup>	58.9
<b>Expenses</b>							
Supplement costs <sup>2</sup>	\$/cow/year	13.8 <sup>a</sup>	14.9	13.6 <sup>a</sup>	13.6	21.1 <sup>b</sup>	17.4
Weaning feed costs <sup>2</sup>	\$/cow/year	11.9 <sup>a</sup>	0.8	13.0 <sup>b</sup>	1.0	14.5 <sup>c</sup>	1.1
Replacement costs <sup>2</sup>	\$/cow/year	229.5 <sup>a</sup>	32.7	239.4 <sup>b</sup>	35.0	255.5 <sup>c</sup>	47.4
Expenditure <sup>2</sup>	\$/cow/year	255.3 <sup>a</sup>	38.8	266.0 <sup>b</sup>	41.1	291.0 <sup>c</sup>	56.3
<b>Weight adjustments<sup>4</sup></b>							
Weight adjustment <sup>2</sup>	\$/cow/year	-2.0 <sup>a</sup>	62.8	0.7 <sup>a</sup>	72.6	1.7 <sup>a</sup>	72.9
<b>Gross margin</b>							
Gross margin <sup>2</sup>	\$/cow/year	515.1 <sup>a</sup>	78.4	554.6 <sup>b</sup>	87.9	587.5 <sup>c</sup>	92.7
Total gross margin <sup>3</sup>	\$/herd/year	105,595.0 <sup>a</sup>	16,066.3	108,148.6 <sup>ab</sup>	17,148.8	111,625.7 <sup>b</sup>	17,615.0

<sup>1</sup>Number of calves weaned per cows wintered.

<sup>2</sup>Average value of a cow in the herd.

<sup>3</sup>Average value of the herd.

<sup>4</sup>Parameter used to adjust economic values for the difference in average live weight of cows at the start and end of each year (refer to Chapter 6).

<sup>a,b,c</sup>means within each row with different superscripts are significantly different ( $P < 0.05$ ).

## **7.5 Discussion**

### **7.5.1 Profitability and key production parameters for different cow types**

Profitability was significantly different across model scenarios such that the total gross margin increased as MWT type increased. Compared to the moderate MWT type, small cow types were on average 7.1% and 2.4% less and large cows 5.9% and 3.2% more profitable on an individual animal level and on a herd level, respectively. The main contributor to the higher profitability of larger MWT types was the greater returns from heavier weaner calves compared to progeny from lighter cow types, although the total number of weaner calves was lower due to a decrease in stocking rate for larger MWT types. This indicated that the increase in revenue from weaner calves increased the gross margin by a larger amount than was compromised for due to a smaller total number of calves.

It needs to be considered that although large MWT types were the most profitable cow type in the current chapter in terms of economic efficiency, they were not necessarily the most biologically efficient animal and this concept has been discussed by several researchers (Morris & Wilton, 1975, Notter, 2002). While the total gross margin was lower for the moderate compared to the large MWT type, productivity in terms of WWR and reproductive performance were more favourable for those lower MWT types. A decrease in WWR with increasing MWT has been previously described in the literature (Dinkel & Brown, 1978) and aligned with values presented by Farrell *et al.* (2021) for similar MWT ranges. Under the scenario presented by Farrell *et al.* (2021), smaller MWT types were slightly more profitable when WWR decreased with increasing MWT. In contrast, Beck *et al.* (2016) found that the negative relationship between cow size and WWR of the calves had no detrimental effect on the profitability of the cow-calf system. The reduction in biological efficiency due to a decrease in WWR with increasing MWT type in the current study was not sufficient to reduce the total gross margin of larger cow types.

### **7.5.2 Impact of supplementation**

The model was designed to prevent cows from dropping below a BCS threshold under which welfare issues would occur (Hickson *et al.*, 2017) by providing supplementation in form of increased pasture allowance to the lowest-conditioned 20 percent of cows when more than five percent of the herd were below a BCS of 4.5. This resulted in similar BCS levels across model scenarios at each time point throughout the annual

production cycle (Table 7.2). The BCS of cows was an important parameter in the model driving the probability of conception (refer to Chapter 3). This means that the main difference between the MWT types was expressed in the amount of supplementation offered rather than the production level achieved, as in all cases, the very poor reproductive performance that might be expected of low conditioned cows was avoided. Comparing BCS profiles of cows to Figure 3.2 in Chapter 3 indicates that failure to provide supplementation, especially at the lower end of the BCS scale, can have detrimental impacts on the reproductive performance of the herd resulting in a large number of empty cows. Thus, the period following winter and leading up to mating is a critical time for farmers to intervene to avoid large production losses due to cows not getting in calf (Hickson *et al.*, 2017) and this was the time when most supplements were provided to the herd in the current study.

Under the current model the greatest amount of supplementation was required by the large MWT type indicating that farming of larger cow types may likely increase the amount of supplementation needed on farm. This practice may not always be applicable under real-life conditions due to the ability of farmers to provide supplements caused by logistical limitations (McCall & Scott, 1988, Beef + Lamb New Zealand, 2017c). The suitability of each cow type likely depends on the individual management system and resources of farmers to provide additional feed to their herd when required such that there are certain system decisions farmers need to make related to each cow type (McCall & Scott, 1988). Small MWT types may be more suitable for farming systems that reject the use of supplements. However, it is likely that cows of a range of mature types can suit any farm system if farmers are prepared to provide the appropriate nutritional resources to reduce the number of low conditioned cows in the herd.

A system where no supplementation was provided in times of restricted nutritional resources is likely to require different management strategies to overcome those limitations, and this may be realised through adjustments in stocking rate. Generally, if no supplementation would be provided outcomes in terms of reproductive performance of the herd would likely be negatively impacted due to animals not being able to maintain body condition over time. Especially under the current assumptions where BCS was driving conception rate, large MWT types would likely diminish their reproductive performance considerably due to their greater need for supplementation compared to smaller cow types. Furthermore, the profitability of cow types may differ if supplements were more or less expensive (Beck *et al.*, 2016). Only at a

supplementation cost of \$2.47 per kg DM would the greater revenue of large MWT types break even with the higher supplementation costs compared to moderate cow types.

The supplementation strategy within the current model, however, followed a more conservative approach such that the impact on production was small. Rather than providing supplementation to maintain the same level of production compared to an average year, only the lowest-conditioned 20 percent of cows were supplemented to avoid starvation of the herd. Winter was comparably long on the farm in this study (April through to August) such that additional pasture allowance was required at times to maintain an acceptable level of BCS above the welfare threshold across the herd. The higher amount of supplementation required for the large cow type is likely to make them less desirable for those production systems compared to systems with shorter winter months and therefore an earlier onset of spring pasture growth.

### **7.5.3 Relevance of mature live weight**

Rather than focussing on MWT alone, this chapter aimed to define current cow types in New Zealand based on MWT and this was associated with other, correlated traits with impact on the phenotypes that tend to vary with changes in MWT (Angus New Zealand, 2022b). The cow types are therefore representing the effects of previous selection decisions rather than future breeding directions. This approach was taken to evaluate the appropriateness of real cow types within the New Zealand beef industry for cow-calf production systems and to understand prior selection emphasis for this breed. While most effects on other, correlated traits were reasonably small (Figure 7.1), the traits considered in the model which were impacted the most by change in MWT EBV were BWT and WWT. It has been widely published in the literature that an increase in MWT is associated with larger calves, both at birth and at weaning (Brinks *et al.*, 1964, Bullock *et al.*, 1993, Kaps *et al.*, 1999), and this was reflected in the current model.

Outcomes from this chapter in a New Zealand farming system context tend to agree with what several researchers have demonstrated before in other contexts: if certain types of cows are managed according to their nutritional requirements for optimal reproductive performance and growth, the impacts of MWT on the profitability of the farming system are small (Andersen, 1978, Jenkins & Ferrell, 1994, Arango & Van Vleck, 2002). However, this is only true provided that the efficiency of those cows is realised through adequate management of nutritional resources. This means that the stocking

rate needs to be adjusted dependent on cow size for a given amount of feed resources on farm (Doye & Lalman, 2011). The model accounted for an increase in energy required for maintenance with increasing MWT (Smeaton *et al.*, 2000, Arthur *et al.*, 2004, Morris, 2008). Thus, given the same average feed supply, farming of heavier cow types required a reduction in stocking rate so as to retain BCS over time (Long *et al.*, 1975, Beck *et al.*, 2016), and this has been demonstrated in this chapter. Generally, for larger MWT types a more conservative approach in terms of stocking rate must be taken to overcome differences in nutritional requirements.

Results indicated that breeding programs are not necessarily reliant on the MWT of cows, so long as an increase in MWT is associated with an increase in calf size. The BCS of the cow may likely contribute to the productivity of the herd on a much larger scale compared to MWT, driving reproductive performance (Chapter 3) and consequently the future production of cows within the herd.

#### ***7.5.4 Impact of cow type on resilience***

The concept of resilience in beef cows has been cited by many researchers (Amer, 2012, Friggens *et al.*, 2017, Misztal, 2017), however, there are somewhat different approaches when it comes to defining the robustness of animals within a particular environment. A robust cow may be defined as an animal that is able to maintain a desirable level of production when exposed to environmental challenges (Rauw & Gomez-Raya, 2015, Friggens *et al.*, 2017, Misztal, 2017). Under New Zealand hill country conditions, this implies a cow's ability to mobilise surplus body energy reserves in times of feed shortage so as to maintain milk production for the development of the calf as well as the buffering capacity to overcome those periods of restricted feeding and replenish body energy reserves when feed is in ample supply (Hickson *et al.*, 2017). Furthermore, beef cows must be able to repeat this process over multiple production cycles without compromising their ability to reproduce over time (Friggens *et al.*, 2017). The overall higher amount of supplementation required for larger MWT types may indicate their lower ability to recover following periods of underfeeding compared to smaller cow types such that additional feed resources were required to maintain an acceptable level of production.

A larger SD associated with production traits generally indicates a wider range of outcomes within a herd. This implies that more animals are likely to be observed at the more extreme ends of the scale such that, dependent on the trait under consideration,

a higher risk may be associated with an increase in SD. Although smaller MWT types in the current study were not the most profitable, from a farm management perspective smaller sized cows may be considered more consistent due to overall lower SD for most key production traits such as PPAI or pregnancy rate compared to large MWT types. This indicated that the least amount of risk was associated with smaller cow types whereas large cow types tended to be the most susceptible to variability. Farmers often aim for a moderate cow size (Smeaton *et al.*, 2000, Beef + Lamb New Zealand, 2017a) and this may partly be explained by the lower risk associated with this cow type. Consequently, the impact of an adverse year where nutritional resources are below energy requirements of the cows over extended periods is likely more recognisable in larger MWT types, especially in the absence of supplementation. However, according to this study large cow types tend to compensate for detrimental environmental conditions within an average or above average year so long as the nutritional resources for an efficient production are provided. One of the main drivers in terms of suitability of cow type for a certain farming system may likely be how risk averse farmers are (Brown *et al.*, 2019) in terms of accepting the challenges associated with larger MWT types. According to the current study, smaller cow types tend to be the most resilient such that compromising some of the profit obtained through larger cow types may be beneficial to reduce the risk associated with more variable production outcomes.

Overall, it is challenging to define the most suitable type of cow as it varies with the production system (Morris & Wilton, 1976, Fitzhugh, 1978). The wide range of environments, locations and management strategies on farm may require different types of cows to optimise biological performance and, consequently, the profitability of the system (Arango & Van Vleck, 2002). While producers often claim 'moderate' sized cows to be most efficient, the term is relative to the entire cow population and may largely differ in an international context. It may be considered that what was defined to be a moderate cow type in the current chapter is the most preferable one, not necessarily in terms of total productivity and gross margin, but rather in terms of resilience and potential impact on environmental traits. The higher emissions intensity (Beef + Lamb New Zealand, 2017b, Ministry for Primary Industries, 2022) and the enhanced risk of soil and pasture damage (Beef + Lamb New Zealand, 2017c, Roesch *et al.*, 2019) of those heavier cow types, especially under hill country conditions, is likely to make them less desirable in respect to the increasing focus of animal breeding and management on the environment.

### **7.5.5 Limitations and future implications**

The model currently allows for the evaluation of key performance and profitability parameters for specific MWT types within the current New Zealand Angus population by utilising information on a range of animals recorded within Angus New Zealand (Angus New Zealand, 2022b). Published animal records within Angus New Zealand cover a wide range of the beef cow population and, therefore, provide a good indication of prior selection emphasis and relationships between EBV for Angus cattle in New Zealand such that they were assumed representative for the current New Zealand Angus population. Conclusions from this chapter may, therefore, be limited to the range of MWT EBV currently available within the New Zealand Angus herd. Consequently, outcomes from this model are likely to differ if a larger range of cow sizes would be considered for the analysis. In a global context where MWT may exceed live weights of 600 kg (Beck *et al.*, 2016, Ribeiro *et al.*, 2022) similar concerns were raised in terms of compromised profitability of those larger beef cows (Bir *et al.*, 2018). Outcomes from this chapter, however, indicate that within the current New Zealand system where the upper limit of MWT in the top percentile is currently only about 40 kg above those of the medium percentile, selecting for larger cow types is unlikely to have a detrimental impact on the profitability of the cow-calf production system. Those outcomes may be revisited if excessive selection on growth traits leads to larger MWT types in the future (refer to Chapter 5).

The amount of LWT change required to change between one unit of BCS was a relevant input parameter in the model and has been derived from outcomes from Chapter 2. Results indicated that the amount of LWT change required was the same, irrespective of size of cows in terms of hip height. Data for this thesis was obtained from a beef progeny test study and this was assumed representative for the current beef cow population within the limitations of the study. The current range of breeding cows within the New Zealand beef population as reflected by beef progeny test data indicated that there was no impact of practical relevance of cow size on the relationship between LWT and BCS. However, with further increase in mature size especially with respect to those larger cow types overseas (Beck *et al.*, 2016, Ribeiro *et al.*, 2022), this relationship may need to be revisited. If the change in LWT per unit BCS was considerably different across a larger range of cow sizes this would likely alter the outcomes from the simulation model. Thus, if much larger cow types were to be considered for further analysis a higher LWT change per unit BCS may be required and, consequently, a higher

feed intake of those larger cow types. This could limit the ability of cows to replenish body energy reserves following periods of restricted feeding under the same feed supply and may likely result in reduced profitability.

The current model simulated beef cow performance and profitability parameters for a Central North Island hill country farm. It needs to be considered that results are likely to change when other locations are considered for the same analysis. With changes in the production system and management strategies on farm, the most suitable cow type may vary. Changes in the environment are likely to impact on the LWT and BCS profiles (Morris *et al.*, 2006, Hickson *et al.*, 2017) and an earlier calving season may result in longer average PPAI (Hansen & Hauser, 1983).

Fixed costs per cow were not accounted for in the current model. However, it is likely that fixed costs associated with production on a per head basis are similar irrespective of cow size. This may lead to higher costs associated with farming of smaller cow types due to overall bigger herd sizes (Kress *et al.*, 1969) for the same amount of feed resources while emphasising the need to get as much return out of a single animal as possible. Thus, it is likely that selection strategies would favour the use of larger cow types and further driving selection towards the use of those larger MWT types.

Future research may consider exploring this model for the use to calculate economic weights such as for MWT under a static and variable feed supply (refer to Chapter 6). To define cow type in the current model, all traits within the simulation were assumed to be correlated to each other based on real cows within the New Zealand Angus population and traits did not vary independently. Modifications in the model may provide an opportunity to examine MWT of cows independent of other traits such as WWT or BCS to evaluate a wider range of cow types. This would allow the impact of different WWR on profitability to be examined. It would be interesting to examine where the current New Zealand cow herd is placed in terms of those much larger cow types internationally.

Within the current limitations of this study such as range of cow sizes, WWR, feed availability and traits associated with MWT, the MWT type did not have a large impact on the profitability of the cow-calf operation. Given the current range of traits within the Angus New Zealand population, the MWT of cows is unlikely to negatively impact on the profitability of the cow-calf unit. Thus, provided there is no significant change in efficiency in terms of WWR selection priority may be given to other traits more relevant

to the profitability of the farming system. This would allow focus on selection for improved growth and higher weights in finishing animals and making use of those heavier calves from larger cow types (refer to Chapter 5) without a negative impact of a correlated increase in MWT.

## **7.6 Conclusions**

This chapter examined the impact of small, moderate and large MWT types on the performance and profitability of the cow-calf production system in response to fluctuations in pasture availability for a central North Island beef cow herd. Outcomes from the model have demonstrated that MWT does not have a large impact on the profitability of the herd so long as the change in MWT is associated with change in other correlated traits, particularly calf size, and cows are managed in a way to align feed resources with the nutritional requirements of the animal to maintain a desirable level of production. This may be realised through adjustments in stocking rate where larger MWT types generally require a more conservative approach compared to smaller cows to overcome differences in nutritional requirements. The wide range of environments and management strategies on New Zealand hill country farms may require different types of cows to optimise biological performance and, consequently, the profitability of the system. Provided that the efficiency of beef cows in terms of WWR aligns with those considered in the current study, selection programs may focus on the finishing performance of the herd as the main source of income and, consequently, making use of those heavier calves from larger cow types without a negative impact from the correlated increase in MWT.

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## **Chapter 8 – Concluding discussion**

## 8.1 Introduction

Beef breeding cows play a diverse role within the New Zealand sheep and beef cattle production system. Feed allocation to cows is driven by competition with other livestock classes as well as availability due to seasonal fluctuations in pasture growth as a response to climatic conditions and management strategies rather than nutritional requirements of the animals (Morris & Hickson, 2016). The flexibility and buffering capacity of cows is thereby often used as a tool to align key events throughout the annual production cycle with the pasture growth curve (Pleasants *et al.*, 1994, Morris, 2007). Limited information exists on the phenotypic and genetic performance of beef breeding cows under New Zealand hill country farming systems and to what extent maternal performance can be enhanced under varying environmental conditions to increase the productivity and profitability of the cow-calf production system within the limitations of the farming system.

Therefore, the objective of this thesis was to quantify the role of genetics on performance of beef breeding cows in New Zealand's pastoral farming system. More specifically, the objectives were to quantify the phenotypic performance of beef cows in terms of live weight (LWT) and body condition score (BCS) profiles on extensive hill country pasture (Chapter 2); to evaluate the relationship between stored body energy reserves expressed as BCS with reproductive success in terms of pregnancy rate to artificial insemination (AI) and natural mating (Chapter 3); to define key maternal performance traits and examine their genetic and phenotypic correlations with each other (Chapter 4) and with the finishing performance of heifer and steer progeny (Chapter 5); to develop a bio-economic model to quantify performance and profitability of beef cows in response to a consistent annual versus a variable feed supply (Chapter 6); and to examine the impact of cow types that differ in their mature live weight (MWT) on the performance and profitability of a production system under variable feed supply (Chapter 7).

## **8.2 Management and breeding directions for live weight, body condition score and reproductive success within the maternal herd**

For New Zealand beef breeding cows where the calf is the sole production output high reproductive rates are required to ensure profitability of the cow herd (Morris & Smeaton, 2009). This thesis provided evidence that for cow-calf production systems where the primary focus is on enhancing the maternal performance of the cow, selection emphasis should be on improving rebreeding ability of first-calving 2-year-old cows and BCS of cows. While nutritional management provides a useful tool to enhance reproductive success of heifers and cows within the breeding herd on a phenotypic level (Chapter 3), selection strategies have the potential to contribute to further improvements in maternal productivity (Chapter 4, Morris, 2008, Morris & Smeaton, 2009, Diskin & Kenny, 2016, Beef + Lamb New Zealand, 2017c) and these points will be addressed in the next paragraphs.

### ***8.2.1 Reproductive success of heifers and mature cows***

Genetic improvement of the breeding herd may be realised through direct selection of traits related to reproductive success. Outcomes from Chapter 4 did not show any significant genetic variation in pregnancy rate of 15-month-old heifers and mature cows ( $\sigma^2_a=0.00$ ), indicating that there is no scope for selection to improve pregnancy rate at these ages. Although genetic evaluations in the United States (Bormann *et al.*, 2006, McAllister *et al.*, 2011) and Canada (Canadian Angus, 2023) include heifer pregnancy as a trait in genetic evaluation programs, the lack of genetic variation of this trait within the current New Zealand population does not allow identification of animals with higher genetic merit for heifer pregnancy.

Results from this thesis, however, indicate that the focus should be on rebreeding performance of first-calving 2-year-old cows as the most heritable reproductive trait ( $h^2=0.12-0.14$ ). Breeding for greater pregnancy rate in 2-year-old cows in combination with adequate management practices has not only the potential to result in desirable enhancements of rebreeding ability in young herd replacements but may also lead to earlier conception within the mating season ( $r_g=-0.99$ ). The most cost-intensive time to replace females within the breeding herd is following their first calving season due to high costs for replacement animals and limited return from calf weaning up until this point, such that this is a critical time for farmers to intervene to minimise production losses (Hickson *et al.*, 2008, Valente *et al.*, 2017). Selection emphasis for rebreeding

ability in 2-year-old cows has the potential to reduce the number of cows leaving the herd after the first calving season due to unsuccessful pregnancies. There is opportunity to identify sires with superior genetic merit for reproductive efficiency while providing an improved estimate of fertility within the herd such that rebreeding performance should be considered in future genetic evaluation programs for genetic improvement of the breeding herd.

The current Days to Calving EBV commonly assessed in genetic evaluation programs is determined by a combination of variation in conception date and gestation length and is generally a lowly heritable trait (Graser *et al.*, 2005). Developing EBV for rebreeding ability may provide an improved estimate of cow fertility (probability of conception) by targeting the component with maximum genetic variation and reasonable heritability while providing a more accessible definition of cow conception.

Overall, outcomes from Chapter 4 have confirmed that traits related to reproductive success that were measured in 15-month-old heifers prior to their first calving can be substantially different from similar traits measured in 2-year-old cows following their first calving and in mature cows. Thus, traits recorded during the first two mating seasons should be evaluated as different traits compared to mature cows.

