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Reducing the level of nutrition to maternal composite ewes from mid-pregnancy to the end of lambing results in predictable decreases in birth weight and weaning weight of their lambs.

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Abstract

Management of nutrition during pregnancy for maternal composite ewes has the potential to improve lamb production and survival in prime lamb production systems but existing condition score (CS) guidelines developed for Merinos may not be appropriate for the optimum production of maternal ewes. Three replicated experiments were conducted at two research sites in Victoria and one in Western Australia. Ewes (770-792 per site) were allocated to 4 CS treatments following pregnancy scanning (~day 50) and differentially fed to reach approximate targets of CS 2.4, 2.8, 3.2 and 3.6 by lambing. Single and multiple bearing ewes grazed together and nutritional treatments were applied until the end of lambing after which ewes and lambs were aggregated into management groups containing all treatments. At lambing, maternal ewe live weight had a range between treatments of 13.7 to 19.1 kg (average 16.4 kg) and CS varied by 1.1 to 1.5 of a CS (average 1.24). Across site analysis indicated that birth weight and weaning weight increased with application of higher CS treatments (*P*<0.001). There was also an improvement in survival of multiple born lambs with increasing CS at lambing (*P*<0.001). Birth weight was significantly related to survival (*P*<0.001) at all sites with no significant effect of birth type on lamb survival. Changes in birthweight and weaning weight could be predicted from ewe joining liveweight, ewe

liveweight change to day 90 and ewe liveweight change day 90 to lambing. The coefficients derived for each of these effects were similar to those found in previous experiments examining Merino and crossbred Border Leicester Merino ewes. The optimum condition score targets for multiple bearing maternal composite ewes may be higher than that recommended for Merino ewes based on observed advantages in survival and weaning weight.

Introduction

Undernutrition of the ewe during pregnancy and lactation is known to negatively affect ewe reproductive performance (Robinson *et al.* 2006, Ferguson *et al.* 2011), productivity (Masters *et al.* 1993, Ferguson *et al.* 2011), lamb birth weight and survival (Scales *et al.* 1986, Knight *et al.* 1988, Oldham *et al.* 2011, Behrendt *et al.* 2011). Using data generated from a series of plot scale and on farm experiments (Thompson *et al.* 2011) management guidelines for Merino ewes in multiple environments and production systems were developed (Young *et al.* 2011). Sheep producers adopting these management guidelines increased their whole farm stocking rate by 14%, increased lamb marking percentages by 11% and decreased ewe mortality by 43% (Trompf *et al.* 2011). However, anecdotal evidence from sheep producers and consultants participating in Lifetime Ewe Management a training program facilitating adoption of these management guidelines, indicated that these guidelines which were developed for Merino ewes may not optimise the performance of maternal composite ewes on Australian farms.

Crossbred and non-Merino ewes have higher liveweights at conception and significantly greater reproduction than Merino ewes (Geenty *et al.* 2014, Paganoni *et al.* 2014). In addition, in experiments where Merino ewes were managed together under the same pasture conditions with crossbred ewes, the crossbred ewes generally gained more liveweight and condition score (CS) (Holst *et al.* 2002, Hocking Edwards *et al.* 2018), although this is not always the case (Blumer *et al*. 2015). An analysis of breeding and production records from 8 genetically linked resource flocks has shown that the birth weight and weaning weight of single, twin or triple born or reared lambs could still be predicted from the liveweight profile of crossbred ewes (Paganoni *et al.* 2014). This study also found that the birth and weaning weight response to changes in ewe liveweight profile during pregnancy did not differ significantly between Merino and crossbred ewes, but the average birth and weaning weights were greater for crossbred ewes and ewes mated to terminal sires. These results were also supported by Hocking Edwards *et al.* (2018) where Border Leicester cross Merino (BLM) ewes were run together with Merinos. However, as the ewes in the genetically linked resource flocks were all managed to Lifetime wool guidelines and CS targets (www.lifetimewool.com.au) (Geenty et al. 2014, Paganoni *et al.* 2014, Young et al. 2011) there was a limited range in CS within the research sites and the data was not based on flocks managed to achieve different CS targets at lambing. Furthermore, the combined management of Merinos and BLM ewes (Hocking Edwards *et al.* 2018) may have allowed the BLM ewes to cope better with reductions in the level of nutrition through competition with Merino ewes grazing the same pasture. Crossbred ewes examined in both Paganoni *et. al.* (2014) and Hocking Edwards *et al.* (2018) were also derived from Merino dams and it is not known if maternal composite ewes with very little Merino sire influence would provide the same response.