### **8.2.2 Selection emphasis for body condition score and live weight of cows**

Body energy reserves and as such the nutritional status of cows as reflected by their BCS are an important determinant of reproductive success in terms of pregnancy rate on a phenotypic level ( $P < 0.001$ ; refer to Chapter 3, Selk *et al.*, 1988, Buckley *et al.*, 2003, Ciccioli *et al.*, 2003, Morris *et al.*, 2006), indicating that cows in above average BCS are more likely to conceive and/or more likely to get in calf early within the breeding season (optimum BCS of 7 at mating time for reproductive success).

The moderate heritability ( $h^2=0.26$ ) and reasonable genetic variance ( $\sigma^2_a=0.15$ ) for BCS in cows (Chapter 4) indicates that selection strategies can contribute to improvements in BCS on a genetic level. Selection provides an opportunity to increase the average body energy reserves of cows within the herd, and this is relevant for greater reproductive success. However, currently there are no EBV published for cow BCS within New Zealand genetic evaluations in beef cattle based on which breeders can select for higher body energy reserves in their cows (Angus New Zealand, 2022), although research EBV are developed for some breeds (Angus Australia, 2023). As a response, breeders often select for higher subcutaneous fat thickness in their finishing

animals (EBV available on rib and/or rump fat depth from ultrasound scanning data) with the aim of increasing cow BCS (as a proxy of the relative amount of metabolisable fat and muscle available as an energy source). Outcomes from Chapter 5, however, have shown that there are only low to moderate genetic correlations between these trait groups ( $r_g=0.02-0.25$ ). Thus, a selection response in cow BCS will likely be slow when selecting for higher rib fat depth in finishing animals either via ultrasound scanning or measured directly on the carcass at slaughter (refer also to Appendix II). This indicates that if breeders want to increase the BCS of their cows by using fat traits in finishing cattle as a selection tool, a large increase in the genetic merit of ultrasound and carcass fat traits would be required for only a small change in BCS. This should also be considered when animals are finished for slaughter where too much fat cover can increase processing costs (New Zealand Meat Classification Authority, 2004, Beef + Lamb New Zealand, 2017d) and therefore potentially limit the return from the beef carcass.

The main aim is to increase BCS in cows independent of the fat depth in finishing animals. Considering that measures recorded on finishing animals (e.g., rib fat depth) are not explaining much of the variation in cow BCS (Chapter 5), future research may consider measuring BCS in cows directly and evaluating BCS as a trait in genetic evaluation programs to directly select sires with superior EBV as a way to genetically improve BCS. The genetic correlation between cow BCS and rebreeding ability was low ( $r_g=-0.10 \pm 0.19$ ) in the current study (refer to Chapter 5). Thus, selection for higher BCS in cows is less about a correlated increase in reproductive success and more related to the fact that cows with a genetic propensity to maintain higher BCS are likely to be easier to manage to meet phenotypic BCS targets. This may not only benefit reproductive success but potentially also feed requirements and animal welfare and has the potential to provide an additional tool to managing animals in an appropriate way to maintain production levels. Genetic evaluations such as in Australia (Angus Australia, 2023) are currently examining the use of BCS EBV to be included in future selection programs to select for improved body energy reserves of cows. Including BCS as a trait in genetic evaluation programs would, however, require animals to be recorded on a much larger scale. It needs to be considered that selection for BCS should account for the correlated impact on maternal weaning weight (i.e., milk production;  $r_g=-0.55$ ) so as to not diminish the milk production potential of dams in subsequent generations. Evaluating BCS from a genetics point of view is likely to require only a

single annual measure due to high genetic correlations of the trait across timepoints ( $r_g=0.84-0.99$ ; refer to Appendix II). Data recording under hill country farming systems should best be conducted when animals are already being yarded together such as at weaning time.

Selection indexes are often constructed in a manner that places negative emphasis on MWT in selection programs so as to avoid cows getting 'too big' (Beef + Lamb New Zealand, 2017c). There is a widely held belief that smaller cow types are generally more robust when it comes to their ability to adjust to variation in feed supply due to overall lower maintenance requirements and feed intake compared to larger cows (Smeaton *et al.*, 2000, Arthur *et al.*, 2004). However, the positive genetic correlation between MWT and BCS ( $r_g=0.24 \pm 0.0$ ) found in Chapter 4, although low, indicates that placing downward pressure on MWT is likely to decrease the ability of cows to reach BCS targets. Chapter 7 has demonstrated that across the current New Zealand Angus population, the impact of cow size on reproductive success and subsequent productivity of the cow-calf production system is small so long as the change in MWT is associated with change in other correlated traits, particularly calf size, and cows are managed according to their nutritional requirements to reach BCS targets. The BCS of cows is, however, a key driver of maternal production in terms of reproductive success (Chapter 3), indicating that given cows are in adequate condition at key time points throughout the annual production cycle (and this may be achieved through supplementation strategies, adjustments in stocking rate for different cow sizes under a given set of feed resources and/or change in feed priorities on mixed sheep and beef cattle farms (Long *et al.*, 1975, Doye & Lalman, 2011, Beck *et al.*, 2016)) it is not crucial as to whether cows are large or small. Consequently, selection strategies may concentrate on other traits relevant for production, independent of a correlated response with MWT.

### **8.2.3 Management directions**

Monitoring the LWT and BCS of cows can be useful to understand the role of beef breeding cows within the system (Chapter 2) and to reach production targets for improved reproductive efficiency on a phenotypic level (Chapter 3). From a management perspective it may be beneficial to measure cow BCS on a regular basis to reach reproduction targets (Chapter 3) but also to benefit animal welfare and health. Body condition score is a relevant trait related to animal wellbeing, where emaciated or obese animals generally are more susceptible to health problems (Eversole *et al.*,

2009, Roche *et al.*, 2009). To examine the performance of beef cows and for nutritional management in commercial herds, the BCS of cows should best be evaluated at key time points such as at weaning, prior to calving and prior to mating as those measures can fluctuate substantially across the annual production cycle (Chapter 2).

Information on the relationship between LWT and BCS from Chapter 2 may be used to inform the amount of feed required to reach BCS targets prior to mating when no LWT data has been recorded. Furthermore, it is useful to know how a unit of BCS translates into LWT change as nutritional equations are often reliant on LWT information (Ferrell & Jenkins, 1985, Freer *et al.*, 2007). The change in LWT required for a one-unit change in BCS ranged from 26.8 to 30.8 kg in the current study and this was similar, irrespective of cow size within the current population. It may be considered that the impact of cow size on the relationship between LWT and BCS should best be revisited if the range of cow sizes within the New Zealand cow population increased in the future.

### **8.3 Genetic improvement of calf performance can impact on live weight, body condition score and reproductive success**

For finishing systems where steers and/or heifers are raised for slaughter, primary selection emphasis is usually on growth and carcass characteristics (Wilson *et al.*, 1976, Wolcott *et al.*, 2013, Pardo *et al.*, 2020). It is relevant to know the genetic components that influence maternal and finishing performance and potential antagonisms between both systems to enhance breeding strategies and optimise selection decisions (Koots *et al.*, 1994, Splan *et al.*, 1998) and ultimately the profitability of the production system (Meyer *et al.*, 1990, Bullock *et al.*, 1993, Nephawe *et al.*, 2004).

Outcomes from Chapter 5 have shown that most traits with positive impact on growth and carcass traits are positively genetically correlated ( $r_g=0.45-0.92$ ) with MWT in cows (Bullock *et al.*, 1993, Koots *et al.*, 1994, Nephawe *et al.*, 2004). Thus, selecting for higher growth potential and carcass weights in slaughter animals is likely to increase the MWT of cows and this has been observed in genetic trends within New Zealand beef cattle as well as internationally. Research has shown that there are advantages from those heavier, earlier finishing calves from larger cow types due to higher sale weights and greater return from the carcass at slaughter due to lower processing costs per kg of product (Kress *et al.*, 1969). Furthermore, faster-growing calves are more likely to achieve target weights for slaughter prior to their second winter. This is considered more efficient from an economics perspective, especially under New Zealand grass-fed

systems where the highest annual pasture costs are associated with winter feed (Litherland & Lambert, 2007, Beef + Lamb New Zealand, 2017b). Given that the MWT of cows is unlikely to negatively impact on the profitability of the cow-calf production system (so long as an increase in MWT is associated with bigger calves; Chapter 7), selection strategies may lean towards prioritising the performance of finishing animals while taking advantage of those larger calves from bigger cows and accepting a correlated increase in MWT (refer to Chapter 7, Kress *et al.*, 1969).

Results from this study indicate that most growth and weight traits in finishing cattle have only limited genetic correlations ( $r_g=0.11-0.22$ ) with rebreeding ability of female herd replacements or cow BCS. Fat traits in finishing animals at either live animal ultrasound scanning or at slaughter were low to moderately genetically correlated ( $r_g=0.36-0.39$ ) with rebreeding ability of heifers following their first calving, but only lowly genetically correlated ( $r_g=0.02-0.25$ ) with cow BCS. The industry target for subcutaneous fat thickness for the highest fat grading (not resulting in any deductions in carcass value) is between 3 and 10 mm (New Zealand Meat Classification Authority, 2004). Whether the genetic correlations between rib fat depth in finishing animals and rebreeding ability of first calving heifers or cow BCS has a detrimental impact on the performance of the maternal herd depends on the average subcutaneous fat thickness within the finishing herd and whether the goal is to increase or decrease the value for future generations.

The results from this study suggest that it is possible to identify animals with favourable genotypes for both finishing and maternal performance so long as measures are available for both trait groups and traits are considered in a multi-trait context (Ponzoni & Newman, 1989). Consequently, finishing systems may primarily focus on how the finishing animal best fits into the system and accepting the type of cow that accompanies the breeding direction. From an economics perspective appropriate transfer of value of the calves is, however, critical when calves change ownership at weaning (i.e., leaving the breeding herd and entering the finishing operation) such that progeny from heavier cow types should return a higher income from weaner sales due to a correlated increase in calf size to offset the need to run slightly fewer large cows on a fixed feed resource.

## **8.4 Implications for bull breeders and commercial cow-calf producers**

The New Zealand beef industry comprises a small bull breeding sector and a larger bull buying sector, the latter having most of the commercial breeding cows. The considerations for bull breeders may thereby differ from commercial cow-calf producers to improve beef production in New Zealand.

Outcomes from this thesis have certain implications for bull breeder strategies and practices where the focus is to produce subsequent generations of bulls that are better for use as sires in commercial herds:

- 1) EBV for rebreeding ability and BCS should be developed, which will require recording of these traits in nucleus herds
- 2) Selection indexes for beef breeding cow herds should be revised to include these new traits, and these indexes should be used for breeding decisions
- 3) Selection indexes for beef breeding cow herds are generally constructed to balance the cost of additional MWT against the benefits of additional growth of finishing cattle – there is no need to apply additional negative pressure on MWT beyond the added costs of maintenance feeding accounted for in the index; selection is best placed for high index provided it adequately accounts for the cost of feeding larger cows

Implications for commercial cow-calf producers buying bulls from bull breeding herds where the focus is on improving the profitability and performance of the breeding herd should be:

- 1) Fat thickness EBV are not a good indicator of cow BCS and should be primarily used to manage the finishing herd to reach a desirable level of fat cover on the carcass at slaughter
- 2) BCS EBV when developed would provide an opportunity to select sires whose daughters may be easier to manage to reach BCS targets
- 3) Focus should be on EBVs relevant to reach production targets aligning with the individual breeding objective on each farm (i.e., weaning weights or carcass merit) and accepting an associated increase in MWT so long as stocking rate is adjusted for a given amount of feed resources on farm (this may allow a larger pool of bulls to select from)
- 4) Index selection should be used to ensure appropriate balance between MWT of cows and growth in finishing cattle

- 5) Cows should be managed to achieve target BCS at mating

### **8.5 Limitations of the study**

The thesis has demonstrated management (Chapter 2 and Chapter 3) and selection strategies (Chapter 4 and Chapter 7) that can be used to enhance the productivity of the maternal herd and provided evidence that breeding decisions may benefit the finishing operation without negatively impacting on the maternal herd (Chapter 5). Data used within this study was dependent on beef progeny test (BPT) data as the primary source of information as well as values and assumptions taken from the literature. Consequently, conclusions that can be drawn from this study are dependent on the quality of the data collected as part of this project. While this provides the best estimates for beef cows under New Zealand hill country farming systems to date, it needs to be considered that there were certain limitations that may impact on the results and need to be considered for future research. Those limitations are outlined in the following paragraphs.

Cows within the progeny test were subject to artificial insemination (AI) and oestrus synchronisation which is not widely used within New Zealand beef herds (Smeaton *et al.*, 2003). The mating system may impact on the relationship between BCS and pregnancy rate. Outcomes from the literature, however, have demonstrated similar relationships independent of the mating system (Morris *et al.*, 2006, Renquist *et al.*, 2006) such that the overall conclusions from this study are likely to also apply for naturally mated cows.

Especially with beef breeding cows where fertility is the primary focus, research often deals with lowly heritable traits (Morris *et al.*, 1987, Meyer *et al.*, 1990, Cammack *et al.*, 2009, Berry *et al.*, 2014) and this can limit the potential for direct selection. Examining the correlations with some lowly heritable traits in the current analysis have led to high standard errors for some genetic parameter estimates (refer to Chapter 4 and Chapter 5). To achieve higher accuracies for those lowly heritable traits more data and deeper pedigree structures would be required to support/verify the outcomes from this study (Hayes & Goddard, 2008, Ekstrøm, 2009). However, the BPT as the primary source of data available for this research is currently the most comprehensive information source for commercially farmed beef cattle in New Zealand and covers a range of farming systems across multiple environments. A much larger scale, especially under commercial environments, may be challenging and would require years of accurate and

sustained data recording. This may not be feasible due to high costs as well as time and/or resource constraints when implementing such large-scale projects (Spedding & Brockington, 1976, Hirooka, 2010) and is unlikely to be practicable in the near future. Data from recorded herds may provide an opportunity to enhance prediction accuracies. However, comparison is limited to those traits currently measured within these herds. Thus, data availability on traits such as rebreeding ability of 2-year-old cows is still limited.

The current thesis focussed on the performance of beef breeding cows within the cow-calf production systems with some genetic links to the finishing part of the operation (Chapter 5). However, no in-depth analysis was conducted to allow the evaluation of the finishing system independent from the cow herd. The model developed in Chapter 6 only modelled a sub system such that it is likely that the profitability of beef production may differ when the finishing system is also included in the analysis. Furthermore, most beef cows in New Zealand are farmed in conjunction with other enterprises such as sheep (McCall, 1994, Morris & Kenyon, 2014) which can impact on the management strategies and, consequently, the profitability of the beef cow herd. The current model was limited to beef cows and their progeny until weaning and did not account for evaluation of profitability parameters across multiple species. Thus, to examine the profitability of cows on a whole farm level all enterprises and their complementary contributions to the farming system need to be considered (Machado *et al.*, 2010, White *et al.*, 2010).

The simulation model in Chapter 6 and Chapter 7 focussed on a Central North Island farming system. Regional pasture curves may, however, differ largely across New Zealand ranging from low fertility high country regions in Southern parts of the country to higher soil fertility on easier hill country in the North Island (Charteris *et al.*, 1999, Beef + Lamb New Zealand, 2022). Considering other locations may likely change the annual feed supply curve and, consequently, the performance and profitability of certain cow types, making them more or less profitable dependent on the local environmental conditions and management strategies.

Outcomes from this thesis have demonstrated that different MWT types were equally profitable so long as change in MWT is associated with change in other, correlated traits such as calf size and cows are managed appropriately (i.e., adjustments in stocking rate and feed supply). Consequently, selection emphasis may be focussed on other desirable

traits such as growth and carcass merit of finishing progeny while accepting a correlated change in MWT (Chapter 7). While this was true for the current system under consideration, this study only covered one potential farming system for a specific range of cow types. The EBV used for comparison between cow types in Chapter 7 were specific to cows recorded within the Angus New Zealand database (Angus New Zealand, 2022). The main traits impacted by change in MWT across the different cow types in the current study were birth weight (BWT) and weaning weight (WWT) of calves. For the current Angus population, a change in MWT EBV of 43.9 kg from moderate (50–55 breed percentile) to large cow types (top 5 breed percentile) was associated with a 2.1 kg increase in BWT EBV and a 10.6 kg increase in WWT EBV (refer to Chapter 7, Angus New Zealand, 2022). Compared to this, for the same cohort of animals considered in Chapter 7, MWT EBV for Hereford cattle increased by 40.1 kg from moderate cow types (50–55 breed percentile) to large cow types (top 5 breed percentile) and this was accompanied by a 2.4 kg increase in BWT EBV and a 9.4 kg increase in WWT EBV (Hereford New Zealand, 2023). The similar range of EBV for key traits that vary with change in MWT EBV between Angus and Hereford cattle indicate that results from this thesis may be applicable also for the current New Zealand Hereford population.

It has been highlighted in Chapter 7 that the current range of MWT types within New Zealand is comparably small to those much larger cow types overseas (Beck *et al.*, 2016, Ribeiro *et al.*, 2022). Some assumptions and conclusions that were drawn from outcomes from this research may, therefore, differ in an international context, for cow breeds of heavier MWT, and when future selection may alter the range of cow types within the current New Zealand beef cow population. This may include the relationship between LWT and BCS for different cow sizes where a much larger range of cow types with higher genetic merit for MWT would likely impact on the amount of LWT change required to change between BCS units, and this may vary with different cow sizes.

The New Zealand farming system is somewhat unique in that it uses extensive pasture grazing and the buffering capacity of cows in terms of their ability to adjust body energy reserves to renew pasture cover (McCall, 1994, Pleasants *et al.*, 1994) with little use of grain and/or supplementary feed (Smeaton *et al.*, 1983, McCall & Scott, 1988). Those features make it relatively challenging to compare production systems within New Zealand to those systems overseas.

## 8.6 Future considerations

Farming systems vary largely and often in response to the local climate such that management strategies need to be adjusted frequently to farm efficiently and profitably.

The simulation study has highlighted research gaps particularly in terms of feed intake and grazing behaviour of beef cows on extensive hill country pasture. More data recording may be beneficial to better understand feeding patterns of cows, especially under feed shortage situations. Most feed intake measurements are collected either on animals in the post-weaning phase and/or in feedlot environments (Arthur *et al.*, 2004). Very few people have examined and explored ways of measuring feed intake directly in extensively farmed beef cows and research is mainly based on estimating intake from faecal samples using marker capsules (Smeaton *et al.*, 2000, Morris *et al.*, 2010, Morris *et al.*, 2014). Little is known about the social hierarchy of cows under extensive farming conditions (Hubbard *et al.*, 2021) and how this may impact on the feed intake behaviour when animals are required to compete for nutritional resources. It is likely that social dominance impacts on the grazing distribution of the herd (Sowell *et al.*, 1999). Thus, it may be beneficial to explore options to measure traits related to feed intake, grazing pattern and associated social interactions in seasonal calving cows. Practical implications may, however, be limited under hill country conditions due to high costs and challenges associated with data collection on extensively grazed farms such that most approaches used within intensive systems are not applicable. To overcome those limitations GPS collars or ear tags may be used in the future as a way to track animals and to determine feeding patterns on a much larger scale (Aquilani *et al.*, 2022). This may also provide a tool to monitor other traits such as reproductive performance of the animals in terms of heat detection (Brassel *et al.*, 2018, Santos *et al.*, 2022) without the requirement to yard animals on a regular basis for reproductive management.

The simulation model developed in Chapter 6 has been used to test cow performance and productivity under a particular scenario (refer to Chapter 7) and outcomes have shown the most suitable cow type for the given circumstances. The model may, however, provide a tool to answer multiple research questions and to test further hypotheses in the future, such as:

### 1) Relationships with other correlated traits

Relationships with other, correlated traits may be considered in the future, and key traits are likely to vary with the research objective. This may include expanding the existing correlation matrix used within the simulation model to incorporate other traits in the matrix; e.g., the general assumption in Chapter 6 and Chapter 7 was that BCS was a linear response of MWT, and future research may consider including BCS as a correlated trait with MWT.

Besides the current traits that have been included in the study, there are likely other traits with a potential impact on the profitability of beef breeding cows in the future and will need to be considered for future research. With the growing concern of livestock farming on the environment it is likely that traits related to soil quality and/or emissions intensity are becoming increasingly important and should best be accounted for when examining the suitability of a certain cow type within the production system (Beef + Lamb New Zealand, 2017a, Roesch *et al.*, 2019, Ministry for Primary Industries, 2022). Direct measures of these trait groups would allow a lower impact of cows on the environment to be realised using genetic selection (Wall *et al.*, 2010). To date there is no data available for extensively farmed beef cows within New Zealand that would allow the evaluation of such traits. However, selection for traits that are likely correlated with these traits such as feed conversion efficiency, cow size or longevity may offer an opportunity to enhance the environmental footprint of the cow population (Wall *et al.*, 2010, Beef + Lamb New Zealand, 2017a). Improvements in reproductive performance, average weight gain and carcass weights are likely to contribute to a decrease in emissions intensity and this may favour the use of larger MWT types in the future (Kress *et al.*, 1969). However, it needs to be considered that farming of those larger cow types is likely to increase the risk of soil and pasture damage, particularly during the winter months (Beef + Lamb New Zealand, 2017a, Roesch *et al.*, 2019).

Health-related traits are key parameters for improved welfare in animals. Selecting for lower susceptibility for certain diseases or parasite resistance are likely to become a focus of selection within New Zealand beef herds in the future. In an international context, breed associations are focussing more on incorporating novel traits in future genetic evaluations including those related to general immune competence (Reverter *et al.*, 2021) or resistance to Tuberculosis (ICBF, 2023) and certain parasites such as liver fluke (Twomey *et al.*, 2016, Twomey *et al.*, 2018).

## 2) Calculation of economic values

The simulation model may be used to calculate economic values for certain production traits under a scenario where cows are required to respond to variable feed availability. Examining economic values for key production traits would allow the impact of change in a single trait to be evaluated while keeping all other parameters constant, and this could easily be implemented in the existing model. This approach may be used to examine the current distribution of cow types for traits such as MWT, BCS, milk production and the resulting reproductive performance and give an indication as to what selection framework may be used to optimise the current distribution of traits under variable environments. Future research may consider that selection strategies lean towards a different combination of traits.

## 3) Modelling of the finishing herd

Including the finishing herd as an additional sub system could be a way to examine the impact of the finishing herd on the overall profitability of the cow-calf production system. The current study has shown that it is not crucial as to whether the cow herd has fewer large cow types, or a higher number of small cow types so long as nutritional requirements are managed appropriately (Chapter 7). It needs to be considered that if breeding goals are focussed on the finishing herd rather than the maternal herd with traits related to growth of finish animals prior to their second winter or carcass weight as the primary selection target, this would likely require larger MWT types such that those production systems may lean towards breeding for bigger cows to optimise profitability. Selection indexes may consider placing less downward pressure on MWT to not limit genetic gain for correlated growth and carcass traits (Beef + Lamb New Zealand, 2017c). The higher emphasis on carcass merit is unlikely to negatively impact on the maternal herd in terms of MWT, BCS and resulting reproductive success as demonstrated in Chapter 5. In fact, higher selection emphasis on finishing performance in terms of growth and weight traits is likely driving the maternal herd towards improved reproductive outcomes ( $r_g=0.22-0.32$ ) and higher average BCS of mature cows ( $r_g=0.12-0.36$ ).

## 8.7 Conclusions

Genetic evaluation programs should incorporate novel traits such as rebreeding ability of 2-year-old cows after their first calving and cow BCS to make use of higher genetic merit animals as a way to enhance reproductive performance of the breeding herd.

Genetic correlations between fat measures in finishing animals and BCS in cows were low in the current study. Selection strategies may therefore be used to identify animals with higher genetic merit for BCS so as to increase the proportion of cows in the herd with a genetic propensity to maintain higher BCS, likely resulting in cows that are easier to manage to meet phenotypic BCS targets for reproductive management. Previous selection pressure indicates that, for the current New Zealand Angus population, it is not crucial as to whether cow types on farm are larger or smaller so long as the increase in MWT is associated with changes in other traits, especially calf size, and animals are managed appropriately (i.e., adjustments in stocking rate and nutritional resources). This would allow more selection emphasis to be placed on the finishing performance of heifer and steer progeny while accepting a correlated increase in MWT.

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## References

- Åby BA, Aass L, Sehested E, Vangen O 2012. A bio-economic model for calculating economic values of traits for intensive and extensive beef cattle breeds. *Livestock Science* 143: 259-269. DOI: 10.1016/j.livsci.2011.10.003
- Adams DC, Clark RT, Klopfenstein TJ, Volesky JD 1996. Matching the cow with forage resources. *Rangelands* 18: 57-62.
- Afolayan RA, Pitchford WS, Deland MPB, McKiernan WA 2007. Breed variation and genetic parameters for growth and body development in diverse beef cattle genotypes. *Animal* 1: 13-20. DOI: 10.1017/S1751731107257933
- Amer PR 2012. Turning science on robust cattle into improved genetic selection decisions. *Animal* 6: 551-556. DOI: 10.1017/S1751731111002576
- Amer PR, Emmans GC, Simm G 1997. Economic values for carcass traits in UK commercial beef cattle. *Livestock Production Science* 51: 267-281. DOI: 10.1016/S0301-6226(97)00055-9
- Amer PR, Kemp RA, Buchanan-Smith JG, Fox GC, Smith C 1994. A bioeconomic model for comparing beef cattle genotypes at their optimal economic slaughter end point. *Journal of Animal Science* 72: 38-50. DOI: 10.2527/1994.72138x
- Amer PR, Simm G, Keane MG, Diskin MG, Wickham BW 2001. Breeding objectives for beef cattle in Ireland. *Livestock Production Science* 67: 223-239. DOI: 10.1016/S0301-6226(00)00201-3
- Andersen BB 1978. Animal size and efficiency, with special reference to growth and feed conversion in cattle. *Animal Science* 27: 381-391. DOI: 10.1017/S000335610003628X
- Angus Australia. 2023. Mature cow body condition [Online]. Available: <https://www.angusaustralia.com.au/education/breeding-and-genetics/understanding-rbvs/mature-cow-body-condition> [Accessed 19 March 2023].
- Angus New Zealand. 2020. Heritability. Heritabilities of traits in Angus Group TACE (TransTasman Cattle Evaluation) [Online]. Available: <https://angusnz.com/cattle/technical/ebvs/heritability/> [Accessed 04 February 2020].
- Angus New Zealand. 2022a. NZ Angus Animal Enquiry [Online]. Available: <http://abri.une.edu.au/online/cgi-bin/i4.dll?1=3538202F&2=2431&3=56&5=2B3C2B3C3A> [Accessed 12 April 2022].
- Angus New Zealand. 2022b. NZ Angus Animal Enquiry by EBV [Online]. Available: <http://abri.une.edu.au/online/cgi-bin/i4.dll?1=3538202F&2=2031&3=56&5=2B3C2B3C3A> [Accessed 16 October 2022].
- Aquilani C, Confessore A, Bozzi R, Sirtori F, Pugliese C 2022. Review: Precision Livestock Farming technologies in pasture-based livestock systems. *Animal* 16: 100429. DOI: 10.1016/j.animal.2021.100429

## References

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- Arango JA, Cundiff LV, Van Vleck LD 2002. Genetic parameters for weight, weight adjusted for body condition score, height, and body condition score in beef cows. *Journal of Animal Science* 80: 3112-3122. DOI: 10.2527/2002.80123112x
- Arango JA, Van Vleck LD 2002. Size of beef cows: early ideas, new developments. *Genetics and Molecular Research* 1: 51-63. DOI: 10.4238/2002.March.30.5
- Archbold H, Shalloo L, Kennedy E, Pierce KM, Buckley F 2012. Influence of age, body weight and body condition score before mating start date on the pubertal rate of maiden Holstein-Friesian heifers and implications for subsequent cow performance and profitability. *Animal* 6: 1143-1151. DOI: 10.1017/S1751731111002692
- Archer JA, Arthur PF, Parnell PF, van de Ven RJ 1998. Effect of divergent selection for yearling growth rate on female reproductive performance in Angus cattle. *Livestock Production Science* 57: 33-40. DOI: 10.1016/S0301-6226(98)00162-6
- Archer JA, Reverter A, Herd RM, Johnson DJ, Arthur PF 2002. Genetic variation in feed intake and efficiency of mature beef cows and relationships with postweaning measurements. *Proceedings of the 7th World Congress on Genetics Applied to Livestock Production*: 221-225.
- Archer JA, Richardson EC, Herd RM, Arthur PF 1999. Potential for selection to improve efficiency of feed use in beef cattle: A review. *Australian Journal of Agricultural Research* 50: 147-162. DOI: 10.1071/A98075
- Archer JA, Santos B, Dennis N, Walmsley BJ, Amer PR, Pitchford WS. 2018. Development of a bio-economic model to compare economic performance of cow genotypes under distinct feed availability scenarios. [unpublished].
- Arnold JW, Bertrand JK, Benyshek LL, Ludwig C 1991. Estimates of genetic parameters for live animal ultrasound, actual carcass data, and growth traits in beef cattle. *Journal of Animal Science* 69: 985-992. DOI: 10.2527/1991.693985x
- Arthur PF, Archer JA, Herd RM 2004. Feed intake and efficiency in beef cattle: overview of recent Australian research and challenges for the future. *Australian Journal of Experimental Agriculture* 44: 361-369. DOI: 10.1071/EA02162
- Arthur PF, Archer JA, Johnston DJ, Herd RM, Richardson EC, Parnell PF 2001. Genetic and phenotypic variance and covariance components for feed intake, feed efficiency, and other postweaning traits in Angus cattle. *Journal of Animal Science* 79: 2805-2811. DOI: 10.2527/2001.79112805x
- Arthur PF, Archer JA, Melville GJ 1999. Factors influencing dystocia and prediction of dystocia in Angus heifers selected for yearling growth rate. *Australian Journal of Agricultural Research* 51: 147-154. DOI: 10.1071/AR99070
- Arthur PF, Hearnshaw H, Barlow R, Williamson PJ, Stephenson PD, Dibley K 1997. Evaluation of Hereford and first-cross cows on three pasture systems. III. Milk yield and its influence on calf performance. *The Journal of Agricultural Science* 129: 91-98. DOI: 10.1017/S0021859697004553
- Arthur PF, Makarechian M 1992. Heritability estimates and correlations among lifetime production traits measured early in life in beef cattle. *Proceedings of the Australian Association of Animal Breeding and Genetics* 10: 400-403.

- Arthur PF, Makarechian M, Berg RT, Weingardt R 1993. Longevity and lifetime productivity of cows in a purebred Hereford and two multibreed synthetic groups under range conditions. *Journal of Animal Science* 71: 1142-1147. DOI: 10.2527/1993.7151142x
- AUS-MEAT. 2018. Australian beef carcass evaluation. Beef and veal chiller assessment language [Online]. AUS-MEAT: Brisbane, Queensland, Australia. Available: [https://www.ausmeat.com.au/WebDocuments/Chiller\\_Assessment\\_Language.pdf](https://www.ausmeat.com.au/WebDocuments/Chiller_Assessment_Language.pdf) [Accessed 28 October 2021].
- AUS-MEAT. 2020. Handbook of Australian beef processing [Online]. Queensland, Australia: AUS-MEAT Limited. Available: [https://www.ausmeat.com.au/WebDocuments/Producer\\_HAP\\_Beef\\_Small.pdf](https://www.ausmeat.com.au/WebDocuments/Producer_HAP_Beef_Small.pdf) [Accessed 18 April 2020].
- Ayres H, Ferreira RM, Torres-Júnior JRS, Demétrio CGB, Sá Filho MF, Gimenes LU, Penteadó L, D'Occhio MJ, Baruselli PS 2014. Inferences of body energy reserves on conception rate of suckled Zebu beef cows subjected to timed artificial insemination followed by natural mating. *Theriogenology* 82: 529-536. DOI: 10.1016/j.theriogenology.2014.04.026
- Baker BB, Bourdon RM, Hanson JD 1992. FORAGE: a model of forage intake in beef cattle. *Ecological Modelling* 60: 257-279. DOI: 10.1016/0304-3800(92)90036-E
- Baker RL, Carter AH, Morris CA, Johnson DL 1990. Evaluation of eleven cattle breeds for crossbred beef production: performance of progeny up to 13 months of age. *Animal Production* 50: 63-77. DOI: 10.1017/S0003356100004475
- Bass JJ, Baker RL, Carter AH, Jones KR 1975. The carcass composition of Angus, Hereford x Angus, Friesian x Angus, Charolaise x Angus and South Devon x Angus steers. *Proceedings of the New Zealand Society of Animal Production* 35: 112-118.
- Beck P, Stewart C, Gadberry M, Haque M, Biermacher J 2016. Effect of mature body weight and stocking rate on cow and calf performance, cow herd efficiency, and economics in the southeastern United States. *Journal of Animal Science* 94: 1689-1702. DOI: 10.2527/jas.2015-0049
- Beef + Lamb New Zealand 2017a. Beef breeding cows. In: Geenty K & Morris ST (eds.) *Guide to New Zealand cattle farming*. Wellington, New Zealand: Beef + Lamb New Zealand. 13-22.
- Beef + Lamb New Zealand 2017b. Beef industry overview. In: Geenty K & Morris ST (eds.) *Guide to New Zealand cattle farming*. Wellington, New Zealand: Beef + Lamb New Zealand. 2-12.
- Beef + Lamb New Zealand. 2017c. Better beef breeding - Bull buying for the commercial beef breeder [Online]. Available: [http://www.blznugenetics.com/files/1507095472\\_Better-Beef-Breeding-2017.pdf](http://www.blznugenetics.com/files/1507095472_Better-Beef-Breeding-2017.pdf) [Accessed 11 March 2020].
- Beef + Lamb New Zealand 2017d. Environment management. In: Geenty K & Morris ST (eds.) *Guide to New Zealand cattle farming*. Wellington, New Zealand: Beef + Lamb New Zealand. 112-120.

## References

---

- Beef + Lamb New Zealand. 2017e. Feed planning in a tough winter [Online]. Available: <https://beeflambnz.com/sites/default/files/factsheets/pdfs/fact-sheet-68-feed-planning-in-a-tough-winter.pdf> [Accessed 16 January 2023].
- Beef + Lamb New Zealand 2017f. Feeding and efficiency. In: Geenty K & Morris ST (eds.) Guide to New Zealand cattle farming. Wellington, New Zealand: Beef + Lamb New Zealand. 37-47.
- Beef + Lamb New Zealand 2017g. Genetic improvement. In: Geenty K & Morris ST (eds.) Guide to New Zealand cattle farming. Wellington, New Zealand: Beef + Lamb New Zealand. 62-81.
- Beef + Lamb New Zealand 2017h. Pasture management. In: Geenty K & Morris ST (eds.) Guide to New Zealand cattle farming. Wellington, New Zealand: Beef + Lamb New Zealand. 48-61.
- Beef + Lamb New Zealand 2017i. Post weaning systems. In: Geenty K & Morris ST (eds.) Guide to New Zealand cattle farming. Wellington, New Zealand: Beef + Lamb New Zealand. 23-36.
- Beef + Lamb New Zealand 2017j. Reproduction. In: Geenty K & Morris ST (eds.) Guide to New Zealand cattle farming. Wellington, New Zealand: Beef + Lamb New Zealand. 82-93.
- Beef + Lamb New Zealand. 2020. Fact sheet - supplementary feed guide [Online]. Wellington, New Zealand. Available: <https://beeflambnz.com/sites/default/files/factsheets/pdfs/fact-sheet-260-Cost%20of%20Feed.pdf> [Accessed 28 October 2022].
- Beef + Lamb New Zealand. 2021. Compendium of New Zealand farm facts [Online]. Wellington. Available: [https://beeflambnz.com/sites/default/files/data/files/Compendium%202021\\_digital.pdf](https://beeflambnz.com/sites/default/files/data/files/Compendium%202021_digital.pdf) [Accessed 29 March 2022].
- Beef + Lamb New Zealand. 2022a. Farm classes [Online]. Available: <https://beeflambnz.com/data-tools/farm-classes> [Accessed 2 February 2020].
- Beef + Lamb New Zealand. 2022b. Mid-Season Update [Online]. Available: <https://beeflambnz.com/sites/default/files/data/files/Mid-Season-Update-2021-22.pdf> [Accessed 14 March 2022].
- Bellows RA, Short RE 1978. Effects of precalving feed level on birth weight, calving difficulty and subsequent fertility. *Journal of Animal Science* 46: 1522-1528. DOI: 10.2527/jas1978.4661522x
- Bellows RA, Short RE, Anderson DC, Knapp BW, Pahnish OF 1971. Cause and effect relationships associated with calving difficulty and calf birth weight. *Journal of Animal Science* 33: 407-415. DOI: 10.2527/jas1971.332407x
- Bellows RA, Short RE, Richardson GV 1982. Effects of sire, age of dam and gestation feed level on dystocia and postpartum reproduction. *Journal of Animal Science* 55: 18-27. DOI: 10.2527/jas1982.55118x
- Benyshek LL 1981. Heritabilities for growth and carcass traits estimated from data on Herefords under commercial conditions. *Journal of Animal Science* 53: 49-56. DOI: 10.2527/jas1981.53149x

- 
- Berry DP, Buckley F, Dillon P 2011. Relationship between live weight and body condition score in Irish Holstein-Friesian dairy cows. *Irish Journal of Agricultural and Food Research* 50: 141-147. DOI: 10.2307/41549247
- Berry DP, Buckley F, Dillon P, Evans RD, Rath M, Veerkamp RF 2003. Genetic relationships among body condition score, body weight, milk yield, and fertility in dairy cows. *Journal of Dairy Science* 86: 2193-2204. DOI: 10.3168/jds.S0022-0302(03)73809-0
- Berry DP, Evans RD 2014. Genetics of reproductive performance in seasonal calving beef cows and its association with performance traits. *Journal of Animal Science* 92: 1412-1422. DOI: 10.2527/jas.2013-6723
- Berry DP, Wall E, Pryce JE 2014. Genetics and genomics of reproductive performance in dairy and beef cattle. *Animal* 8: 105-121. DOI: 10.1017/S1751731114000743
- Bir C, De Vuyst EA, Rolf M, Lalman D 2018. Optimal beef cow weights in the US Southern Plains. *Journal of Agricultural and Resource Economics* 43: 103-117. DOI: 10.22004/ag.econ.267612
- Bishop DK, Wettemann RP, Spicer LJ 1994. Body energy reserves influence the onset of luteal activity after early weaning of beef cows. *Journal of Animal Science* 72: 2703-2708. DOI: 10.2527/1994.72102703x
- Blanc F, Agabriel J 2008. Modelling the reproductive efficiency in a beef cow herd: effect of calving date, bull exposure and body condition at calving on the calving-conception interval and calving distribution. *The Journal of Agricultural Science* 146: 143-161. DOI: 10.1017/S0021859608007715
- Bochud M 2012. Estimating heritability from nuclear family and pedigree data. *Statistical human genetics. Methods in molecular biology (methods and protocols)*. Humana Press. Available: 10.1007/978-1-61779-555-8\_10, 171-186.
- Boldt RJ, Speidel SE, Thomas MG, Enns RM 2018. Genetic parameters for fertility and production traits in Red Angus cattle. *Journal of Animal Science* 96: 4100-4111. DOI: 10.1093/jas/sky294
- Boligon AA, Albuquerque LG 2011. Genetic parameters and relationships of heifer pregnancy and age at first calving with weight gain, yearling and mature weight in Nelore cattle. *Livestock Science* 141: 12-16. DOI: 10.1016/j.livsci.2011.04.009
- Boligon AA, Albuquerque LG, Mercadante MEZ, Lobo RB 2008. Models for genetic evaluation of Nelore cattle mature body weight. *Journal of Animal Science* 86: 2840-2844. DOI: 10.2527/jas.2007-0823
- Boligon AA, Ayres DR, Pereira RJ, Morotti NP, Albuquerque LG 2012. Genetic associations of visual scores with subsequent rebreeding and days to first calving in Nelore cattle. *Journal of Animal Breeding and Genetics* 129: 448-456. DOI: 10.1111/j.1439-0388.2012.00998.x
- Boligon AA, Baldi F, Albuquerque LGd 2011. Genetic parameters and relationships between growth traits and scrotal circumference measured at different ages in Nelore cattle. *Genetics and Molecular Biology* 34: 225-230. DOI: 10.1590/s1415-47572011005000004
-

## References

---

- Bormann JM, Totir LR, Kachman SD, Fernando RL, Wilson DE 2006. Pregnancy rate and first-service conception rate in Angus heifers. *Journal of Animal Science* 84: 2022-2025. DOI: 10.2527/jas.2005-615
- Börner V, Johnston DJ, Graser H-U 2013. Genetic relationships between live animal scan traits and carcass traits of Australian Angus bulls and heifers. *Animal Production Science* 53: 1075-1082. DOI: 10.1071/AN12435
- Bourdon RM 1999a. Correlated response to selection. In: *Understanding animal breeding*. New-Jersey: Prentice-Hall. 275-293.
- Bourdon RM 1999b. Heritability and repeatability. In: *Understanding animal breeding*. 2nd Edition ed. New Jersey: Prentice-Hall. 161-197.
- Bourdon RM 1999c. Statistics and their application to quantitative traits. In: *Understanding animal breeding*. New Jersey: Prentice-Hall. 123-160.
- Bourdon RM, Brinks JS 1982. Genetic, environmental and phenotypic relationships among gestation length, birth weight, growth traits and age at first calving in beef cattle. *Journal of Animal Science* 55: 543-553. DOI: 10.2527/jas1982.553543x
- Bourdon RM, Brinks JS 1987. Simulated efficiency of range beef production. I. Growth and milk production. *Journal of Animal Science* 65: 943-955. DOI: 10.2527/jas1987.654943x
- Brassel J, Rohrssen F, Failing K, Wehrend A 2018. Automated oestrus detection using multimetric behaviour recognition in seasonal-calving dairy cattle on pasture. *New Zealand Veterinary Journal* 66: 243-247. DOI: 10.1080/00480169.2018.1479316
- BREEDPLAN. 2019. Available: <http://breedplan.une.edu.au/> [Accessed 10 February 2020].
- Brinks JS, Clark RT, Kieffer NM, Urick JJ 1964. Estimates of genetic, environmental and phenotypic parameters in range Hereford females. *Journal of Animal Science* 23: 711-716. DOI: 10.2527/jas1964.233711x
- Brockington NR, Gonzalez CA, Veil JM, Vera RR, Teixeira NM, de Assis AG 1983. A bio-economic modelling project for small-scale milk production systems in South-East Brasil. *Agricultural Systems* 12: 37-60. DOI: 10.1016/0308-521X(83)90020-3
- Brody S 1945. *Bioenergetics and growth*, New York, Reinhold Publisher Co.
- Brody S, Lardy HA 1946. Bioenergetics and growth. *The Journal of Physical Chemistry* 50: 168-169. DOI: 10.1021/j150446a008
- Brown DJ, Atkins K, Huisman AE 2005. Expression of body weight, fleece weight and fibre diameter in across flock genetic evaluation. *Proceedings of the Association for the Advancement of Animal Breeding and Genetics* 16: 84-87.
- Brown JE, Fitzhugh HA, Jr., Cartwright TC 1976. A comparison of nonlinear models for describing weight-age relationships in cattle. *Journal of Animal Science* 42: 810-818. DOI: 10.2527/jas1976.424810x