The relationships between birth weight and survival for different ewe and sire breed combinations used in the 8 genetically linked resource flocks have been established (Paganoni *et al.* 2014). The birth weight and survival relationships were similar to other reports in the literature (Dalton *et al.*1980, Knight *et al.* 1988, Oldham *et al.* 2011, Hinch and Brien 2014, Hocking Edwards *et al.* 2018), but the survival rates were high for lambs born to terminal cross maternal matings with 89.3%, 84.6% and 73.4% lambs surviving to weaning for single, twin and triplet born lambs respectively. This possibly reflects the high level of management intervention and small paddock size at lambing for these flocks. These levels of survival would appear to be greater than reported for Australian flocks (Hinch and Brien 2014). They also appear to be inconsistent with industry benchmarking of the average marking percentages of crossbred and non-Merino flocks in farm bench marking studies and industry survey data (Blackshaw and Ough 2015, Curtis 2009). This same discrepancy between plot scale research and commercial enterprises occurred in the Lifetime Wool project (Oldham *et al.* 2011), so commercial scale validation sites were required to refine the responses relating ewe liveweight profile, lamb birth weight and survival (Behrendt *et al.* 2011), to enable management guidelines to be developed for Merino ewes across multiple environments and production systems (Young *et al.* 2011).

Maternal undernutrition, particularly in the last third of pregnancy, consistently reduces birth weight of lambs and with consequences for subsequent lamb performance (reviewed by Greenwood *et al.* 2010; Kenyon and Blair 2014; Rooke *et al.* 2015). However, the impact of undernutrition in early to mid-pregnancy and the impact of nutrition above maintenance requirements appear to be more variable. Previous economic modelling (Young *et al.* 2010) has shown that the profit of prime lamb systems is sensitive to nutrition during pregnancy and the CS achieved at lambing. In that study, increasing ewe liveweight by 7 to 10kg or 1 CS through reduced stocking rate and feeding extra grain increased profit by $50/ha. Prime lamb production systems, however, are largely driven by the number of ewes mated per ha, live lambs produced per ewe to weaning and lamb liveweight at sale. Productivity and profit is likely to be sensitive to effects of ewe nutrition on lamb survival, birth weight and weaning weight and thus differences in the impact of ewe nutrition during gestation between Merino and maternal composite may have consequences for the optimum targets for ewe liveweight and CS during pregnancy.

Three field experiments were conducted across southern Australia with maternal composite ewes joined to lamb at different times to test our first hypothesis that on a commercial scale, the impact of ewe liveweight change during pregnancy would have consistent and predictable effects on lamb birth weight and weaning weight, and that lamb birth weight would be strongly associated with lamb survival. A primary aim of the project was to generate data similar to that established in the Lifetime Wool project (Thompson *et al.* 2011, Behrendt *et al.* 2011) for maternal composite ewes to enable prediction of birth weight, survival and weaning weight responses from liveweight change during pregnancy. As such our second hypothesis was that relationships established for maternal composite ewes would be different to those established for Merinos.