- Brown P, Daigneault A, Dawson J 2019. Age, values, farming objectives, past management decisions, and future intentions in New Zealand agriculture. *Journal of Environmental Management* 231: 110-120. DOI: 10.1016/j.jenvman.2018.10.018
- Buckley F, O'Sullivan K, Mee JF, Evans RD, Dillon P 2003. Relationships among milk yield, body condition, cow weight, and reproduction in spring-calved Holstein-Friesians. *Journal of Dairy Science* 86: 2308-2319. DOI: 10.3168/jds.S0022-0302(03)73823-5
- Bullock KD, Bertrand JK, Benyshek LL 1993. Genetic and environmental parameters for mature weight and other growth measures in Polled Hereford cattle. *Journal of Animal Science* 71: 1737-1741. DOI: 10.2527/1993.7171737x
- Burriss MJ, Blunn CT 1952. Some factors affecting gestation length and birth weight of beef cattle. *Journal of Animal Science* 11: 34-41. DOI: 10.2527/jas1952.111134x
- Burrow HM 2001. Variances and covariances between productive and adaptive traits and temperament in a composite breed of tropical beef cattle. *Livestock Production Science* 70: 213-233. DOI: 10.1016/S0301-6226(01)00178-6
- Buskirk DD, Lemenager RP, Horstman LA 1992. Estimation of net energy requirements ( $NE_m$  and  $NE_\Delta$ ) of lactating beef cows. *Journal of Animal Science* 70: 3867-3876. DOI: 10.2527/1992.70123867x
- Buzanskas ME, Pires PS, Chud TCS, Bernardes PA, Rola LD, Savegnago RP, Lôbo RB, Munari DP 2017. Parameter estimates for reproductive and carcass traits in Nelore beef cattle. *Theriogenology* 92: 204-209. DOI: 10.1016/j.theriogenology.2016.09.057
- Cammack KM, Thomas MG, Enns RM 2009. Reproductive traits and their heritabilities in beef cattle. *The Professional Animal Scientist* 25: 517-528. DOI: 10.15232/S1080-7446(15)30753-1
- Campos GS, Braccini Neto J, Oaigen RP, Cardoso FF, Cobuci JA, Kern EL, Campos LT, Bertoli CD, McManus CM 2014. Bioeconomic model and selection indices in Aberdeen Angus cattle. *Journal of Animal Breeding and Genetics* 131: 305-312. DOI: 10.1111/jbg.12069
- Canadian Angus. 2023. AngusONE: Genetic evaluations [Online]. Available: <https://www.cdnangus.ca/adding-value/angusone-epd-genetic-evaluations/> [Accessed 19 March 2023].
- Carlson DH, Thurow TL 1996. Comprehensive evaluation of the improved SPUR model (SPUR-91). *Ecological Modelling* 85: 229-240. DOI: 10.1016/0304-3800(94)00190-1
- Carter AH 1975. Evaluation of cattle breeds for beef production in New Zealand—A review. *Livestock Production Science* 2: 327-340. DOI: 10.1016/0301-6226(75)90117-7
- Cartwright TC 1970. Selection criteria for beef cattle for the future. *Journal of Animal Science* 30: 706-711. DOI: 10.2527/jas1970.305706x
- Cartwright TC 1979. The use of systems analysis in animal science with emphasis on animal breeding. *Journal of Animal Science* 49: 817-825. DOI: 10.2527/jas1979.493817x

## References

---

- Cavani L, Garcia DA, Carreño LOD, Ono RK, Pires MP, Farah MM, Ventura HT, Millen DD, Fonseca R 2015. Estimates of genetic parameters for reproductive traits in Brahman cattle breed. *Journal of Animal Science* 93: 3287-3291. DOI: 10.2527/jas.2015-8970
- Charmley E, Stephens ML, Kennedy PM 2008. Predicting livestock productivity and methane emissions in northern Australia: development of a bio-economic modelling approach. *Australian Journal of Experimental Agriculture* 48: 109-113. DOI: 10.1071/EA07264
- Charteris PL, Garrick DJ 1996. Characterisation of beef cattle breeding industry structure. *Proceedings of the New Zealand Society of Animal Production* 56: 386-389.
- Charteris PL, Morris ST, Matthews PNP 1999. Pasture-based beef production in New Zealand. WP Institute of Veterinary Animal and Biomedical Sciences Massey University, New Zealand.
- Ciccioli NH, Wettemann RP, Spicer LJ, Lents CA, White FJ, Keisler DH 2003. Influence of body condition at calving and postpartum nutrition on endocrine function and reproductive performance of primiparous beef cows. *Journal of Animal Science* 81: 3107-3120. DOI: 10.2527/2003.81123107x
- Clark DA, Woodward SL 2007. Supplementation of dairy cows, beef cattle and sheep grazing pasture. *Occasional Publication - New Zealand Society of Animal Production* 14: 117-132.
- Coleman LW, Back PJ, Lopez-Villalobos N, Blair HT, Hickson RE 2018. Heritability of gestation length in beef-cross-dairy calves born to Angus and Hereford bulls. *Proceedings of the World Congress on Genetics Applied to Livestock Production* 11.
- Cooke JR 2018. Using mathematics as a problem-solving tool. In: *Agricultural Systems Modeling and Simulation*. CRC Press. 63-92.
- Copping KJ, Accioly JM, Deland MPB, Edwards NJ, Graham JF, Hebart ML, Herd RM, Jones FM, Laurence M, Lee SJ, Speijers EJ, Pitchford WS 2016. Divergent genotypes for fatness or residual feed intake in Angus cattle. 3. Performance of mature cows. *Animal Production Science* 58: 55-66. DOI: 10.1071/AN13295
- Cortés-Lacruz X, Casasús I, Revilla R, Sanz A, Blanco M, Villalba D 2017. The milk yield of dams and its relation to direct and maternal genetic components of weaning weight in beef cattle. *Livestock Science* 202: 143-149. DOI: 10.1016/j.livsci.2017.05.025
- Costa RB, Misztal I, Elzo MA, Bertrand JK, Silva LOC, Łukaszewicz M 2011. Estimation of genetic parameters for mature weight in Angus cattle. *Journal of Animal Science* 89: 2680-2686. DOI: 10.2527/jas.2010-3574
- Crews DH, Jr. 2006. Age of dam and sex of calf adjustments and genetic parameters for gestation length in Charolais cattle. *Journal of Animal Science* 84: 25-31. DOI: 10.2527/2006.84125x
- Crews DH, Jr., Lowerison M, Caron N, Kemp RA 2004. Genetic parameters among growth and carcass traits of Canadian Charolais cattle. *Canadian Journal of Animal Science* 84: 589-597. DOI: 10.4141/A04-019

- Cundiff LV, Gregory KE, Koch RM, Dickerson GE 1971. Genetic relationships among growth and carcass traits of beef cattle. *Journal of Animal Science* 33: 550-555. DOI: 10.2527/jas1971.333550x
- Davis MP, Wettemann RP. 2009. Relationship between weight at puberty and mature weight in beef cattle [Online]. Available: <https://extension.okstate.edu/programs/beef-extension/research-reports/site-files/documents/2009/wettemann.pdf> [Accessed 2021 24 July].
- De Ruiter JM, Dalley DE, Hughes TP, Fraser TJ, Dewhurst RJ 2007. Types of supplements: Their nutritive value and use. *Occasional Publication - New Zealand Society of Animal Production* 14: 97-115.
- DeRouen SM, Franke DE, Morrison DG, Wyatt WE, Coombs DF, White TW, Humes PE, Greene BB 1994. Prepartum body condition and weight influences on reproductive performance of first-calf beef cows. *Journal of Animal Science* 72: 1119-1125. DOI: 10.2527/1994.7251119x
- Dinkel CA, Brown MA 1978. An evaluation of the ratio of calf weight to cow weight as an indicator of cow efficiency. *Journal of Animal Science* 46: 614-617. DOI: 10.2527/jas1978.463614x
- Diskin MG, Kenny DA 2016. Managing the reproductive performance of beef cows. *Theriogenology* 86: 379-387. DOI: 10.1016/j.theriogenology.2016.04.052
- Donoghue KA, Lee SJ, Parnell PF, Pitchford WS 2016. Maternal body composition in seedstock herds. 4. Genetic parameters for body composition of Angus and Hereford cows. *Animal Production Science* 58: 145-155. DOI: 10.1071/AN13258
- Doornbos DE, Bellows RA, Burfening PJ, Knapp BW 1984. Effects of dam age, prepartum nutrition and duration of labor on productivity and postpartum reproduction in beef females. *Journal of Animal Science* 59: 1-10. DOI: 10.2527/jas1984.5911
- Dowle K, Doyle CJ, Spedding AW, Pollott GE 1988. A model for evaluating grassland management decisions on beef and sheep farms in the UK. *Agricultural Systems* 28: 299-317. DOI: 10.1016/0308-521X(88)90072-8
- Doye DG, Lalman DL 2011. Moderate versus big cows: Do big cows carry their weight on the ranch? *Southern Agricultural Economics Association Annual Meeting*. DOI: 10.22004/ag.econ.98748
- Doyle CJ, Baars JA, Bywater AC 1989. A simulation model of bull beef production under rotational grazing in the Waikato Region of New Zealand. *Agricultural Systems* 31: 247-278. DOI: 10.1016/0308-521X(89)90024-3
- Doyle SP, Golden BL, Green RD, Brinks JS 2000. Additive genetic parameter estimates for heifer pregnancy and subsequent reproduction in Angus females. *Journal of Animal Science* 78: 2091-2098. DOI: 10.2527/2000.7882091x
- Ebersohn JP 1976. A commentary on systems studies in agriculture. *Agricultural Systems* 1: 173-184. DOI: 10.1016/0308-521X(76)90039-1
- Ekstrøm CT 2009. The impact of pedigree structure on heritability estimates. *Human Heredity* 68: 243-251. DOI: 10.1159/000228922

## References

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- Eler JP, Van Vleck LD, Ferraz JB, Lôbo RB 1995. Estimation of variances due to direct and maternal effects for growth traits of Nelore cattle. *Journal of Animal Science* 73: 3253-3258. DOI: 10.2527/1995.73113253x
- Endecott RL, Funston RN, Mulliniks JT, Roberts AJ 2013. Joint Alpharma-Beef Species Symposium: Implications of beef heifer development systems and lifetime productivity. *Journal of Animal Science* 91: 1329-1335. DOI: 10.2527/jas.2012-5704
- Everett RW, Keown JF 1984. Mixed model sire evaluation with dairy cattle—experience and genetic gain. *Journal of Animal Science* 59: 529-541. DOI: 10.2527/jas1984.592529x
- Eversole DE, Browne MF, Hall JB, Dietz RE. 2009. Body condition scoring beef cows [Online]. Available: <https://vtechworks.lib.vt.edu/bitstream/handle/10919/50710/400-795.pdf> [Accessed 16 February 2021].
- Farrell LJ, Morris ST, Kenyon PR, Tozer PR 2021. Simulating beef cattle herd productivity with varying cow liveweight and fixed feed supply. *Agriculture* 11: 35-50. DOI: 10.3390/agriculture11010035
- Ferrell CL, Jenkins TG 1984. Energy utilization by mature, nonpregnant, nonlactating cows of different types. *Journal of Animal Science* 58: 234-243. DOI: 10.2527/jas1984.581234x
- Ferrell CL, Jenkins TG 1985. Cow type and the nutritional environment: nutritional aspects. *Journal of Animal Science* 61: 725-741. DOI: 10.2527/jas1985.613725x
- Fitzhugh HA 1978. Animal size and efficiency, with special reference to the breeding female. *Animal Science* 27: 393-401. DOI: 10.1017/S0003356100036291
- Fitzhugh HA, Jr. 1976. Analysis of growth curves and strategies for altering their shape. *Journal of Animal Science* 42: 1036-1051. DOI: 10.2527/jas1976.4241036x
- Forbes JM 2003. The multifactorial nature of food intake control. *Journal of Animal Science* 81: E139-E144. DOI: 10.2527/2003.8114\_suppl\_2E139x
- Forni S, Albuquerque LG 2005. Estimates of genetic correlations between days to calving and reproductive and weight traits in Nelore cattle. *Journal of Animal Science* 83: 1511-1515. DOI: 10.2527/2005.8371511x
- Foster DL, Nagatani S 1999. Physiological perspectives on leptin as a regulator of reproduction: Role in timing puberty. *Biology of Reproduction* 60: 205-215. DOI: 10.1095/biolreprod60.2.205
- France J, Gill M, Thornley JHM, England P 1987. A model of nutrient utilization and body composition in beef cattle. *Animal Science* 44: 371-385. DOI: 10.1017/S0003356100012307
- Freer M, Dove H, Nolan JV 2007. Energy requirements of the animal. In: *Nutrient requirements of domesticated ruminants*. Collingwood, Australia: CSIRO Publishing. 14-61.
- Friggens NC, Blanc F, Berry DP, Pullet L 2017. Review: Deciphering animal robustness. A synthesis to facilitate its use in livestock breeding and management. *Animal* 11: 2237-2251. DOI: 10.1017/S175173111700088X

- 
- Gilmour AR, Gogel BJ, Cullis BR, Welham SJ, Thompson R 2015. ASReml user guide release 4.1 structural specification. VSN international Ltd.: Hemel Hempstead, UK.
- Gompertz B 1825. On the nature of the function expressive of the law of human mortality, and on a new mode of determining the value of life contingencies. *Philosophical transactions of the Royal Society of London* 115: 513-583.
- Goodling RC, Shook GE, Weigel KA, Zwald NR 2005. The effect of synchronization on genetic parameters of reproductive traits in dairy cattle. *Journal of Dairy Science* 88: 2217-2225. DOI: 10.3168/jds.S0022-0302(05)72897-6
- Graser H-U, Tier B, Johnston DJ, Barwick SA 2005. Genetic evaluation for the beef industry in Australia. *Australian Journal of Experimental Agriculture* 45: 913-921. DOI: 10.1071/EA05075
- Greenwood PL, Cafe LM 2007. Prenatal and pre-weaning growth and nutrition of cattle: long-term consequences for beef production. *Animal* 1: 1283-1296. DOI: 10.1017/S175173110700050X
- Greenwood PL, Gardner GE, Ferguson DM 2018. Current situation and future prospects for the Australian beef industry—A review. *Asian-Australasian Journal of Animal Sciences* 31: 992-1006. DOI: 10.5713/ajas.18.0090
- Gregory KE 1972. Beef cattle type for maximum efficiency “Putting it all together”. *Journal of Animal Science* 34: 881-884. DOI: 10.2527/jas1972.345881x
- Groen AF, Steine T, Colleau J-J, Pedersen J, Pribyl J, Reinsch N 1997. Economic values in dairy cattle breeding, with special reference to functional traits. *Livestock Production Science* 49: 1-21. DOI: 10.1016/S0301-6226(97)00041-9
- Grosshans T, Xu ZZ, Burton LJ, Johnson DL, Macmillan KL 1997. Performance and genetic parameters for fertility of seasonal dairy cows in New Zealand. *Livestock Production Science* 51: 41-51. DOI: 10.1016/S0301-6226(97)00104-8
- Gutiérrez JP, Alvarez I, Fernández I, Royo LJ, Díez J, Goyache F 2002. Genetic relationships between calving date, calving interval, age at first calving and type traits in beef cattle. *Livestock Production Science* 78: 215-222. DOI: 10.1016/S0301-6226(02)00100-8
- Hansen PJ, Hauser ER 1983. Genotype  $\times$  environmental interactions on reproductive traits of bovine females. III. Seasonal variation in postpartum reproduction as influenced by genotype, suckling and dietary regimen. *Journal of Animal Science* 56: 1362-1369. DOI: 10.2527/jas1983.5661362x
- Harper GS, Pethick DW 2004. How might marbling begin? *Australian Journal of Experimental Agriculture* 44: 653-662. DOI: 10.1071/EA02114
- Hayes BJ, Goddard ME 2008. Prediction of breeding values using marker-derived relationship matrices. *Journal of Animal Science* 86: 2089-2092. DOI: 10.2527/jas.2007-0733
- Hereford New Zealand. 2023. NZ Hereford Animal Enquiry by EBV [Online]. Available: <http://abri.une.edu.au/online/cgi-bin/i4.dll?1=3538292F&2=2031&3=56&5=2B3C2B3C3A> [Accessed 19 March 2023].
-

## References

---

- Hess BW, Lake SL, Scholljegerdes EJ, Weston TR, Nayigihugu V, Molle JDC, Moss GE 2005. Nutritional controls of beef cow reproduction. *Journal of Animal Science* 83: E90-E106. DOI: 10.2527/2005.8313\_supplE90x
- Hickson RE, Anderson WJ, Kenyon PR, Lopez-Villalobos N, Morris ST 2008a. A survey of beef cattle farmers in New Zealand, examining management practices of primiparous breeding heifers. *New Zealand Veterinary Journal* 56: 176-183. DOI: 10.1080/00480169.2008.36831
- Hickson RE, Balcomb C, Fraser K, Lopez-Villalobos KP, Morris ST 2011. The effect of breed on the onset of puberty in heifers. *Proceedings of the Association for the Advancement of Animal Breeding and Genetics* 19: 51-54.
- Hickson RE, Corner-Thomas R, Martin NP, Kenyon PR, Lopez-Villalobos N, Morris ST 2015. Stayability of beef-cross-dairy breeding cows to six years of age. *Proceedings of the New Zealand Society of Animal Production* 75: 159-163.
- Hickson RE, Kenyon PR, Lopez-Villalobos N, Morris ST 2008b. Effects of liveweight gain during pregnancy of 15-month-old Angus heifers on dystocia and birth weight, body dimensions, estimated milk intake and weaning weight of the calves. *New Zealand Journal of Agricultural Research* 51: 171-180. DOI: 10.1080/00288230809510445
- Hickson RE, Lopez-Villalobos N, Kenyon PR, Morris ST 2014. Breed effects and heterosis for productivity traits at first calving of Angus, Holstein Friesian, Jersey and crossbred beef cows. *Animal Production Science* 54: 1381-1387. DOI: 10.1071/AN14223
- Hickson RE, Lopez-Villalobos N, Kenyon PR, Ridler BJ, Morris ST 2010. Profitability of calving heifers at 2 compared with 3 years of age and the effect of incidence of assistance at parturition on profitability. *Animal Production Science* 50: 354-358. DOI: 10.1071/AN09180
- Hickson RE, Morris ST, Kenyon PR, Lopez-Villalobos N 2006. Dystocia in beef heifers: A review of genetic and nutritional influences. *New Zealand Veterinary Journal* 54: 256-264. DOI: 10.1080/00480169.2006.36708
- Hickson RE, Morris ST, Thomson BC. 2017. Beef cow body condition scoring [Online]. Available: <https://beeflambnz.com/knowledge-hub/PDF/beef-cow-body-condition-scoring> [Accessed 28 November 2022].
- Hickson RE, Pitchford WS 2021. Selection strategies for beef cow size and condition. *Animal Production Science* 61: 1925-1931. DOI: 10.1071/AN21077
- Hirooka H 2010. Systems approaches to beef cattle production systems using modeling and simulation. *Animal Science Journal* 81: 411-424. DOI: 10.1111/j.1740-0929.2010.00769.x
- Hirooka H, Yamada Y 1990. A general simulation model for cattle growth and beef production. *Asian-Australasian Journal of Animal Sciences* 3: 205-218. DOI: 10.5713/ajas.1990.205
- Hocquette JF, Gondret F, Baéza E, Médale F, Jurie C, Pethick DW 2010. Intramuscular fat content in meat-producing animals: development, genetic and nutritional control, and identification of putative markers. *Animal* 4: 303-319. DOI: 10.1017/S1751731109991091

- Hohenboken WD, Dudley A, Moody DE 1992. A comparison among equations to characterize lactation curves in beef cows. *Animal Science* 55: 23-28. DOI: 10.1017/S0003356100037223
- Houghton PL, Turlington LM 1992. Application of ultrasound for feeding and finishing animals: a review. *Journal of Animal Science* 70: 930-941. DOI: 10.2527/1992.703930x
- Hubbard AJ, Foster MJ, Daigle CL 2021. Social dominance in beef cattle — A scoping review. *Applied Animal Behaviour Science* 241: 105390. DOI: 10.1016/j.applanim.2021.105390
- Hudson GFS, Van Vleck LD 1981. Relationship between production and stayability in Holstein cattle. *Journal of Dairy Science* 64: 2246-2250. DOI: 10.3168/jds.S0022-0302(81)82836-6
- ICBF. 2023. Genetic Resistance for TB and liver fluke infection [Online]. Available: <https://www.icbf.com/health-trait-results/> [Accessed 25 February 2023].
- Ingrand S 2000. Feeding behaviour, intake and performance in beef cattle managed in groups. *Productions Animales* 13: 151-163.
- Ingvartsen KL 1994. Models of voluntary food intake in cattle. *Livestock Production Science* 39: 19-38. DOI: 10.1016/0301-6226(94)90149-X
- Interest New Zealand. 2022a. Cow prime - processor schedules [Online]. Available: <https://www.interest.co.nz/rural/beef/cow-prime> [Accessed 10 September 2022].
- Interest New Zealand. 2022b. Heifer weaner calf - saleyard transactions [Online]. Available: [https://www.interest.co.nz/rural/beef/calf/heifer\\_weaner](https://www.interest.co.nz/rural/beef/calf/heifer_weaner) [Accessed 11 November 2022].
- Interest New Zealand. 2022c. Steer weaner calf - saleyard transactions [Online]. Available: [https://www.interest.co.nz/rural/beef/calf/steer\\_weaner](https://www.interest.co.nz/rural/beef/calf/steer_weaner) [Accessed 11 November 2022].
- Jenkins TG, Ferrell CL 1984. A note on lactation curves of crossbred cows. *Animal Science* 39: 479-482. DOI: 10.1017/S0003356100032232
- Jenkins TG, Ferrell CL 1994. Productivity through weaning of nine breeds of cattle under varying feed availabilities: I. Initial evaluation. *Journal of Animal Science* 72: 2787-2797. DOI: 10.2527/1994.72112787x
- Jenkins TG, Kaps M, Cundiff LV, Ferrell CL 1991. Evaluation of between- and within-breed variation in measures of weight-age relationships. *Journal of Animal Science* 69: 3118-3128. DOI: 10.2527/1991.6983118x
- Joandet GE, Cartwright TC 1975. Modeling beef production systems. *Journal of Animal Science* 41: 1238-1246. DOI: 10.2527/jas1975.4141238x
- Johanson JM, Berger PJ 2003. Birth weight as a predictor of calving ease and perinatal mortality in holstein cattle. *Journal of Dairy Science* 86: 3745-3755. DOI: 10.3168/jds.S0022-0302(03)73981-2
- Johnston DJ 2014. Genetic improvement of reproduction in beef cattle. *Proceedings of the 10th World Congress of Genetics Applied to Livestock Production*: 17-22.