Methodology

All procedures involving animals within this group of experiments were conducted in accordance with the Australian Code for the Care and Use of Animals Used for Scientific Purposes, under approval of the Animal Ethics Committees of the three collaborating research institutions Murdoch University R117 (Mount Barker); RIST R2647 (Pigeon Ponds); and Department of Economic Development, Jobs, Transport and Resources 2015-01 (Hamilton).

Experimental Sites

The experiments were undertaken at three sites; near Hamilton (37°50´S, 142°04´E) and Pigeon Ponds (37°16´S, 141°40´E), Victoria and Mount Barker (34°38´S, 117°40´E), Western Australia. Each site was in a temperate Mediterranean environment with a winter dominant rainfall pattern. The Hamilton site was on a research farm, 200 m above sea level and received 476 mm of rainfall in 2014 compared to the long term average (LTA) of 686 mm. The Pigeon Ponds site was on a commercial farm, 300 m above sea level and received 500 mm rainfall in 2014 compared to the LTA of 600 mm. The Mount Barker site was on a commercial farm, 260 m above sea level and received 496 mm rainfall in 2014 compared to the LTA of 581 mm. The 2014 pasture growing season was 6, 6 and 7 months long for the Hamilton, Pigeon Ponds and Mount Barker sites respectively. The pastures grazed at the Hamilton site were based on perennial ryegrass (*Lolium perenne* L.), tall fescue (*Festuca arundinacea* Schreb.), lucerne (*Medicago sativa* L.) mixed with subterranean clover (*Trifolium subterranean* L.). Pastures at the Pigeon Ponds site were predominately mixed perennial ryegrass, phalaris (*Phalaris aquatica* L.) pastures with annual grasses and subterranean clover. The pastures at Mount Barker were based on annuals, comprising subterranean clover, barley grass (*Hordeum glaucum and H. leporinum*), ryegrass (*Lolium rigidum* gaud.), brome grass (*Bromus spp.*) and silver grass (*Vulpia spp.*) and capeweed (*Arctotheca calendula* L.).

Ewe Mating

At Hamilton, 1178 maternal composite ewes were naturally mated in groups of 49 or 50 to 24 individual maternal composite sires from the 14 March to 17 April 2014. At Pigeon Ponds, 1000 maternal composite ewes were artificially inseminated to 2 Poll Dorset sires over 4 days from 3 February to 6 February 2014. At Mount Barker, 1780 maternal composite ewes were naturally mated to a syndicate of 25 maternal composite sires from the 31 January 2014 to 11 March 2014. Ewes were randomly allocated to sires or mating groups based on a stratification for liveweight and CS at joining. Ewes were then ultrasound scanned at approximately day 50 of pregnancy to determine those ewes that were pregnant. All ewes pregnant to artificial insemination at Pigeon Ponds and all ewes assessed as being pregnant in the first 21 days for the Hamilton site were then used for allocation to the experiments at those sites. The same procedure was also used at the Mt Barker site but because insufficient ewes were scanned as pregnant in the first cycle, some ewes scanned pregnant on the second cycle were also included.

Sire selection

Maternal composite and terminal prime lamb sires were selected to meet the individual aims of the research farm or collaborating farms at each experimental site but represented a broad range in Australian Sheep Breeding Values for all traits commonly used within the Australian sheep industry. Birthweight and post-weaning weight ASBVs ranged from +0.2 to +0.5 kg and +6.7 to +16.5 kg, post-weaning fat ranging from -1.7 to 0.4 mm and post-weaning eye muscle depth -0.8 to 3.7 mm.

Reproductive rates

The total number of ewes mated across all sites ewes was 3958. Between 770 and 840 pregnant ewes were generated per site over the defined periods that enabled between 66 and 77 pregnant ewes to be allocated to each of the two or three replicates of the four ewe CS treatments at each site (Table 1). The potential reproductive rate (foetuses scanned per pregnant ewe) of ewes allocated to each plot/paddock system varied with each research site between 128 to 170% and the incidence of triplets was low (2% or less) at all sites.