## References

---

- Johnston DJ, Barwick SA, Fordyce G, Holroyd RG, Williams PJ, Corbet NJ, Grant T 2014. Genetics of early and lifetime annual reproductive performance in cows of two tropical beef genotypes in northern Australia. *Animal Production Science* 54: 1-15. DOI: 10.1071/AN13043
- Johnston DJ, Bunter KL 1996. Days to calving in Angus cattle: Genetic and environmental effects, and covariances with other traits. *Livestock Production Science* 45: 13-22. DOI: 10.1016/0301-6226(95)00088-7
- Johnston DJ, Chandler H, Graser HU 1996. Genetic parameters for cow weight and condition score in Angus, Hereford, and Poll Hereford cattle. *Australian Journal of Agricultural Research* 47: 1251-1260. DOI: 10.1071/AR9961251
- Jones HE, Amer PR, Lewis RM, Emmans GC 2004. Economic values for changes in carcass lean and fat weights at a fixed age for terminal sire breeds of sheep in the UK. *Livestock Production Science* 89: 1-17. DOI: 10.1016/j.livprodsci.2004.02.002
- Jones JW, Antle JM, Basso B, Boote KJ, Conant RT, Foster I, Godfray HCJ, Herrero M, Howitt RE, Janssen S, Keating BA, Munoz-Carpena R, Porter CH, Rosenzweig C, Wheeler TR 2017. Brief history of agricultural systems modeling. *Agricultural Systems* 155: 240-254. DOI: 10.1016/j.agsy.2016.05.014
- Kahn HE, Spedding CRW 1983. A dynamic model for the simulation of cattle herd production systems: Part 1—General description and the effects of simulation techniques on model results. *Agricultural Systems* 12: 101-111. DOI: 10.1016/0308-521X(83)90041-0
- Kaps M, Herring WO, Lamberson WR 1999. Genetic and environmental parameters for mature weight in Angus cattle. *Journal of Animal Science* 77: 569-574. DOI: 10.2527/1999.773569x
- Kaps M, Herring WO, Lamberson WR 2000. Genetic and environmental parameters for traits derived from the Brody growth curve and their relationships with weaning weight in Angus cattle. *Journal of Animal Science* 78: 1436-1442. DOI: 10.2527/2000.7861436x
- Kemp DJ, Herring WO, Kaiser CJ 2002. Genetic and environmental parameters for steer ultrasound and carcass traits. *Journal of Animal Science* 80: 1489-1496. DOI: 10.2527/2002.8061489x
- Kenyon PR, Maloney SK, Blache D 2014. Review of sheep body condition score in relation to production characteristics. *New Zealand Journal of Agricultural Research* 57: 38-64. DOI: 10.1080/00288233.2013.857698
- Koong LJ, Falter KH, Lucas HL 1982. A mathematical model for the joint metabolism of nitrogen and energy in cattle. *Agricultural Systems* 9: 301-324. DOI: 10.1016/0308-521X(82)90083-X
- Koots KR, Gibson JP 1998. Economic values for beef production traits from a herd level bioeconomic model. *Canadian Journal of Animal Science* 78: 29-45. DOI: 10.4141/A97-038
- Koots KR, Gibson JP, Smith C, Wilton JW 1994a. Analyses of published genetic parameter estimates for beef production traits. 1. Heritability. *Animal Breeding Abstracts* 62: 309-338.

- Koots KR, Gibson JP, Wilton JW 1994b. Analyses of published genetic parameter estimates for beef production traits. 2. Phenotypic and genetic correlations. *Animal Breeding Abstracts* 62: 825-853.
- Kress DD, Hauser ER, Chapman AB 1969. Efficiency of production and cow size in beef cattle. *Journal of Animal Science* 29: 373-383. DOI: 10.2527/jas1969.293373x
- Lalman DL, Keisler DH, Williams JE, Scholljegerdes EJ, Mallett DM 1997. Influence of postpartum weight and body condition change on duration of anestrus by undernourished suckled beef heifers. *Journal of Animal Science* 75: 2003-2008. DOI: 10.2527/1997.7582003x
- Lalman DL, Selk G, Stein D 2021. Body condition scoring of cows [Online]. Available: <https://extension.okstate.edu/fact-sheets/print-publications/afs/body-condition-scoring-of-cows-afs-3283.pdf> [Accessed 03 September 2023].
- Law NL, Hickson RE, Lopez-Villalobos N, Kenyon PR, Morris ST 2013. Efficiency of beef breeding cows that vary in live weight and milking potential. *Proceedings of the New Zealand Society of Animal Production* 73: 11-16.
- Lee SJ, Nuberg IK, Pitchford WS 2018. Maternal body composition in seedstock herds. 1. Grazing management strategy influences perspectives on optimal balance of production traits and maternal productivity. *Animal Production Science* 58: 117-124. DOI: 10.1071/AN13060
- Lesmeister JL, Burfening PJ, Blackwell RL 1973. Date of first calving in beef cows and subsequent calf production. *Journal of Animal Science* 36: 1-6. DOI: 10.2527/jas1973.3611
- Litherland AJ, Lambert MG 2007. Factors affecting the quality of pastures and supplements produced on farms. *Occasional Publication - New Zealand Society of Animal Production* 14: 81-96.
- Loewer OJ, Taul KL, Turner LW, Gay N, Muntifering R 1987. Graze: A model of selective grazing by beef animals. *Agricultural Systems* 25: 297-309. DOI: 10.1016/0308-521X(87)90040-0
- Long CR, Cartwright TC, Fitzhugh HA, Jr. 1975a. Systems analysis of sources of genetic and environmental variation in efficiency of beef production: cow size and herd management. *Journal of Animal Science* 40: 409-420. DOI: 10.2527/jas1975.403409x
- Long CR, Cartwright TC, Fitzhugh Jr HA 1975b. Systems analysis of sources of genetic and environmental variation in efficiency of beef production: cow size and herd management. *Journal of Animal Science* 40: 409-420. DOI: 10.2527/jas1975.403409x
- Lopez-Gatius F, Yaniz J, Madriles-Helm D 2003. Effects of body condition score and score change on the reproductive performance of dairy cows: a meta-analysis. *Theriogenology* 59: 801-812. DOI: 10.1016/s0093-691x(02)01156-1
- Lopez-Villalobos N, Garrick DJ, Harris BL, Blair HT 1994. Accounting for scale effects in genetic evaluation of dairy cattle. *Proceedings of the New Zealand Society of Animal Production* 54: 275-279.
- Lowe KI 1994. Managing the high performance beef cow herd - where to next? *Proceedings of the New Zealand Society of Animal Production* 54: 315-318.

## References

---

- Lubritz DL, Forrest K, Robison OW 1989. Age of cow and age of dam effects on milk production of Hereford cows. *Journal of Animal Science* 67: 2544-2549. DOI: 10.2527/jas1989.67102544x
- Lush JL 1949. Heritability of quantitative characters in farm animals. *Hereditas* 35: 356-375. DOI: 10.1111/j.1601-5223.1949.tb03347.x
- Macdonald KA, Penno JW, Lancaster JAS, Roche JR 2008. Effect of stocking rate on pasture production, milk production, and reproduction of dairy cows in pasture-based systems. *Journal of Dairy Science* 91: 2151-2163. DOI: 10.3168/jds.2007-0630
- Machado CF, Morris ST, Hodgson J, Arroqui MA, Mangudo PA 2010. A web-based model for simulating whole-farm beef cattle systems. *Computers and Electronics in Agriculture* 74: 129-136. DOI: 10.1016/j.compag.2010.07.007
- Machado CF, Morris ST, Hodgson J, Fathalla M 2005. Seasonal changes of herbage quality within a New Zealand beef cattle finishing pasture. *New Zealand Journal of Agricultural Research* 48: 265-270. DOI: 10.1080/00288233.2005.9513655
- MacNeil MD, Northcutt SL 2008. National cattle evaluation system for combined analysis of carcass characteristics and indicator traits recorded by using ultrasound in Angus cattle. *Journal of Animal Science* 86: 2518-2524. DOI: 10.2527/jas.2008-0901
- Males JR 1987. Optimizing the utilization of cereal crop residues for beef cattle. *Journal of Animal Science* 65: 1124-1130. DOI: 10.2527/jas1987.6541124x
- Martinez GE, Koch RM, Cundiff LV, Gregory KE, Kachman SD, Van Vleck LD 2005. Genetic parameters for stayability, stayability at calving, and stayability at weaning to specified ages for Hereford cows. *Journal of Animal Science* 83: 2033-2042. DOI: 10.2527/2005.8392033x
- McAllister CM, Speidel SE, Crews Jr DH, Enns RM 2011. Genetic parameters for intramuscular fat percentage, marbling score, scrotal circumference, and heifer pregnancy in Red Angus cattle. *Journal of Animal Science* 89: 2068-2072. DOI: 10.2527/jas.2010-3538
- McBride WD, Kenneth MJ. 2011. The diverse structure and organization of U.S. beef cow-calf farms [Online]. U.S. Department of Agriculture, Economic Research Services. Available: [https://www.ers.usda.gov/webdocs/publications/44530/7611\\_eib73.pdf?v=0](https://www.ers.usda.gov/webdocs/publications/44530/7611_eib73.pdf?v=0) [Accessed 12 August 2022].
- McCall DG 1994. The complementary contribution of the beef cow to other livestock enterprises. *Proceedings of the New Zealand Society of Animal Production* 54: 323-328.
- McCall DG, Scott ML 1988. Calf weaning and summer grazing strategies for efficient beef cow use on hill country. *Proceedings of the New Zealand Society of Animal Production* 48: 237-242.
- McClintock SE, Beard KT, Goddard ME, Johnston DJ 2005. Interactions between gestation length, calf size, dystocia and calf mortality. *Proceedings of the Association for the Advancement of Animal Breeding and Genetics* 16: 275-278.

- McFadden AM, Heuer C, Jackson R, West DM, Parkinson TJ 2005. Reproductive performance of beef cow herds in New Zealand. *New Zealand Veterinary Journal* 53: 39-44. DOI: 10.1080/00480169.2005.36467
- McNaughton LR, Morgan SR, Gore P, Verkerk GA, Holmes CW, Parkinson TJ 2002. Monitoring onset of puberty in three genetic strains of Holstein-Friesian dairy cattle. *Proceedings of the New Zealand Society of Animal Production* 62: 30-33.
- Meijering A 1984. Dystocia and stillbirth in cattle — A review of causes, relations and implications. *Livestock Production Science* 11: 143-177. DOI: 10.1016/0301-6226(84)90057-5
- Mercadante MEZ, Packer IU, Razook AG, Cyrillo JNSG, Figueiredo LA 2003. Direct and correlated responses to selection for yearling weight on reproductive performance of Nelore cows. *Journal of Animal Science* 81: 376-384. DOI: 10.2527/2003.812376x
- Mertens DR 1987. Predicting intake and digestibility using mathematical models of ruminal function. *Journal of Animal Science* 64: 1548-1558. DOI: 10.2527/jas1987.6451548x
- Meyer K 1992. Variance components due to direct and maternal effects for growth traits of Australian beef cattle. *Livestock Production Science* 31: 179-204. DOI: 10.1016/0301-6226(92)90017-X
- Meyer K 1995a. Estimates of genetic parameters and breeding values for New Zealand and Australian Angus cattle. *Australian Journal of Agricultural Research* 46: 1219-1229. DOI: 10.1071/AR9951219
- Meyer K 1995b. Estimates of genetic parameters for mature weight of Australian beef cows and its relationship to early growth and skeletal measures. *Livestock Production Science* 44: 125-137. DOI: 10.1016/0301-6226(95)00067-4
- Meyer K 2000. Random regressions to model phenotypic variation in monthly weights of Australian beef cows. *Livestock Production Science* 65: 19-38. DOI: 10.1016/S0301-6226(99)00183-9
- Meyer K, Carrick MJ, Donnelly BJP 1993. Genetic parameters for growth traits of Australian beef cattle from a multibreed selection experiment. *Journal of Animal Science* 71: 2614-2622. DOI: 10.2527/1993.71102614x
- Meyer K, Carrick MJ, Donnelly BJP 1994. Genetic parameters for milk production of Australian beef cows and weaning weight of their calves. *Journal of Animal Science* 72: 1155-1165. DOI: 10.2527/1994.7251155x
- Meyer K, Hammond K, Parnell PF, MacKinnon MJ, Sivarajasingam S 1990. Estimates of heritability and repeatability for reproductive traits in Australian beef cattle. *Livestock Production Science* 25: 15-30. DOI: 10.1016/0301-6226(90)90038-8
- Mialon M-M, Renand G, Krauss D, Ménessier F 2000. Genetic variability of the length of postpartum anoestrus in Charolais cows and its relationship with age at puberty. *Genetics Selection Evolution* 32: 403-414. DOI: 10.1186/1297-9686-32-4-403
- Ministry for Primary Industries. 2020. National Animal Identification and Tracing (NAIT) programme [Online]. Available: <https://www.mpi.govt.nz/growing->

## References

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- and-harvesting/livestock-and-animal-care/national-animal-identification-and-tracing/ [Accessed 09 April 2020].
- Ministry for Primary Industries. 2022. Methodology for calculation of New Zealand's agricultural greenhouse gas emissions [Online]. Available: <https://www.mpi.govt.nz/dmsdocument/13906-detailed-methodologies-for-agricultural-greenhouse-gas-emission-calculation> [Accessed 10 February 2023].
- Misztal I 2017. Breeding and Genetics Symposium: Resilience and lessons from studies in genetics of heat stress. *Journal of Animal Science* 95: 1780-1787. DOI: 10.2527/jas.2016.0953
- Montaño-Bermudez M, Nielsen MK, Deutscher GH 1990. Energy requirements for maintenance of crossbred beef cattle with different genetic potential for milk. *Journal of Animal Science* 68: 2279-2288. DOI: 10.2527/1990.6882279x
- Montgomery GW 1985. The effects of season on reproduction in beef cows - a review. *Proceedings of the New Zealand Society of Animal Production* 45: 43-48.
- Morris CA, Archer JA 2007. Application of new technologies in New Zealand for beef cattle and deer improvement. *New Zealand Journal of Agricultural Research* 50: 163-179. DOI: 10.1080/00288230709510289
- Morris CA, Baker RL, Cullen NG, Hickey SM, Wilson JA 1993. Genetic analyses of cow lifetime production up to 12 mating years in crossbred beef cattle. *Animal Science* 57: 29-36. DOI: 10.1017/S0003356100006577
- Morris CA, Baker RL, Johnson DL, Carter AH, Hunter JC 1987. Reciprocal crossbreeding of Angus and Hereford cattle 3. Cow weight, reproduction, maternal performance, and lifetime production. *New Zealand Journal of Agricultural Research* 30: 453-467. DOI: 10.1080/00288233.1987.10417957
- Morris CA, Bennett GL, Baker RL, Carter AH 1986. Birth weight, dystocia and calf mortality in some New Zealand beef breeding herds. *Journal of Animal Science* 62: 327-343. DOI: 10.2527/jas1986.622327x
- Morris CA, Cullen NG 1994. A note on genetic correlations between pubertal traits of males or females and lifetime pregnancy rate in beef cattle. *Livestock Production Science* 39: 291-297. DOI: 10.1016/0301-6226(94)90291-7
- Morris CA, Cullen NG, McCall DG 1999. Genetic and phenotypic relationships among carcass measurements in beef cattle. *New Zealand Journal of Agricultural Research* 42: 415-421. DOI: 10.1080/00288233.1999.9513390
- Morris CA, Wilson JA, Bennett GL, Cullen NG, Hickey SM, Hunter JC 2000. Genetic parameters for growth, puberty, and beef cow reproductive traits in a puberty selection experiment. *New Zealand Journal of Agricultural Research* 43: 83-91. DOI: 10.1080/00288233.2000.9513411
- Morris CA, Wilton JW 1975. Influence of mature cow weight on economic efficiency in beef cattle production. *Canadian Journal of Animal Science* 55: 233-250. DOI: 10.4141/cjas75-028
- Morris CA, Wilton JW 1976. Influence of body size on the biological efficiency of cows: a review. *Canadian Journal of Animal Science* 56: 613-647. DOI: 10.4141/cjas76-076

- 
- Morris ST 2007. Pastures and supplements in beef production systems. Occasional Publication - New Zealand Society of Animal Production 14: 243-254.
- Morris ST 2008. A review of beef cross dairy bred cattle as beef breeding cows, Palmerston North, New Zealand, Meat & Wool New Zealand.
- Morris ST 2013a. Presidential address 2012 – the New Zealand beef cattle industry. Proceedings of the New Zealand Society of Animal Production 73: 1-4.
- Morris ST 2013b. Sheep and beef cattle production systems. In: Dymond JR ed. Ecosystems services in New Zealand - conditions and trends. Lincoln, New Zealand: Manaaki Whenua Press. 79–84.
- Morris ST, Chan FY, Lopez-Villalobos N, Kenyon PR, Garrick DJ, Blair HT 2014. Growth, feed intake and maternal performance of Angus heifers from high and low feed efficiency selection lines. Animal Production Science 54: 1428–1431. DOI: 10.1071/AN14220
- Morris ST, Garrick DJ, Lopez-Villalobos N, Kenyon PR, Burke J, Blair H 2010. Growth, feed intake and maternal performance of Angus heifers selected for high or low growth and milk production. Animal Production Science 50: 349-353. DOI: 10.1071/AN09181
- Morris ST, Hickson RE 2016. An overview of current and potential hill country livestock systems. Hill Country - Grassland Research and Practice Series 16: 309-316.
- Morris ST, Kenyon PR 2014. Intensive sheep and beef production from pasture — A New Zealand perspective of concerns, opportunities and challenges. Meat Science 98: 330-335. DOI: 10.1016/j.meatsci.2014.06.011
- Morris ST, Kenyon PR, Burnham DL 2002. A comparison of two scales of body condition scoring in Hereford x Friesian beef breeding cows. Proceedings of the New Zealand Grassland Association 64: 121–123.
- Morris ST, Morel PCH, Kenyon PR 2006. The effect of individual liveweight and condition of beef cows on their reproductive performance and birth and weaning weights of calves. New Zealand Veterinary Journal 54: 96–100. DOI: 10.1080/00480169.2006.36619
- Morris ST, Smeaton DC 2009. Profitable farming of beef cows, Hamilton, New Zealand, Meat & Wool New Zealand.
- Mossman DH, Hanly GJ 1977. A theory of beef production. New Zealand Veterinary Journal 25: 96-100. DOI: 10.1080/00480169.1977.34370
- Muir PD, Thomson BC. 2008. A review of dressing out percentage in New Zealand livestock [Online]. Available: <https://www.mpi.govt.nz/dmsdocument/2963/direct> [Accessed 20 March 2020].
- Muir PD, Thomson BC. 2011. Better estimation of national ewe and beef cow liveweights [Online]. Available: <https://www.mpi.govt.nz/dmsdocument/3089/direct> [Accessed 28 August 2021].
-

## References

---

- Mwansa PB, Crews Jr DH, Wilton JW, Kemp RA 2002. Multiple trait selection for maternal productivity in beef cattle. *Journal of Animal Breeding and Genetics* 119: 391-399. DOI: 10.1046/j.1439-0388.2002.00363.x
- Nephawe KA, Cundiff LV, Dikeman ME, Crouse JD, Van Vleck LD 2004. Genetic relationships between sex-specific traits in beef cattle: Mature weight, weight adjusted for body condition score, height and body condition score of cows, and carcass traits of their steer relatives. *Journal of Animal Science* 82: 647-653. DOI: 10.2527/2004.823647x
- New Zealand Meat Classification Authority. 2004. New Zealand meat - Guide to beef carcass classification [Online]. Available: <https://www.interest.co.nz/files/rural/beefgrade.pdf> [Accessed 18 April 2020].
- Newman S, Morris CA, Baker RL, Nicoll GB 1992. Genetic improvement of beef cattle in New Zealand: breeding objectives. *Livestock Production Science* 32: 111-130. DOI: 10.1016/S0301-6226(12)80031-5
- Nicol AM, Brookes IM 2007. The metabolisable energy requirements of grazing livestock. *Occasional Publication - New Zealand Society of Animal Production* 14: 151-172.
- Nicol DC, Graser HU, Tier B, Hammond K 1985. BREEDPLAN - a new within-herd evaluation system for the national beef recording scheme. *Proceedings of the Australian Association of Animal Breeding and Genetics* 5: 151-153.
- Nicoll GB, Hight GK, Everitt GC 1978. Some components of improved beef cow productivity on hill country. *Proceedings of the New Zealand Society of Animal Production* 38: 151-160.
- Nitter G, Graser HU, Barwick SA 1994. Evaluation of advanced industry breeding schemes for Australian beef cattle. I. Method of evaluation and analysis for an example population structure. *Australian Journal of Agricultural Research* 45: 1641-1656. DOI: 10.1071/AR9941641
- NIWA. 2022. Climate publications [Online]. Available: <https://niwa.co.nz/our-science/climate/publications> [Accessed Mar 17 2022].
- Northcutt SL, Wilson DE 1993. Genetic parameter estimates and expected progeny differences for mature size in Angus cattle. *Journal of Animal Science* 71: 1148-1153. DOI: 10.2527/1993.7151148x
- Northcutt SL, Wilson DE, Willham RL 1992. Adjusting weight for body condition score in Angus cows. *Journal of Animal Science* 70: 1342-1345. DOI: 10.2527/1992.7051342x
- Notter DR 2002. Defining biological efficiency of beef production. *Proceedings of the 34th Beef Improvement Federation Symposium*.
- Ochsner KP, MacNeil MD, Lewis RM, Spangler ML 2017. Economic selection index development for Beefmaster cattle II: general-purpose breeding objective. *Journal of Animal Science* 95: 1913-1920. DOI: 10.2527/jas.2016.1232
- Osoro K, Wright IA 1992. The effect of body condition, live weight, breed, age, calf performance, and calving date on reproductive performance of spring-calving