Experimental design and allocation of treatments

The Hamilton site contained forty eight ~1 ha paddocks blocked for topography and pasture type. The Pigeon Ponds site contained 10 paddocks averaging 9.8ha (7.2 ha - 13.3 ha) blocked for similar topography and shelter. The Mount Barker site also had 10 paddocks averaging 10.5ha (9.0 ha - 13.2 ha) blocked according to exposure to the prevailing winds.

For the Hamilton site, a randomized block design with three replicates of four CS treatments was used. For the Pigeon Ponds and Mount Barker sites, an unbalanced randomized block design was used with four CS treatments replicated twice with the 2.4 and 3.2 CS treatments having an additional replicate (Table 1). At Pigeon Ponds, the four CS treatments were allocated to two blocks of four plots classed as tablelands and the additional replicate was a block comprising two plots of low lying and undulating aspect. At Mount Barker, the four CS treatments were allocated to two blocks of four plots with exposure to the prevailing winds and the additional replicate was applied to a block of two plots most protected from the prevailing winds. Using these designs, the pregnant ewes were allocated randomly to each treatment using stratification for ewe liveweight and CS at joining and balancing treatments for potential reproductive rate (the number of single and multiple-bearing ewes) and sire (Table 1).

Ewe management from joining to pregnancy scanning aimed to maintain ewe liveweight and CS. Treatments commenced following pregnancy scanning (between 60 and 90 days after the start of mating) and aimed to achieve the required target CS at lambing (Table 1). Treatments were maintained until the end of lambing at which point ewes were aggregated into larger management groups based on their block structure. While there were slightly different CS targets at each site (Table 1), based on variation in the requirements of the different institutional animal ethics committees, the target CS of 2.4, 2.8, 3.2 and 3.6 at the end of lambing are used for descriptive purposes of the treatments throughout the paper.

Management of ewe nutrition

The CS treatments were achieved at different sites by either restricting or increasing the feed on offer (FOO, kg DM /ha) available to each flock and supplementing ewes with additional hay or grain as required to increase or decrease liveweight and CS. The FOO available to the ewes in each pasture paddock/plot was manipulated through various methods. At Hamilton, rotational grazing was practiced with faster or slower rotations to manipulate FOO. In addition, paddocks were also pre-grazed to lower FOO. For the Pigeon Ponds site, paddocks were set-stocked and additional stock were added to manipulate FOO. At Mount Barker, electric fencing was used to modify the available area and grazing pressure. The average stocking rate across the experimental area was 17.4, 8.3 and 7.7 ewes/ha for the Hamilton, Pigeon Ponds and Mount Barker sites respectively. At Hamilton, the supplements fed were barley (12.9 MJ/kg DM and 10.6% CP) and hay (6.9 MJ/kg DM and 5.4% CP), whilst Pigeon Ponds fed oats (13.1 MJ/kg DM and 10.9% CP) and Mount Barker fed barley (13.5 MJ/kg DM and 12.8% CP).

Feed on offer was assessed using either a rising plate meter (Earle and McGowan 1979) or using a calibrated visual method (Cayley and Bird 1996; Thompson *et al.* 1994). Each method was calibrated by harvesting pasture to ground level from quadrats covering the range of FOO for each of the pasture species at the experimental sites. Samples were sorted to remove non-vegetative matter, washed and then dried at 60°C for 48 hours. Ewes at all sites received a pre-lambing drench and vaccination. Other typical preventative animal health and husbandry practices were implemented according to farm practice at each site.

Ewe liveweight and condition score measurement

Ewes were weighed and CS measured at approximately two to three weekly intervals during the experiments from pre-joining until weaning. Condition score was assessed by a single experienced operator for each research site according to Jefferies (1961), Russel *et al.* (1969), van Burgel *et al.* (2011). All operators attended a calibration training exercise prior to the experiment to reduce between-operator variation in CS assessment. Conceptus-free ewe liveweight at day 90 and at lambing was calculated using Wheeler *et al.* 1971and used to calculate liveweight change between joining and day 90, and day 90 and lambing.

Lambing Management and Measurements

Across all sites, ewes were set-stocked within their paddocks/plot systems for the duration of lambing. At the Hamilton site, ewes were randomly allocated from within their replicates to the 4 plots (~1ha) within each paddock system, plus an additional 2 hedgerow plots (~0.25ha). The latter plots contained Tall Wheatgrass (*Thinopyrum ponticum* popd.) hedgerows at 10 m spacing (McCaskill *et al.* 2010) with between row area containing perennial ryegrass, subterranean clover and some broadleaf weeds, principally capeweed (*Arctotheca calendula* L.). Ewes and lambs within each replicate were aggregated after the last ewe gave birth and managed as either replicate cohorts or a single cohort to weaning. At the other two sites ewes and lambs were aggregated when more than 90% of ewes had lambed.

Measurements on ewes and lambs at lambing were based on the methods used in Brien *et al.* (2010). Lambing rounds were conducted daily with lambs individually tagged at birthand birth weight, lamb status (alive or dead), sex (male or female), type of birth (single, twin, triplet or higher order birth) and date of birth recorded. Lamb rectal temperature was also recorded at tagging at the Hamilton site. The gestation length was calculated for the Pigeon Ponds site using date of lamb birth and the date of artificial insemination for the ewes. Gestation lengths below 130 days or above 170 were removed from the analysis as they were not probable.

Necropsies were undertaken at the Hamilton site to determine cause of death for all dead lambs (Holst 2004). Any observed natural mismothering/adoption/stealing of lambs was not corrected. However, if ewes failed to return to the lamb during the conduct of measurement rounds, short term isolation (48 hours) of the ewe and lamb in a lambing ring to try to encourage ewe/lamb bonding was performed. These interventions were recorded as were all ewe deaths.

At the end of lambing, management groups of ewes and their lambs from each block were allowed *ad libitum* access to the volunteer FOO at all sites with the aim of maximising lamb growth rates from the end of lambing to weaning. The weight and CS of ewes and liveweight of lambs was measured at lamb marking and weaning.

Statistical Analysis

The experimental unit were the groups of ewes (and their scanned foetuses) assigned to each CS treatment during pregnancy to the end of lambing.

Within Site Analysis

All data was initially analysed separately for each site using plot level means and subjecting them to the ANOVA or unbalanced ANOVA procedure to test for the effect of CS treatment. Plot means for ewe liveweight and CS were calculated separately for all ewes, and those scanned as single or twin bearing ewes. Lamb data was examined by averaging data across all lambs born per plot. Lamb data was also analysed based on plot level means of single, twin and triplet birth type lambs for the Hamilton site or single and multiple birth type lambs for the Pigeon Ponds and Mount Barker sites.

For Hamilton, the blocking structure was block/plot within the ANOVA procedure, while an unbalanced ANOVA, adjusted for block was used for the Pigeon Ponds and Mount Barker sites. Treatment means were compared using a least significant difference (LSD, P=0.05) for sites with a balanced design or the maximum LSD (P=0.05) for sites with an unbalanced design.

Across Site Analysis

Restricted maximum likelihood (REML) was used to examine the effect of site and CS treatment and their interaction on lamb birth weight, survival to marking, marking weight and weaning weight. These analyses utilised plot mean data, as described above, from all experimental sites. Experimental site, CS treatment and an interaction thereof were fitted as a fixed effect. Block within site and plot within block were fitted as random effects. For comparisons of means the maximum LSD (P=0.05) has been presented.

Within site individual animal analysis

Individual analyses to evaluate progeny birth weight and weaning liveweight data was conducted by REML. These analyses were used to examine the effects of ewe liveweight, ewe liveweight change, sires/sire group, birth type, rear type, lamb sex and their interactions. All possible models were examined to define statistical significance of these effects and interactions accepted at $P < 0.05$.