- 
- beef cows. *Journal of Animal Science* 70: 1661-1666. DOI: 10.2527/1992.7061661x
- Owens FN, Gill DR, Secrist DS, Coleman SW 1995. Review of some aspects of growth and development of feedlot cattle. *Journal of Animal Science* 73: 3152-3172. DOI: 10.2527/1995.73103152x
- Oyama K, Katsuta T, Anada K, Mukai F 2004. Genetic parameters for reproductive performance of breeding cows and carcass traits of fattening animals in Japanese Black (Wagyu) cattle. *Animal Science* 78: 195-201. DOI: 10.1017/S1357729800053984
- Pang H, Makarechian M, Basarab JA, Berg RT 1999. Structure of a dynamic simulation model for beef cattle production systems. *Canadian Journal of Animal Science* 79: 409-417. DOI: 10.4141/A99-020
- Pardo AM, Elzo MA, Gama LT, Melucci LM 2020. Genetic parameters for growth and cow productivity traits in Angus, Hereford and crossbred cattle. *Livestock Science* 233: 103952. DOI: 10.1016/j.livsci.2020.103952
- Perry GA 2016. Factors affecting puberty in replacement beef heifers. *Theriogenology* 86: 373-378. DOI: 10.1016/j.theriogenology.2016.04.051
- Pickering NK, Dodds KG, Blair HT, Hickson RE, Johnson PL, McEwan JC 2012. Genetic parameters for production traits in New Zealand dual-purpose sheep, with an emphasis on dagginess. *Journal of Animal Science* 90: 1411-1420. DOI: 10.2527/jas.2011-4163
- Pitchford WS, Deland MPB, Siebert BD, Malau-Aduli AEO, Bottema CDK 2001. Breed differences and genetic parameters for fat traits of crossbred cattle. *Proceedings of the Association for the Advancement of Animal Breeding and Genetics* 14: 477-480.
- Pleasants AB, Barton RA, Batley PJ 1991. The role of beef breeding cows in strategic management of feed supply under pasture variability. *Proceedings of the New Zealand Grassland Association* 53: 145-149.
- Pleasants AB, Barton RA, McCall DG 1994. Nutritional buffering: Do we make the best use of this phenomena in the breeding cow? *Proceedings of the New Zealand Society of Animal Production* 54: 329-332.
- Ponzoni RW, Newman S 1989. Developing breeding objectives for Australian beef cattle production. *Animal Science* 49: 35-47. DOI: 10.1017/S0003356100004232
- Pravia MI, Ravagnolo O, Urioste JI, Garrick DJ 2014. Identification of breeding objectives using a bioeconomic model for a beef cattle production system in Uruguay. *Livestock Science* 160: 21-28. DOI: 10.1016/j.livsci.2013.12.006
- Price TD, Wiltbank JN 1978. Dystocia in cattle a review and implications. *Theriogenology* 9: 195-219. DOI: 10.1016/0093-691X(78)90030-4
- Purchas RW 2003. Factors affecting carcass composition and beef quality. In: Smeaton D (ed.) *Profitable beef production in New Zealand*. MPI: New Zealand beef council report. 124-152.

## References

---

- R Core Team. 2019. R: A language and environment for statistical computing [Online]. R Foundation for Statistical Computing, Vienna, Austria. Available: <https://www.R-project.org/> [Accessed 20 June 2020].
- Rauw WM, Gomez-Raya L 2015. Genotype by environment interaction and breeding for robustness in livestock. *Frontiers in Genetics* 6: 310-324. DOI: 10.3389/fgene.2015.00310
- Renquist BJ, Oltjen JW, Sainz RD, Calvert CC 2006. Relationship between body condition score and production of multiparous beef cows. *Livestock Science* 104: 147-155. DOI: 10.1016/j.livsci.2006.04.004
- Reverter A, Hine BC, Porto-Neto L, Li Y, Duff CJ, Dominik S, Ingham AB 2021. ImmuneDEX: a strategy for the genetic improvement of immune competence in Australian Angus cattle. *Journal of Animal Science* 99: 1-7. DOI: 10.1093/jas/skaa384
- Reverter A, Johnston DJ, Graser H-U, Wolcott ML, Upton WH 2000. Genetic analyses of live-animal ultrasound and abattoir carcass traits in Australian Angus and Hereford cattle. *Journal of Animal Science* 78: 1786-1795. DOI: 10.2527/2000.7871786x
- Reynolds WL, Urlick JJ, Knapp BW 1990. Biological type effects on gestation length, calving traits and calf growth rate. *Journal of Animal Science* 68: 630-639. DOI: 10.2527/1990.683630x
- Ribeiro AMF, Sanglard LP, Snelling WM, Thallman RM, Kuehn LA, Spangler ML 2022. Genetic parameters, heterosis, and breed effects for body condition score and mature cow weight in beef cattle. *Journal of Animal Science* 100: 1-7. DOI: 10.1093/jas/skac017
- Richards FJ 1959. A flexible growth function for empirical use. *Journal of Experimental Botany* 10: 290-301. DOI: 10.1093/jxb/10.2.290
- Robinson DL 1996. Estimation and interpretation of direct and maternal genetic parameters for weights of Australian Angus cattle. *Livestock Production Science* 45: 1-11. DOI: 10.1016/0301-6226(95)00083-6
- Robinson DL, Hammond K, McDonald CA 1993. Live animal measurement of carcass traits: estimation of genetic parameters for beef cattle. *Journal of Animal Science* 71: 1128-1135. DOI: 10.2527/1993.7151128x
- Robinson DL, Oddy VH 2004. Genetic parameters for feed efficiency, fatness, muscle area and feeding behaviour of feedlot finished beef cattle. *Livestock Production Science* 90: 255-270. DOI: 10.1016/j.livprodsci.2004.06.011
- Roca Fraga FJ. 2013. Prediction of milk yield of 3-year-old Angus cows and the influence of maternal milk production on the postnatal growth of beef steers. Master Thesis, Massey University, Palmerston North, New Zealand.
- Roche JR, Berry DP, Lee JM, Macdonald KA, Boston RC 2007a. Describing the body condition score change between successive calvings: a novel strategy generalizable to diverse cohorts. *Journal of Dairy Science* 90: 4378-4396. DOI: 10.3168/jds.2006-729
- Roche JR, Friggens NC, Kay JK, Fisher MW, Stafford KJ, Berry DP 2009. Invited review: Body condition score and its association with dairy cow productivity, health,

- and welfare. *Journal of Dairy Science* 92: 5769-5801. DOI: 10.3168/jds.2009-2431
- Roche JR, Macdonald KA, Burke CR, Lee JM, Berry DP 2007b. Associations among body condition score, body weight, and reproductive performance in seasonal-calving dairy cattle. *Journal of Dairy Science* 90: 376-391. DOI: 10.3168/jds.S0022-0302(07)72639-5
- Roesch A, Weisskopf P, Oberholzer H, Valsangiacomo A, Nemecek T 2019. An approach for describing the effects of grazing on soil quality in life-cycle assessment. *Sustainability* 11: 4870-4883. DOI: 10.3390/su11184870
- Rotz CA, Buckmaster DR, Comerford JW 2005. A beef herd model for simulating feed intake, animal performance, and manure excretion in farm systems. *Journal of Animal Science* 83: 231-242. DOI: 10.2527/2005.831231x
- Roughsedge T, Amer PR, Simm G 2003. A bio-economic model for the evaluation of breeds and mating systems in beef production enterprises. *Animal Science* 77: 403-416. DOI: 10.1017/S1357729800054357
- Russel AJF, Doney JM, Gunn RG 1969. Subjective assessment of body fat in live sheep. *The Journal of Agricultural Science* 72: 451-454. DOI: 10.1017/S0021859600024874
- Russell JR, Brasche MR, Cowen AM 1993. Effects of grazing allowance and system on the use of corn-crop residues by gestating beef cows. *Journal of Animal Science* 71: 1256-1265. DOI: 10.2527/1993.7151256x
- Samsonstuen S, Åby BA, Crosson P, Beauchemin KA, Bonesmo H, Aass L 2019. Farm scale modelling of greenhouse gas emissions from semi-intensive suckler cow beef production. *Agricultural Systems* 176: 102670. DOI: 10.1016/j.agsy.2019.102670
- Sanders JO, Cartwright TC 1979a. A general cattle production systems model. I: Structure of the model. *Agricultural Systems* 4: 217-227. DOI: 10.1016/0308-521X(79)90031-3
- Sanders JO, Cartwright TC 1979b. A general cattle production systems model. Part 2—Procedures used for simulating animal performance. *Agricultural Systems* 4: 289-309. DOI: 10.1016/0308-521X(79)90004-0
- Santos CA, Landim NM, Araújo HX, Paim TD 2022. Automated Systems for estrous and calving detection in dairy cattle. *AgriEngineering* 4: 475-482. DOI: 10.3390/agriengineering4020031
- Scholefield D, Lockyer DR, Whitehead DC, Tyson KC 1991. A model to predict transformations and losses of nitrogen in UK pastures grazed by beef cattle. *Plant and Soil* 132: 165-177. DOI: 10.1007/BF00010397
- Selk GE, Wettemann RP, Lusby KS, Oltjen JW, Mobley SL, Rasby RJ, Garmendia JC 1988. Relationship among weight change, body condition and reproductive performance of range beef cows. *Journal of Animal Science* 66: 3153-3159. DOI: 10.2527/jas1988.66123153x
- Senft RL 1989. Hierarchical foraging models: Effects of stocking and landscape composition on simulated resource use by cattle. *Ecological Modelling* 46: 283-303. DOI: 10.1016/0304-3800(89)90023-9

## References

---

- Shibata M, Terada F, Kurihara M, Nishida T, Iwasaki K 1993. Estimation of methane production in ruminants. *Animal Science and Technology* 64: 790-796.
- Short RE, Bellows RA, Staigmiller RB, Berardinelli JG, Custer EE 1990. Physiological mechanisms controlling anestrus and infertility in postpartum beef cattle. *Journal of Animal Science* 68: 799-816. DOI: 10.2527/1990.683799x
- Smeaton DC, Bown MD, Clayton JB 2000. Optimum liveweight, feed intake, reproduction, and calf output in beef cows on North Island hill country, New Zealand. *New Zealand Journal of Agricultural Research* 43: 71-82. DOI: 10.1080/00288233.2000.9513410
- Smeaton DC, Harris BL, Xu ZZ, Vivanco WH 2003. Factors affecting commercial application of embryo technologies in New Zealand: a modelling approach. *Theriogenology* 59: 617-634. DOI: 10.1016/S0093-691X(02)01244-X
- Smeaton DC, McCall DG, Clayton JB, Dow BW 1986. Calving date effects on beef cow productivity. *Proceedings of the New Zealand Society of Animal Production* 46: 149-152.
- Smeaton DC, McCall DG, Wadams TK 1983. Effects of pasture allowance level after calving on performance of beef cows on hill country. *New Zealand Journal of Experimental Agriculture* 11: 303-308. DOI: 10.1080/03015521.1983.10427774
- Smith EM, Tharel LM, Brown MA, Dougherty CT, Limbach K 1985. A simulation model for managing perennial grass pastures. Part I—structure of the model. *Agricultural Systems* 17: 155-180. DOI: 10.1016/0308-521X(85)90026-5
- Snelling WM, Golden BL, Bourdon RM 1994. An EPD for stayability of beef cows. *Proceedings of the 5th World Congress on Genetic Applied to Livestock Production* 17: 169-172.
- Sørensen JT 1990. Validation of livestock herd simulation models: a review. *Livestock Production Science* 26: 79-90. DOI: 10.1016/0301-6226(90)90058-E
- Sørensen JT 1998. Modeling and simulation in applied livestock production science. In: Peart RM & Curry RB (eds.) *Agricultural systems modeling and simulation*. 475-494.
- Sowell BF, Mosley JC, Bowman JGP 1999. Social behavior of grazing beef cattle: Implications for management. *Proceedings of the American Society of Animal Science* 78: 1-6. DOI: 10.2527/jas2000.00218812007700ES0021x
- Spedding CRW 1988. A systems approach to agriculture. In: Spedding CRW (ed.) *An introduction to agricultural systems*. Dordrecht, Netherlands: Springer. Available: 10.1007/978-94-011-6408-5\_2, 15-40.
- Spedding CRW, Brockington NR 1976. Experimentation in agricultural systems. *Agricultural Systems* 1: 47-56. DOI: 10.1016/0308-521X(76)90021-4
- Splan RK, Cundiff LV, Dikeman ME, Van Vleck LD 2002. Estimates of parameters between direct and maternal genetic effects for weaning weight and direct genetic effects for carcass traits in crossbred cattle. *Journal of Animal Science* 80: 3107-3111. DOI: 10.2527/2002.80123107x

- Splan RK, Cundiff LV, Van Vleck LD 1998. Genetic parameters for sex-specific traits in beef cattle. *Journal of Animal Science* 76: 2272-2278. DOI: 10.2527/1998.7692272x
- Sprott LR, Harris MD, Richardson JW, Gray AW, Forrest DW, Northcutt-Dolezal S, Cundiff LV 1998. Pregnancy to artificial insemination in beef cows as affected by body condition and number of services. *The Professional Animal Scientist* 14: 231-235. DOI: 10.15232/S1080-7446(15)31835-0
- Stats NZ. 2019. Livestock numbers [Online]. Available: <https://www.stats.govt.nz/indicators/livestock-numbers> [Accessed 23 Nov 2020].
- Stats NZ. 2021. Agricultural production statistics: Year to June 2021 [Online]. Available: <https://www.stats.govt.nz/information-releases/agricultural-production-statistics-year-to-june-2021-provisional> [Accessed 14 March 2022].
- Stats NZ. 2022. Livestock Slaughtering [Online]. Available: <https://infoshare.stats.govt.nz/ViewTable.aspx?pxID=ef4f6b0b-202b-471e-beae-bf5da2c8df3b> [Accessed 21 March 2022].
- Szabó F, Dákay I 2009. Estimation of some productive and reproductive effects on longevity of beef cows using survival analysis. *Livestock Science* 122: 271-275. DOI: 10.1016/j.livsci.2008.09.024
- Tait IM, Morris ST, Kenyon PR, Garrick DJ, Pleasants AB, Hickson RE 2017. Effect of cow body condition score on inter-calving interval, pregnancy diagnosis, weaning rate and calf weaning weight in beef cattle. *Proceedings of the New Zealand Society of Animal Production* 77: 23-28.
- Tanure S, Nabinger C, Becker JL 2015. Bioeconomic model of decision support system for farm management: proposal of a mathematical model. *Systems Research and Behavioral Science* 32: 658-671. DOI: 10.1002/sres.2252
- Tennant CJ, Spitzer JC, Bridges WC, Jr., Hampton JH 2002. Weight necessary to change body condition scores in Angus cows. *Journal of Animal Science* 80: 2031-2035. DOI: 10.1093/ansci/80.8.2031
- Thomas CW. 2008. Current practices and future possibilities of performance recording extensively-grazed commercial beef herds in New Zealand. Master Thesis, Lincoln University, Lincoln, New Zealand.
- Troy DJ, Kerry JP 2010. Consumer perception and the role of science in the meat industry. *Meat Science* 86: 214-226. DOI: 10.1016/j.meatsci.2010.05.009
- Tweedie M, Archer JA, Proctor LE 2019. Demonstrating BREEDPLAN estimated breeding values in New Zealand commercial beef herds. *Proceedings of the Association for the Advancement of Animal Breeding and Genetics* 23: 532-535.
- Twomey AJ, Carroll RI, Doherty ML, Byrne N, Graham DA, Sayers RG, Blom A, Berry DP 2018. Genetic correlations between endo-parasite phenotypes and economically important traits in dairy and beef cattle. *Journal of Animal Science* 96: 407-421. DOI: 10.1093/jas/sky008
- Twomey AJ, Sayers RG, Carroll RI, Byrne N, Brien EO, Doherty ML, McClure JC, Graham DA, Berry DP 2016. Genetic parameters for both a liver damage phenotype caused by *Fasciola hepatica* and antibody response to *Fasciola hepatica*

## References

---

- phenotype in dairy and beef cattle. *Journal of Animal Science* 94: 4109-4119. DOI: 10.2527/jas.2016-0621
- Valente TS, Albito OD, Sant'Anna AC, Carvalheiro R, Baldi F, Albuquerque LG, Paranhos da Costa MJR 2017. Genetic parameter estimates for temperament, heifer rebreeding, and stayability in Nellore cattle. *Livestock Science* 206: 45-50. DOI: 10.1016/j.livsci.2017.10.010
- Valentine I, Kemp PD 2017. Pasture and supplement resources. *Occasional Publication - New Zealand Society of Animal Production* 14: 3-12.
- Van Melis MH, Eler JP, Oliveira HN, Rosa GJM, Silva JAV, II, Ferraz JBS, Pereira E 2007. Study of stayability in Nellore cows using a threshold model. *Journal of Animal Science* 85: 1780-1786. DOI: 10.2527/jas.2005-608
- Van Melis MH, Oliveira HN, Eler JP, Ferraz JBS, Casellas J, Varona L 2010. Additive genetic relationship of longevity with fertility and production traits in Nellore cattle based on bivariate models. *Genetics and Molecular Research* 9: 176-187. DOI: 10.4238/vol9-1gmr710
- Vargas CA, Elzo MA, Chase CC, Jr., Olson TA 2000. Genetic parameters and relationships between hip height and weight in Brahman cattle. *Journal of Animal Science* 78: 3045-3052. DOI: 10.2527/2000.78123045x
- Veysset P, Lherm M, Bébin D 2010. Energy consumption, greenhouse gas emissions and economic performance assessments in French Charolais suckler cattle farms: Model-based analysis and forecasts. *Agricultural Systems* 103: 41-50. DOI: 10.1016/j.agsy.2009.08.005
- Vishwanath R 2003. Artificial insemination: the state of the art. *Theriogenology* 59: 571-584. DOI: 10.1016/S0093-691X(02)01241-4
- Visscher PM, Hill WG, Wray NR 2008. Heritability in the genomics era — concepts and misconceptions. *Nature Reviews Genetics* 9: 255-266. DOI: 10.1038/nrg2322
- Von Bertalanffy L 1957. Quantitative laws in metabolism and growth. *The Quarterly Review of Biology* 32: 217-231. DOI: 10.1086/401873
- Wagner JJ. 1984. Carcass composition in mature Hereford cows: Estimation and influence on metabolizable energy requirements for maintenance during winter. PhD Thesis, Oklahoma State University, Stillwater, United States.
- Wagner JJ, Lusby KS, Oltjen JW, Rakestraw J, Wettemann RP, Walters LE 1988. Carcass composition in mature hereford cows: estimation and effect on daily metabolizable energy requirement during winter. *Journal of Animal Science* 66: 603-612. DOI: 10.2527/jas1988.663603x
- Wall E, Simm G, Moran D 2010. Developing breeding schemes to assist mitigation of greenhouse gas emissions. *Animal* 4: 366-376. DOI: 10.1017/S175173110999070X
- Walmsley BJ, Lee SJ, Parnell PF, Pitchford WS 2018. A review of factors influencing key biological components of maternal productivity in temperate beef cattle. *Animal Production Science* 58: 1-19. DOI: 10.1071/AN12428

- 
- Warner RD, Greenwood PL, Pethick DW, Ferguson DM 2010. Genetic and environmental effects on meat quality. *Meat Science* 86: 171-183. DOI: 10.1016/j.meatsci.2010.04.042
- Washburn SP, White SL, Green JT, Benson GA 2002. Reproduction, mastitis, and body condition of seasonally calved Holstein and Jersey cows in confinement or pasture systems. *Journal of Dairy Science* 85: 105-111. DOI: 10.3168/jds.S0022-0302(02)74058-7
- Wenham KM. 2019. The interaction between pasture variability, calving time and maternal productivity. Bachelor with Honours Thesis, The University of Adelaide, Adelaide, Australia.
- White TA, Snow VO, King WM 2010. Intensification of New Zealand beef farming systems. *Agricultural Systems* 103: 21-35. DOI: 10.1016/j.agsy.2009.08.003
- Whitman RW. 1975. Weight change, condition and beef-cow reproduction. PhD Thesis, Colorado State University, Fort Collins, United States.
- Wilson LL, McCurley JR, Ziegler JH, Watkins JL 1976. Genetic parameters of live and carcass characters from progeny of polled Hereford sires and Angus-Holstein cows. *Journal of Animal Science* 43: 569-576. DOI: 10.2527/jas1976.433569x
- Wiltbank JN 1970. Research needs in beef cattle reproduction. *Journal of Animal Science* 31: 755-762. DOI: 10.2527/jas1970.314755x
- Wilton JW, Danell ÖE 1981. Relative rates of discounted expressions of traits in beef crossbreeding programs. *Acta Agriculturae Scandinavica* 31: 207-218. DOI: 10.1080/00015128109435319
- Wolcott ML, Johnston D, Barwick S, Corbet N, Burrow HM 2013. Genetic relationships between steer performance and female reproduction and possible impacts on whole herd productivity in two tropical beef genotypes. *Animal Production Science* 54: 85-96. DOI: 10.1071/AN13141
- Wolcott ML, Johnston DJ, Barwick SA 2014a. Genetic relationships of female reproduction with growth, body composition, maternal weaning weight and tropical adaptation in two tropical beef genotypes. *Animal Production Science* 54: 60-73. DOI: 10.1071/AN13012
- Wolcott ML, Johnston DJ, Barwick SA, Corbet NJ, Williams PJ 2014b. The genetics of cow growth and body composition at first calving in two tropical beef genotypes. *Animal Production Science* 54: 37-49. DOI: 10.1071/AN12427
- Wood PDP 1967. Algebraic model of the lactation curve in cattle. *Nature* 216: 164-165. DOI: 10.1038/216164a0
- Wright IA, Rhind SM, Whyte TK, Smith AJ 1992. Effects of body condition at calving and feeding level after calving on LH profiles and the duration of the post-partum anoestrous period in beef cows. *Animal Science* 55: 41-46. DOI: 10.1017/S0003356100037259
- Yan T, Frost JP, Keady TWJ, Agnew RE, Mayne CS 2007. Prediction of nitrogen excretion in feces and urine of beef cattle offered diets containing grass silage. *Journal of Animal Science* 85: 1982-1989. DOI: 10.2527/jas.2006-408

## References

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Young OA, West J, Hart AL, van Otterdijk FFH 2004. A method for early determination of meat ultimate pH. *Meat Science* 66: 493-498. DOI: 10.1016/S0309-1740(03)00140-2

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## Appendices

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## **Appendix I – Supplementary tables for Chapter 2**

Appendix I

**Appendix I. Table 1.** Least-square means of live weight (kg) of mixed-aged beef breeding cows and their standard errors ( $\pm$ SEM) at different events throughout the production cycle (mating, weaning and calving) for each farm (Label A-I); results are adjusted for age of cows.