For Hamilton, ewe liveweight at joining, ewe liveweight change at joining until Day 90 of pregnancy, ewe liveweight change from Day 90 of pregnancy until lambing, hedge lambing group, ewe age, birth type or rearing type and sex of progeny were included in the model as fixed effects while block, plot, hedge plot, lamb date of birth and sire were included as random effects. For the Pigeon Ponds site ewe liveweight at joining, ewe liveweight change at joining until Day 90 of pregnancy, ewe liveweight change from Day 90 of pregnancy until lambing, ewe age, birth type or rearing type, sex of progeny and sire were included as fixed effects while block, plot and lamb date of birth were included as random effects. For Mount Barker, ewe liveweight at joining, ewe liveweight change at joining until Day 90 of pregnancy, ewe liveweight change from Day 90 of pregnancy until lambing, birth type or rearing type, weaning group (for weaning weight only) and sex of progeny were fitted as fixed effects while block, plot and date of birth were fitted as random effects.

For each site, estimates of lamb survival were assessed by fitting General Linear Mixed Models (GLMM; Genstat Committee 2008). The approach used a logit transformation and binomial distribution. For Hamilton, using additive models, logits were predicted as a function of lamb birth weight (quadratic effect), ewe age, birth type and sex as fixed effects and block, plot and sire as random effects. For Pigeon Pond, using additive models, logits were predicted as a function of lamb birth weight (quadratic effect), ewe age, sire, birth type and sex as fixed effects and block and plot as random effects. For Mount Barker using additive models, logits were predicted as a function of lamb birth weight (quadratic effect), birth type and sex as fixed effects and block and plot as random effects. All possible models were examined to define statistical significance of effects and interactions accepted at $P < 0.05$.

Across site individual data modelling

Across site modelling of individual data was conducted using REML to provide a summary perspective of the effects of ewe liveweight, ewe liveweight change, birth type and lamb sex on lamb birthweight and weaning weight. The modelling was conducted across sites, fitting site and nesting within site the terms block, plot, sire, lamb date of birth and ewe age as random terms. All possible models were examined to define statistical significance of these effects and interactions accepted at $P < 0.05$. Estimates of lamb survival across sites for all individual data were also assessed by fitting General Linear Mixed Models (GLMM; Genstat Committee 2008). The approach used a logit transformation and binomial distribution. Using additive models, logits were predicted as a function of lamb birth weight (quadratic effect), birth type and sex as fixed effects with site and nesting within site the terms block, plot, and lamb date of birth, ewe age and sire fitted as random terms. All possible models were examined to define statistical significance of effects and interactions accepted at $P < 0.05$.

All statistical analyses were performed using GENSTAT 17th edition (VSN International Ltd, Hemel, Hempstead, UK).

Results

Feed on offer & Supplement

Average feed on offer for treatments from allocation post-pregnancy scanning to the end of lambing are shown for each experimental site in Figure 1. In general terms, greater FOO was available within the higher CS treatments and lower FOO in the low CS treatments across all sites. The levels of FOO required to the achieve weight and CS loss required to meet the CS 2.4 target was very low, even in late pregnancy (<600-800 kg DM/ha). All sites used supplementary feeding in the period between the allocation of ewes to treatments and lambing to assist with the manipulation of nutrition to meet the CS targets at lambing. At Hamilton the total amount of barley fed was 0.4, 1.9, 24.1 and 54.8 kg / head for the CS 2.4, 2.8, 3.2 and 3.6 treatments respectively. Hay was also fed at the Hamilton site to a total amount of 5.8, 0.6, 0 and 1.6kg / head for the CS 2.4, 2.8, 3.2 and 3.6 treatments respectively. At Pigeon Ponds, oats were fed totalling 4.8, 9.1, 21.6 and 39.5 kg / head and Mount Barker fed 3.2, 26.3, 28.7 and 46.9 kg / head of barley to the CS 2.4, 2.8, 3.2 and 3.6 treatments respectively.