Farm	Season	Mating	Weaning	Calving
<b>A</b>	2015	519.01 $\pm$ 2.0	508.71 $\pm$ 2.0	516.48 $\pm$ .21
	2016	529.51 $\pm$ 1.7	513.86 $\pm$ 1.7	543.44 $\pm$ 1.7
	2017	521.62 $\pm$ 1.6	500.32 $\pm$ 1.6	555.35 $\pm$ 1.7
	2018	533.76 $\pm$ 1.6	527.05 $\pm$ 1.6	552.60 $\pm$ 1.7
	2019	537.65 $\pm$ 1.7	550.91 $\pm$ 1.7	582.02 $\pm$ 1.8
<b>B</b>	2015	552.25 $\pm$ 2.4	481.76 $\pm$ 2.4	462.62 $\pm$ 2.4
	2016	538.24 $\pm$ 2.2	576.36 $\pm$ 2.3	512.95 $\pm$ 2.3
	2017	598.61 $\pm$ 2.3	558.18 $\pm$ 2.2	517.61 $\pm$ 2.3
	2018	600.36 $\pm$ 2.3	592.07 $\pm$ 2.3	548.08 $\pm$ 2.4
	2019	612.15 $\pm$ 2.6	566.37 $\pm$ 2.4	518.02 $\pm$ 2.7
<b>C</b>	2015	533.25 $\pm$ 2.4	566.52 $\pm$ 2.4	568.03 $\pm$ 2.5
	2016	553.54 $\pm$ 2.3	551.59 $\pm$ 2.3	559.88 $\pm$ 2.3
	2017	534.18 $\pm$ 2.1	568.05 $\pm$ 2.1	588.34 $\pm$ 2.2
	2018	559.23 $\pm$ 2.1	570.88 $\pm$ 2.1	609.01 $\pm$ 2.2
	2019	580.48 $\pm$ 2.2	592.92 $\pm$ 2.2	
<b>D</b>	2015		526.85 $\pm$ 2.5	492.51 $\pm$ 2.5
	2016	542.84 $\pm$ 2.4	557.63 $\pm$ 2.4	506.81 $\pm$ 2.6
	2017	507.76 $\pm$ 3.2	528.72 $\pm$ 2.3	513.48 $\pm$ 2.3
	2018	573.89 $\pm$ 2.3	604.50 $\pm$ 2.4	562.63 $\pm$ 2.4
	2019	606.22 $\pm$ 2.6	588.01 $\pm$ 2.6	540.93 $\pm$ 2.8
<b>F</b>	2015	523.49 $\pm$ 4.2	567.50 $\pm$ 4.1	
	2016	506.80 $\pm$ 3.9	573.26 $\pm$ 3.9	558.36 $\pm$ 4.1
	2017	526.72 $\pm$ 3.8	583.32 $\pm$ 3.8	581.87 $\pm$ 4.0
<b>G</b>	2015	602.02 $\pm$ 4.3	597.96 $\pm$ 4.3	530.20 $\pm$ 4.5
	2016	587.72 $\pm$ 4.1	625.63 $\pm$ 4.1	550.70 $\pm$ 4.2
	2017	618.65 $\pm$ 4.0	596.64 $\pm$ 4.0	548.43 $\pm$ 4.2
<b>H</b>	2014		616.21 $\pm$ 2.8	559.13 $\pm$ 2.8
	2015	596.24 $\pm$ 2.4	611.99 $\pm$ 2.5	547.68 $\pm$ 2.6
	2016	592.95 $\pm$ 2.3	611.79 $\pm$ 2.3	551.67 $\pm$ 2.5
	2017	615.63 $\pm$ 2.3	639.51 $\pm$ 2.4	577.01 $\pm$ 2.5
<b>Ia</b>	2015	576.66 $\pm$ 1.9	552.69 $\pm$ 1.8	
	2016	537.52 $\pm$ 1.7	539.82 $\pm$ 1.7	505.95 $\pm$ 1.8
	2017	535.13 $\pm$ 1.6	545.52 $\pm$ 1.7	480.50 $\pm$ 1.7
<b>Ib</b>	2014		612.79 $\pm$ 2.0	531.41 $\pm$ 2.1
	2015	584.58 $\pm$ 1.7	588.83 $\pm$ 1.7	476.67 $\pm$ 2.0
	2016	568.29 $\pm$ 1.6	560.33 $\pm$ 1.6	520.11 $\pm$ 1.8
	2017	580.21 $\pm$ 1.7	587.28 $\pm$ 1.7	497.56 $\pm$ 1.8

\*Blank cells with missing values.

**Appendix I. Table 2** Least-square means of body condition score (1–10 score) of mixed-aged beef breeding cows and their standard errors ( $\pm$ SEM) at different events throughout the production cycle (mating, weaning and calving) for each farm (Label A-I); results are adjusted for age of cows.

Farm	Season	Mating	Weaning	Calving
<b>A</b>	2015	7.30 $\pm$ 0.04	7.30 $\pm$ 0.04	7.00 $\pm$ 0.04
	2016	7.80 $\pm$ 0.03	7.00 $\pm$ 0.03	7.10 $\pm$ 0.03
	2017	7.00 $\pm$ 0.03	6.10 $\pm$ 0.03	6.30 $\pm$ 0.03
	2018	6.50 $\pm$ 0.02	6.30 $\pm$ 0.03	6.20 $\pm$ 0.03
	2019	6.90 $\pm$ 0.03	6.80 $\pm$ 0.03	6.80 $\pm$ 0.03
<b>B</b>	2015	7.50 $\pm$ 0.04	6.30 $\pm$ 0.04	5.40 $\pm$ 0.04
	2016	7.10 $\pm$ 0.04	7.30 $\pm$ 0.04	5.50 $\pm$ 0.04
	2017	7.90 $\pm$ 0.04	7.30 $\pm$ 0.04	5.10 $\pm$ 0.04
	2018	7.60 $\pm$ 0.04	7.40 $\pm$ 0.04	6.40 $\pm$ 0.04
	2019	7.80 $\pm$ 0.05	6.70 $\pm$ 0.04	6.00 $\pm$ 0.05
<b>C</b>	2015	6.00 $\pm$ 0.04	7.20 $\pm$ 0.04	6.80 $\pm$ 0.04
	2016	7.00 $\pm$ 0.04	6.80 $\pm$ 0.04	5.70 $\pm$ 0.04
	2017	6.60 $\pm$ 0.03	6.60 $\pm$ 0.03	6.20 $\pm$ 0.04
	2018	6.80 $\pm$ 0.03	6.70 $\pm$ 0.03	6.60 $\pm$ 0.04
	2019	7.20 $\pm$ 0.04	6.90 $\pm$ 0.04	
<b>D</b>	2015		7.40 $\pm$ 0.04	6.50 $\pm$ 0.04
	2016	6.80 $\pm$ 0.04	7.20 $\pm$ 0.04	6.20 $\pm$ 0.04
	2017	7.00 $\pm$ 0.06	7.20 $\pm$ 0.04	6.00 $\pm$ 0.04
	2018	6.90 $\pm$ 0.04	7.70 $\pm$ 0.04	6.20 $\pm$ 0.04
	2019	7.50 $\pm$ 0.04	6.50 $\pm$ 0.04	5.60 $\pm$ 0.05
<b>F</b>	2015	5.40 $\pm$ 0.06	6.10 $\pm$ 0.06	
	2016	6.00 $\pm$ 0.06	6.70 $\pm$ 0.06	6.10 $\pm$ 0.07
	2017	6.50 $\pm$ 0.06	7.10 $\pm$ 0.06	6.50 $\pm$ 0.06
<b>G</b>	2015	6.90 $\pm$ 0.07	6.50 $\pm$ 0.07	5.30 $\pm$ 0.07
	2016	6.70 $\pm$ 0.06	7.10 $\pm$ 0.07	5.80 $\pm$ 0.07
	2017	7.10 $\pm$ 0.06	7.10 $\pm$ 0.06	5.90 $\pm$ 0.07
<b>H</b>	2014		6.40 $\pm$ 0.05	5.40 $\pm$ 0.04
	2015	6.40 $\pm$ 0.04	5.90 $\pm$ 0.04	5.00 $\pm$ 0.04
	2016	7.20 $\pm$ 0.04	7.30 $\pm$ 0.04	5.60 $\pm$ 0.04
	2017	7.10 $\pm$ 0.04	7.30 $\pm$ 0.04	6.30 $\pm$ 0.04
<b>Ia</b>	2015	6.40 $\pm$ 0.03	6.40 $\pm$ 0.03	
	2016	6.80 $\pm$ 0.03	6.90 $\pm$ 0.03	5.60 $\pm$ 0.03
	2017	6.90 $\pm$ 0.03	7.00 $\pm$ 0.03	6.20 $\pm$ 0.03
<b>Ib</b>	2014		7.40 $\pm$ 0.04	5.00 $\pm$ 0.04
	2015	6.80 $\pm$ 0.03	6.60 $\pm$ 0.03	5.20 $\pm$ 0.04
	2016	6.80 $\pm$ 0.03	6.90 $\pm$ 0.03	5.70 $\pm$ 0.03
	2017	7.10 $\pm$ 0.03	7.30 $\pm$ 0.03	6.30 $\pm$ 0.03

\*Blank cells with missing values.

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## **Appendix II** – Genetic parameters for mature cow body condition scores and fat and muscle traits in finishing beef cattle

### **Publications arising from this chapter:**

Weik F, Hickson RE, Morris ST, Garrick DJ and Archer JA (2021). Genetic parameters for mature cow body condition scores and fat and muscle traits in finishing beef cattle. Proceedings of the 12th World Congress of Genetics Applied to Livestock Production: 2716-2719. DOI: 10.3920/978-90-8686-940-4\_658

### **Abstract**

Traits related to muscle and fat deposition are economically relevant for beef cattle finishing but may also influence reproductive performance in mature beef cows. The aim of this study was to examine the genetic relationships of mature cow body condition score (MBCS) with fat and muscle traits in finishing cattle. Genetic correlations among MBCS at different seasonal time points were high, with the lowest estimate of 0.84 between MBCS at weaning and MBCS prior to calving. Generally, muscle and fat traits in both mature cows and finishing cattle were lowly genetically correlated but similarly so across all measured time points. There is scope to identify animals with favourable genotypes for both maternal and finishing fat and muscle traits. Improving genetic merit for muscling or fat content in finishing cattle may be achieved without greatly impacting on body energy reserves in mature cows.

## **Introduction**

Body energy reserves are key components determining the reproductive performance of beef cows in the breeding herd (Osoro & Wright, 1992). The optimum condition of cows may differ throughout the production cycle and for varying production systems. Cow body condition scoring is a tool to subjectively assess stored energy reserves in cows, made up of fat and muscle (Hickson *et al.*, 2017). Currently, in New Zealand breeding values are commonly available for ultrasound (US) or carcass fat and muscle traits in finishing cattle but not for body condition score in mature cows (MBCS). Some breeders are selecting carcass fat traits with the objective of maintaining MBCS in cows. Although extensive research exists on the genetic relationships among economically relevant traits in beef cattle, there is only limited information on the relationship of subjective measures of body condition in cows with objectively measured muscling and fat traits in slaughtered cattle (De Lacerda *et al.*, 2019). Outcomes from Chapter 5 showed that genetic correlations were low between cow MBCS and finishing traits in New Zealand beef cattle, assuming that MBCS measured at different time points was genetically the same trait. The aim of this study was to determine whether distinct genetic relationships exist for cow MBCS at different seasonal time points, considered as separate traits, with muscle and fat traits in finishing beef cattle.

## **Materials and methods**

### ***Dataset***

All manipulations were approved by the AgResearch Animal Ethics Committee. Data originated from an ongoing beef progeny test by Beef + Lamb New Zealand Genetics conducted on commercial New Zealand hill country farms since 2014 (refer to Chapter 2). Measures on several performance and production traits were recorded for the original population of Angus or Hereford cows and their crossbred progeny. This study used data on traits related to muscling and fat composition measured on cows in the breeding herd (Angus, Hereford or Stabilizer sired) and males and females as part of the finishing operation (Angus, Hereford, Simmental, Stabilizer or Charolais sired).

### ***Traits***

Body condition score was obtained through visual assessment of body energy reserves of mature cows from three years of age on a 1 to 10 scale (1= emaciated, 10 = obese; Hickson *et al.*, 2017) for a total of 4,590 cows. Scoring was conducted by a trained scorer or by the farmer under regular supervision and training. Measures were taken at three seasonal time points: prior to mating, at weaning and prior to calving. Scanning of the US traits eye-muscle area (EMA) and rib fat depth (FD<sub>RIB</sub>) was conducted on live animals between 475 and 616 days of age by a BREEDPLAN-accredited technician on 1,900 steers and 2,049 heifers. The traits carcass eye-muscle area (CEMA) and carcass rib fat depth (RF) were recorded between 541 and 1,029 days of age by trained graders using the Meat Australia chiller assessment system (AUS-MEAT, 2018) on the day following slaughter of 1,615 steers and 354 heifers.

### ***Data editing***

A contemporary group (CG) was assigned to each animal and trait. For MBCS, CG comprised herd, recording date and management group at the time of measurement. For US and carcass traits, CG also included the sex of the animal and management groups leading up to the US scan or slaughter date, respectively. Phenotypes were removed from the dataset when only one individual was recorded in a CG or when all animals within a CG had equal phenotypes.

Cow MBCS was pre-adjusted to five years of age by fitting a fixed effects model with cow age in years (cows  $\geq 12$  years of age in a single class) and CG as class effects in the model. Finishing traits were pre-adjusted to either a constant LWT of 432 kg for US traits or a constant carcass weight of 310 kg for traits measured at slaughter

(representing the mean weight at US scanning or slaughter, respectively) to compare muscularity and fatness rather than absolute size. Adjustments on an individual animal basis were obtained using the four-step procedure presented by Reverter *et al.* (2000) and fitting either LWT at US scanning or carcass weight as linear and quadratic covariates as well as CG as a factor in that model. Following pre-adjustments, observations above or below three standard deviations (SD) from the CG mean were removed. All traits were tested for heterogeneity of variances. Traits with a significant regression ( $P < 0.05$ ) of the CG SD on the CG mean were scaled to homogenize the variances (refer to Chapter 4, Pickering *et al.*, 2012).

### **Statistical analysis**

Data cleaning and pre-adjustments of the phenotypes were done using R version 3.6.0. Genetic parameters were estimated using restricted maximum likelihood in ASREML 4.1 (Gilmour *et al.*, 2015). Variance components were obtained for MBCS and US traits using univariate animal models. For carcass traits bivariate models were used by including LWT at US scanning as a correlated trait to account for any selection prior to slaughter due to drafting of animals in weight-dependent slaughter management groups following US scanning. Genetic and phenotypic correlations were estimated from bivariate animal models, or trivariate models when a carcass trait together with LWT at US scanning was included.

A CG class effect, and covariates for breed percentage and heterosis (0 = purebred; 1 = first-cross) were fitted as fixed effects for all traits, and an age of dam class effect was included for US traits only. A random animal and residual error term were fitted for each trait. Additionally, a random permanent environmental effect was fitted for each MBCS trait to account for correlated residuals on repeated measures from the same animal. Variance structures for the random effects were assumed as follows:  $\text{var}(a) = \mathbf{A}\sigma_a^2$ ,  $\text{var}(pe) = \mathbf{I}\sigma_{pe}^2$  and  $\text{var}(e) = \mathbf{I}\sigma_e^2$ . The numerator relationship matrix  $\mathbf{A}$  comprised a total of 14,240 animals including 424 sires and 4,473 dams.

## Results

Among seasonal MBCS traits, the phenotypic mean was lowest prior to calving but the associated SD were similar and small across seasons (Appendix II. Table 1). Variance components for MBCS traits were in a similar range across seasons for the additive genetic (0.13–0.17) and the residual (0.33–0.37) variances, however, the permanent environmental variance was slightly higher at weaning than at other seasons, and this is reflected in the higher repeatability. Heritabilities for MBCS traits were the same across seasons (0.26–0.27). Heritabilities of finishing fat and muscle traits were higher overall compared to MBCS at any season. At US scanning, heritability was higher for  $FD_{RIB}$  compared to EMA whereas CEMA was more heritable than RF at slaughter.

**Appendix II. Table 1** Means ( $\pm$ standard deviations), variance components ( $\sigma^2_a$ =direct additive genetic,  $\sigma^2_{pe}$ =permanent environmental,  $\sigma^2_\epsilon$ =residual), heritabilities ( $h^2 \pm$ standard errors) and repeatabilities ( $t \pm$ standard errors) in New Zealand beef cattle.

Trait	Mean	$\sigma^2_a$	$\sigma^2_{pe}$	$\sigma^2_\epsilon$	$h^2$	$t$
MBCS mating	7.25 (0.91)	0.15	0.04	0.37	0.27 (0.04)	0.34 (0.01)
MBCS weaning	6.93 (0.91)	0.17	0.10	0.36	0.27 (0.04)	0.43 (0.01)
MBCS calving	6.46 (0.93)	0.13	0.05	0.33	0.26 (0.06)	0.35 (0.01)
EMA <sup>1</sup>	63.24 (5.03)	5.84		10.26	0.36 (0.05)	
$FD_{RIB}$ <sup>1</sup>	3.53 (0.98)	0.53		0.45	0.54 (0.05)	
CEMA <sup>1</sup>	74.58 (6.75)	13.91		18.79	0.43 (0.11)	
RF <sup>1</sup>	5.35 (2.59)	2.01		5.18	0.28 (0.07)	

MBCS=mature cow body condition score; EMA=eye-muscle area (ultrasound);  $FD_{RIB}$ =rib fat depth (ultrasound); CEMA=eye-muscle area (carcass); RF=rib fat depth (carcass)

<sup>1</sup>Finishing cattle; parameters presented in Chapter 5.

Genetic correlations among MBCS traits were high across all seasons, ranging from 0.84 to 0.99 (Appendix II. Table 2). The lowest estimate was observed between MBCS at weaning and MBCS before calving.

Genetic correlations were generally low among MBCS at all seasonal time points with finishing traits (Appendix II. Table 3), but moderate correlations were obtained for MBCS prior to calving with either EMA (0.31) or  $FD_{RIB}$  (0.32). Genetic correlations of finishing traits with MBCS tended to be highest at calving and lowest at weaning with the exception of CEMA. Across all time points MBCS traits were slightly higher genetically correlated with fat traits compared to muscling.

**Appendix II. Table 2** Genetic ( $\pm$ standard errors; below diagonal) and phenotypic ( $\pm$ standard errors; above diagonal) correlations for body condition scores (MBCS) at different seasons in mature New Zealand beef cows.

	MBCS mating	MBCS weaning	MBCS calving
MBCS mating		0.65 (0.01)	0.47 (0.01)
MBCS weaning	0.95 (0.03)		0.54 (0.01)
MBCS calving	0.99 (0.06)	0.84 (0.09)	

**Appendix II. Table 3** Genetic ( $r_g$ ) and phenotypic ( $r_p$ ) correlations ( $\pm$ standard errors) among MBCS in mature New Zealand beef cows and muscle and fat traits in finishing cattle.

	EMA		$FD_{RIB}$		CEMA <sup>1</sup>	RF <sup>1</sup>
	$r_g$	$r_p$	$r_g$	$r_p$	$r_g$	$r_g$
MBCS	0.18	0.06	0.27	0.10	-0.07	0.08
mating	(0.07)	(0.04)	(0.06)	(0.04)	(0.11)	(0.12)
MBCS	0.14	-0.01	0.16	0.08	-0.05	-0.06
weaning	(0.08)	(0.04)	(0.06)	(0.04)	(0.12)	(0.12)
MBCS	0.31	0.14	0.32	0.21	0.03	0.17
calving	(0.09)	(0.05)	(0.08)	(0.05)	(0.12)	(0.13)

MBCS=mature cow body condition score; EMA=eye-muscle area (ultrasound);  $FD_{RIB}$ =rib fat depth (ultrasound); CEMA=eye-muscle area (carcass); RF=rib fat depth (carcass)

<sup>1</sup>No  $r_p$  identifiable between traits not expressed within the same animal (carcass and MBCS traits)

## Discussion

Heritabilities for MBCS were similar across seasons but overall higher compared to results presented by Arango *et al.* (2002). Arango *et al.* (2002) reported slightly higher permanent environmental variation at weaning compared to measures taken prior to mating and calving, which aligns with results found in the current study. Results indicate potential to improve MBCS through direct selection at any season, but genetic progress may be slow due to low phenotypic variation. A selection response is likely to be stronger for muscling and fat traits in finishing animals compared to MBCS traits in cows due to higher heritabilities (Wolcott *et al.*, 2013).

In agreement with Arango *et al.* (2002) and Wolcott *et al.* (2013), cow MBCS traits were highly genetically correlated across seasons. Thus, animals with a higher genetic merit for MBCS at any season are likely to also exhibit greater body energy reserves at other seasons in the annual production cycle. The lower genetic correlation between MBCS at weaning and MBCS prior to calving compared to MBCS at mating may be attributable to the physiological status of the cows during lactation or pregnancy which is likely to impact on fat deposition (Arango *et al.*, 2002).

Generally, genetic associations of fat and muscle traits in finishing cattle with mature cow MBCS traits were low and similar across time points such that treating seasonal MBCS measures as different traits may not be required. The MBCS before calving, however, tended to be slightly higher genetically correlated to all finishing traits compared to MBCS at other seasons and this may also be induced by physiological differences during late pregnancy. Direct selection on carcass traits with the objective of increasing cow MBCS throughout the annual cycle is likely to be inefficient. Ultrasound rib fat and EMA offered the best options for selecting on finishing traits to generate a correlated response in cow MBCS and results were similar to those presented by De Lacerda *et al.* (2019). However, genetic progress in maternal and finishing fat and muscle traits is likely to be more efficient when animals are measured for both trait groups.

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## References

- Arango JA, Cundiff LV, Van Vleck LD 2002. Genetic parameters for weight, weight adjusted for body condition score, height, and body condition score in beef cows. *Journal of Animal Science* 80: 3112-3122. DOI: 10.2527/2002.80123112x
- AUS-MEAT. 2018. Australian beef carcass evaluation. Beef and veal chiller assessment language [Online]. AUS-MEAT: Brisbane, Queensland, Australia. Available: [https://www.ausmeat.com.au/WebDocuments/Chiller\\_Assessment\\_Language.pdf](https://www.ausmeat.com.au/WebDocuments/Chiller_Assessment_Language.pdf) [Accessed 28 October 2021].
- De Lacerda VV, Campos GS, Silveira DD, Roso VM, Santana ML, Souza FRP, Boligon AA 2019. Genetic associations between mature size and condition score of Nelore cows, and weight, subjective scores and carcass traits as yearlings. *Animal Production Science* 59: 1209-1217. DOI: 10.1071/AN17873
- Gilmour AR, Gogel BJ, Cullis BR, Welham SJ, Thompson R 2015. ASReml user guide release 4.1 structural specification. VSN international Ltd.: Hemel Hempstead, UK.
- Hickson RE, Morris ST, Thomson BC. 2017. Beef cow body condition scoring [Online]. Available: <https://beeflambnz.com/knowledge-hub/PDF/beef-cow-body-condition-scoring> [Accessed 28 November 2022].
- Osoro K, Wright IA 1992. The effect of body condition, live weight, breed, age, calf performance, and calving date on reproductive performance of spring-calving beef cows. *Journal of Animal Science* 70: 1661-1666. DOI: 10.2527/1992.7061661x
- Pickering NK, Dodds KG, Blair HT, Hickson RE, Johnson PL, McEwan JC 2012. Genetic parameters for production traits in New Zealand dual-purpose sheep, with an emphasis on dagginess. *Journal of Animal Science* 90: 1411-1420. DOI: 10.2527/jas.2011-4163
- Reverter A, Johnston DJ, Graser H-U, Wolcott ML, Upton WH 2000. Genetic analyses of live-animal ultrasound and abattoir carcass traits in Australian Angus and Hereford cattle. *Journal of Animal Science* 78: 1786-1795. DOI: 10.2527/2000.7871786x
- Wolcott ML, Johnston D, Barwick S, Corbet N, Burrow HM 2013. Genetic relationships between steer performance and female reproduction and possible impacts on whole herd productivity in two tropical beef genotypes. *Animal Production Science* 54: 85-96. DOI: 10.1071/AN13141

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## **Appendix III** – Genetic parameters for structural traits in New Zealand beef cattle and their correlations with production traits

### **Publications arising from this chapter:**

Weik F, Hickson RE, Morris ST, Garrick DJ and Archer JA 2021. Genetic parameters for structural traits in New Zealand beef cattle and their correlations with production traits. Proceedings of the Association for the Advancements of Animal Breeding and Genetics 24: 435–438.

**Abstract**

Structural soundness has the potential to affect the length of a productive life in beef cattle. The objectives of this study were to estimate genetic parameters for structural traits and to examine their relationship with production traits (mature live weight, body condition score, 18-month weight and yearling hip height) measured in beef cattle in New Zealand. Heritabilities for structural traits were low to moderate ranging from 0.09 to 0.25. Genetic correlations among structural traits ranged from 0.18 to 1.00 whereas phenotypic and genetic correlations with production traits were generally low positive to moderate negative (-0.54–0.23) indicating only a limited impact on production.

**Introduction**

Structural soundness is believed to influence fitness of cattle in extensive pasture-based farming systems. Beef cattle may be required to walk long distances to graze so unsound structure may impact on cow performance. Scientific literature on structural traits of beef cattle is sparse and there are no previous reports from New Zealand. Research on structural soundness has been predominantly conducted in dairy cattle (Dechow *et al.*, 2002) and there is some evidence that females with good conformation stay in the herd for longer (Berry *et al.*, 2005). Most reports, however, have been focused on type traits other than feet and leg scores. Therefore, the objectives of this study were to estimate genetic parameters for nine structural feet and leg traits recorded in commercially farmed beef cattle in New Zealand and to examine their relationship with mature live weight (MWT), body condition score (MBCS), 18-month weight (W18) and yearling hip height (YHIP).

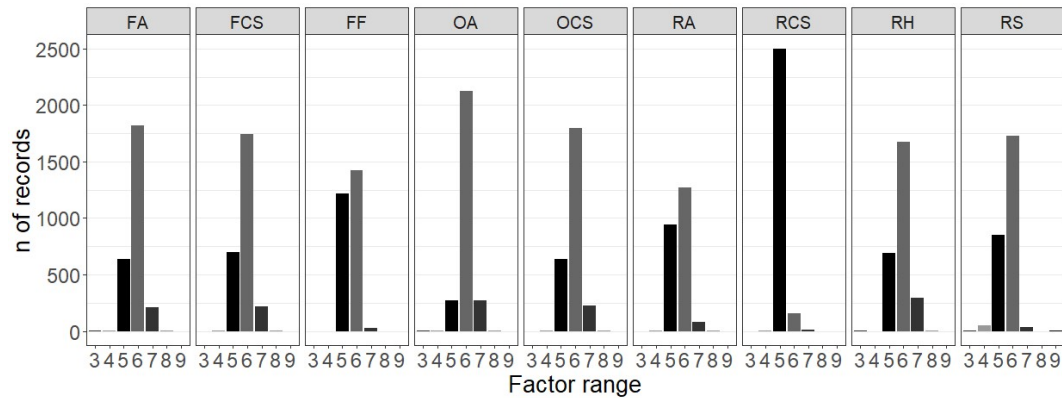
## **Materials and methods**

### ***Dataset***

The project was approved by the AgResearch Invermay Animal Ethics Committee. Data were obtained from an ongoing progeny test initiated in 2014 on five commercial New Zealand hill country farms to compare the performance of progeny derived from matings of Angus, Hereford, Simmental, Stabilizer and Charolais bulls over Angus or Hereford cows (refer to Chapter 2). The current study used data recorded between 2014 and 2020 for structural and production traits. Birth dates were not recorded, but age was assigned based on fetal age scanning.

### ***Trait definitions***

Structural traits were assessed according to the Beef Class Structural Assessment system (BREEDPLAN, 2021). Seven traits were recorded: front feet angle (FA), front feet claw set (FCS), front legs front view (FF), rear feet angle (RA), rear feet claw set (RCS), rear legs hind view (RH) and rear legs side view (RS). Records were available for a total of 2,294 animals for RA, 2,670 animals for RH and RS and 2,671 animals for all other structural traits at approximately 16–20 months of age by the same experienced BREEDPLAN-accredited assessor across all farms. Each trait was recorded following a linear assessment on a 1 to 9 scale, with 1 and 9 representing biological extremes with 5 as the intermediate optimum. No animals were scored at the extreme ends of the scale (1–2 or 9, respectively) and 99.6% of observations were between 5 and 7 (Appendix III. Figure 1). Overall feet score was calculated for each animal by taking the worst score for FA and RA, or FCS and RCS, for overall feet angle (OA) and overall claw set (OCS), respectively.



**Appendix III. Figure 1** Distribution of scores for front feet angle (FA), front feet claw set (FCS), front legs front view (FF), rear feet angle (RA), rear feet claw set (RCS), rear legs hind view (RH), rear legs side view (RS), overall feet angle (OA) and overall claw set (OCS).

Four production traits were included in the correlation analyses, namely MWT, MBCS, W18 and YHIP. A total of 39,464 records were available for MWT. Data were obtained at three timepoints annually, prior to mating, at calf weaning and prior to calving for cows aged over two years. Cow MBCS was recorded at the same times, generating 39,467 records based on visual assessment on a 1 to 10 scale (1=emaciated, 10=obese; Hickson *et al.*, 2017). Both traits were adjusted to a constant six years of age using fixed effect models with age and contemporary group (CG) as factors in the model.

A total of 7,048 progeny were recorded for weaning weight (WWT) between 110 and 228 days of age. Measures on W18 were available for 4,189 individuals measured between 455 and 752 days of age. Each animal was recorded once for WWT and W18. Linear and quadratic adjustments to 200 and 600 days of age were applied for WWT and W18 using a multiplicative approach similar to that described by Reverter *et al.* (2000). Records for YHIP were obtained once per animal between 277 and 417 days of age for 5,125 individuals, and adjusted to 365 days, using quadratic age adjustments.

Observations for production traits further than three standard deviations from the CG mean were deleted. For all structural traits, WWT and W18, CG comprised farm, sex, recording date and management group from birth until the day of recording. The CG for MWT and MBCS consisted of farm, time of year, recording date and management group at the time of data collection. The YHIP CGs were made up of farm, sex and recording date. Individuals with missing CG information or CG containing only one animal were excluded from analyses. All production traits were tested for evidence of heterogeneity.

Traits with a significant regression of CG mean on CG SD were scaled to homogenize the variance (Pickering *et al.*, 2012).

### **Statistical analysis**

Data quality control and pre-adjustments of phenotypes were conducted using R version 3.6.0 (R Core Team, 2019). (Co)variance parameters were estimated using ASREML 4.1 (Gilmour *et al.*, 2009). For all traits, WWT was included as a correlated trait to account for preselection. Thus, heritability estimates were obtained from bivariate animal models and genetic and phenotypic correlations from (co)variance parameters using a range of trivariate animal models.

Fixed effects included for all traits were CG, breed percentage and heterosis (purebred = 0, first-cross = 1). Age of dam was fitted as a factor for all structural traits as well as WWT, W18 and YHIP. Age at scoring was fitted as a linear covariate in the model for each structural trait. An animal effect and a residual error term were fitted as random effects for each trait, a permanent environmental effect was fitted for MWT and MBCS due to repeated measures over time and a maternal additive genetic as well as a permanent environmental effect of the dam were fitted for WWT. Variance structures for the random effects were assumed as follows:  $\text{var}(\mathbf{a}) = \mathbf{A}\sigma^2_a$ ,  $\text{var}(\mathbf{m}) = \mathbf{A}\sigma^2_m$ ,  $\text{var}(\mathbf{pe}) = \mathbf{I}\sigma^2_{pe}$  and  $\text{var}(\mathbf{e}) = \mathbf{I}\sigma^2_e$ . No covariance was fitted between direct and maternal genetic effects. The numerator relationship matrix ( $\mathbf{A}$ ) included 13,325 animals with 394 sires and 4,098 dams.

## Results and Discussion

Means, phenotypic standard deviations and estimated heritabilities from bivariate analyses with WWT for each structural trait are presented in Appendix III. Table 1. The means of all structural traits ranged from 5.1 to 6.0. The standard deviations (SD) were similar for most traits except RCS. The limited number of extreme scores meant that SD were low for all structural traits.

**Appendix III. Table 1** Raw means, phenotypic standard deviations ( $\sigma_p$ ) and heritabilities ( $h^2$ ) for structural traits with standard errors shown in brackets.

	<b>FA</b>	<b>FCS</b>	<b>FF</b>	<b>RA</b>	<b>RCS</b>	<b>RH</b>	<b>RS</b>	<b>OA</b>	<b>OCS</b>
Mean	5.8	5.8	5.6	5.6	5.1	5.9	5.7	6.0	5.8
$\sigma_p$	0.53	0.52	0.50	0.53	0.26	0.57	0.53	0.43	0.51
	(0.09)	(0.09)	(0.08)	(0.09)	(0.04)	(0.10)	(0.09)	(0.07)	(0.09)
$h^2$	0.23	0.10	0.09	0.17	0.09	0.22	0.12	0.25	0.11
	(0.05)	(0.04)	(0.04)	(0.05)	(0.04)	(0.05)	(0.04)	(0.06)	(0.04)

FA = front feet angle; FCS = front feet claw set; FF = front legs front view; RA = rear feet angle; RCS = rear feet claw set; RH = rear legs hind view; RS = rear legs side view; OA = overall feet angle; OCS = overall claw set.

**Appendix III. Table 2** Genetic (below diagonal) and phenotypic (above diagonal) correlations (se) from trivariate animal models among structural and production traits in New Zealand beef cattle.

	FA	FCS	FF	RA	RCS	RH	RS	OA	OCS	MWT	MBCS	W18	YHIP
FA		0.38 (0.02)	0.22 (0.02)	-0.03 (0.02)	0.07 (0.02)	0.14 (0.02)	0.12 (0.02)	0.74 (0.01)	0.36 (0.02)	-0.07 (0.03)	-0.06 (0.03)	-0.09 (0.02)	0.00 (0.02)
FCS	0.99 (0.12)		0.17 (0.02)	0.02 (0.02)	0.02 (0.02)	0.12 (0.02)	0.14 (0.02)	0.27 (0.02)	0.95 (0.00)	-0.03 (0.03)	-0.04 (0.03)	-0.03 (0.02)	0.04 (0.02)
FF	0.54 (0.20)	0.66 (0.27)		0.08 (0.02)	0.04 (0.02)	0.21 (0.02)	0.12 (0.02)	0.15 (0.02)	0.16 (0.02)	-0.06 (0.03)	-0.08 (0.03)	-0.13 (0.02)	0.01 (0.02)
RA	0.24 (0.20)	0.19 (0.26)	0.69 (0.24)		0.15 (0.02)	0.09 (0.02)	0.08 (0.02)	0.39 (0.02)	0.04 (0.02)	-0.07 (0.03)	0.00 (0.04)	-0.12 (0.02)	-0.06 (0.03)
RCS	0.33 (0.23)	0.57 (0.32)	0.27 (0.32)	0.36 (0.26)		0.04 (0.02)	0.03 (0.02)	0.12 (0.02)	0.20 (0.02)	-0.05 (0.03)	-0.04 (0.03)	0.01 (0.02)	0.01 (0.02)
RH	0.21 (0.17)	0.38 (0.21)	0.61 (0.21)	0.50 (0.18)	0.43 (0.24)		0.29 (0.02)	0.11 (0.02)	0.12 (0.02)	-0.08 (0.03)	-0.14 (0.03)	-0.17 (0.02)	0.07 (0.02)
RS	0.42 (0.19)	0.60 (0.25)	0.18 (0.28)	0.72 (0.21)	0.53 (0.30)	0.26 (0.20)		0.12 (0.02)	0.13 (0.02)	-0.06 (0.03)	-0.14 (0.03)	-0.14 (0.02)	-0.02 (0.02)
OA	0.92 (0.04)	0.76 (0.15)	0.79 (0.19)	0.53 (0.16)	0.32 (0.23)	0.27 (0.16)	0.56 (0.18)		0.26 (0.02)	-0.10 (0.03)	0.00 (0.03)	-0.11 (0.02)	-0.03 (0.03)
OCS	0.91 (0.12)	1.00 (0.02)	0.61 (0.26)	0.22 (0.24)	0.66 (0.26)	0.34 (0.21)	0.59 (0.25)	0.69 (0.15)		-0.05 (0.03)	-0.05 (0.03)	-0.02 (0.02)	0.04 (0.02)
MWT	-0.19 (0.07)	-0.10 (0.11)	-0.21 (0.12)	-0.16 (0.09)	-0.16 (0.12)	-0.16 (0.08)	-0.16 (0.10)	-0.20 (0.07)	-0.13 (0.11)				
MBCS	-0.07 (0.09)	-0.14 (0.13)	-0.27 (0.14)	-0.10 (0.11)	-0.09 (0.14)	-0.54 (0.10)	-0.35 (0.12)	-0.03 (0.09)	-0.12 (0.12)				
W18	-0.17 (0.12)	-0.04 (0.17)	-0.30 (0.17)	-0.53 (0.13)	-0.27 (0.18)	-0.09 (0.12)	-0.06 (0.16)	-0.32 (0.11)	-0.08 (0.16)				
YHIP	0.07 (0.12)	0.15 (0.17)	0.23 (0.18)	-0.19 (0.15)	-0.07 (0.18)	0.19 (0.12)	-0.12 (0.16)	-0.03 (0.12)	0.14 (0.16)				

FA = front feet angle; FCS = front feet claw set; FF = front legs front view; RA = rear feet angle; RCS = rear feet claw set; RH = rear legs hind view; RS = rear legs side view; OA = overall feet angle; OCS = overall claw set; MWT = mature cow weight; MBCS = body condition score; W18 = 18-month weight; YHIP = yearling hip height

The estimated heritabilities for structural traits were in the low-to-mid range from 0.09 to 0.25, consistent with Jeyaruban *et al.* (2012) and Vallee *et al.* (2015). Heritabilities for front feet observations were higher than their rear counterparts. The highest heritabilities were estimated for FA, RH and OA. Production traits were moderately to highly heritable with 0.57 (0.03) for MWT, 0.54 (0.04) for W18 and 0.52 (0.04) for YHIP and the estimated heritability was lowest for MBCS at 0.25 (0.03). Those values are consistent with estimates from the literature.

Genetic and phenotypic correlations are shown in Appendix III. Table 2. Phenotypic correlations among structural traits were generally positive and lower than genetic correlations. The estimated genetic correlations were positive among all structural traits ranging from 0.18 to 1.00. The highest correlations were observed between FA and FCS (0.99) and the part-whole correlations FA and OA (0.92) and FCS and OCS

(1.00). Correlations between both rear feet traits and the overall foot scores, however, were lower with 0.53 between RA and OA and 0.66 between RCS and OCS, indicating that overall feet scores are primarily driven by the condition of the front feet. Jeyaruban *et al.* (2012) reported high genetic correlations between FA and RA, which were considerably lower in the current study (0.24). The correlation between FCS and RCS (0.57) in this study, however, was consistent with their reported estimate of 0.63. Genetic correlations were generally higher among traits measured on the front feet (0.54–0.99) than on the rear feet (0.26–0.72).

The phenotypic correlations were generally low between structural and production traits, indicating that there is no evidence that structural traits in this study have a substantial impact on those production traits measured later in life. Genetic correlations between structural and production traits were similar for MWT, MBCS and W18 and were generally low and negative and this may be attributable to low variation of the observed structural traits. The only moderate genetic correlations further than 2 standard errors from zero were the negative correlations between MBCS and RH (-0.54), MBCS and RS (-0.35), W18 and RA (-0.53) and between W18 and OA (-0.32). Given the distribution of scores above the optimum these suggest that selecting for MBCS and W18 is unlikely to increase the frequency of animals with unsound structure. The genetic correlation between structural traits and YHIP were low overall with the highest genetic correlation estimated for YHIP and FF (0.23).

## **Conclusions**

Low to moderate heritabilities for structural traits exist in commercially farmed beef cattle in New Zealand. Genetic and phenotypic correlations among structural and production traits were generally low to moderate and negative, indicating only weak associations and, thus, a limited impact of structural traits on the recorded production traits in this study.







## References

- Berry D, Harris B, Winkelman A, Montgomerie W 2005. Phenotypic associations between traits other than production and longevity in New Zealand dairy cattle. *Journal of Dairy Science* 88: 2962-2974. DOI: 10.3168/jds.S0022-0302(05)72976-3
- BREEDPLAN. 2021. Recording structural soundness [Online]. Available: <https://breedplan.une.edu.au/media/1zhdxy51/recording-structural-soundness-information.pdf> [Accessed 27 January 2021].
- Dechow CD, Rogers GW, Clay JS 2002. Heritability and correlations among body condition score loss, body condition score, production and reproductive performance. *J Dairy Sci* 85: 3062-70. DOI: 10.3168/jds.S0022-0302(02)74393-2
- Gilmour AR, Gogel BJ, Cullis BR, Welham SJ, Thompson R 2015. ASReml user guide release 4.1 structural specification. VSN international Ltd.: Hemel Hempstead, UK.
- Hickson RE, Morris ST, Thomson BC. 2017. Beef cow body condition scoring [Online]. Available: <https://beeflambnz.com/knowledge-hub/PDF/beef-cow-body-condition-scoring> [Accessed 28 November 2022].
- Jeyaruban G, Tier B, Johnston D, Graser H 2012. Genetic analysis of feet and leg traits of Australian Angus cattle using linear and threshold models. *Animal Production Science* 52: 1-10.
- Pickering NK, Dodds KG, Blair HT, Hickson RE, Johnson PL, McEwan JC 2012. Genetic parameters for production traits in New Zealand dual-purpose sheep, with an emphasis on dagginess. *Journal of Animal Science* 90: 1411-1420. DOI: 10.2527/jas.2011-4163
- R Core Team. 2019. R: A language and environment for statistical computing [Online]. R Foundation for Statistical Computing, Vienna, Austria. Available: <https://www.R-project.org/> [Accessed 20 June 2020].
- Reverter A, Johnston DJ, Graser H-U, Wolcott ML, Upton WH 2000. Genetic analyses of live-animal ultrasound and abattoir carcass traits in Australian Angus and Hereford cattle. *Journal of Animal Science* 78: 1786-1795. DOI: 10.2527/2000.7871786x
- Vallée A, Breider I, van Arendonk J, Bovenhuis H 2015. Genetic parameters for large-scale behavior traits and type traits in Charolais beef cows. *Journal of animal science* 93: 4277-4284.

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