For the Hamilton site, a portion of ewes from each replicate group had access to Tall wheatgrass hedgerows at lambing and these plots contained an average FOO of 1602 kg DM/ha (range 1248-2370 kg DM/ha). There was no significant difference in the FOO in plots provided at lambing to any of the treatment groups within the hedgerows. However, the FOO in the open plots at the start of lambing was lower than the hedgerows and ranged from 1066, 1141, 1223 and 1218kg DM/ha for the CS 2.4, 2.8, 3.2 and 3.6 treatments respectively ($P<0.05$, LSD=110).

Ewe condition score and liveweight

The profiles for the CS and liveweight of ewes from joining (~day 0) to weaning (~Day 240 to 260) achieved at the three research sites are presented in figure 2 and 3. Condition score and liveweight at joining and allocation to treatments following pregnancy scanning were not significantly different ($P>0.05$). The nutritional treatments were successfully imposed at all sites resulting in significant separation of CS ($P<0.05$) and liveweight ($P<0.01$) by lambing across all sites. At approximately day 90, the effect of nutritional treatment on CS was significant at Hamilton ($P<0.01$) and Mount Barker ($P<0.05$). By day 90, liveweight had been significantly affected at all sites ($P<0.05$).

The average CS and live weight of the ewes at mating varied across sites from CS 3.1 to 3.4 and 57.8 to 71.7 kg. All sites achieved a range in CS and ewe liveweight at lambing between extreme treatments of 1.1 to 1.5 (average 1.24) in CS and 13.7 to 19.1 kg (average 16.4 kg) in liveweight. The average range in ewe CS between the highest and lowest treatments at day 90 was 0.15 to 0.67 (average 0.44). Ewe liveweight at day 90 differed between the highest and lowest treatments by 4.2 to 8.1 kg (average 6.0 kg).

The degree of separation between treatments for average liveweight adjusted for conceptus reflected the range in raw liveweight measurements. At Hamilton the CS treatments significantly affected conceptus corrected liveweight at day 90 and day 140 with mean values of 57.2, 59.8, 62.8 and 65.1 kg ($P<0.05$, LSD=5.27) and 53.4, 58.1, 65.1 and 70.0kg ($P<0.001$, LSD=4.10) for the CS 2.4, 2.8, 3.2 and 3.6 treatments respectively. Likewise, at Pigeon Ponds conceptus corrected liveweight at day 90 and day 140 were 53.7, 54.3, 57.3 and 59.3kg ($P<0.05$, LSD=3.40) and 53.7, 55.2, 61.7 and 67.1 kg ($P<0.01$, LSD=4.3) for the CS 2.4, 2.8, 3.2 and 3.6 treatments respectively. The same effects were also produced at Mount Barker, where the mean conceptus corrected liveweight at day 90 and day 140 were 64.0, 65.4, 66.5 and 68.1 ($P<0.01$, LSD=0.96) and 63.1, 71.8, 76.4 and 81.9 kg ($P<0.05$, LSD=8.58) for the CS 2.4, 2.8, 3.2 and 3.6 treatments respectively. The conceptus adjusted data shows that the CS 2.4 treatment lost maternal liveweight (-3.9 to -8.8 kg) from day 0 to lambing. The average change was -7.1 kg across all sites. For the CS 2.8 treatment, the average change in maternal weight was -2.1 kg (0.1 kg to -4.1 kg), while the CS 3.2 treatment resulted in an average increase in maternal liveweight of 3.8 kg (2.9 kg to 4.7 kg). The highest CS treatment increased maternal liveweight by an average 8.9 kg (7.7 to 10.3 kg).

Following lambing, the CS 2.4 treatments increased liveweight and CS compared to their conceptus free liveweight and CS prior to lambing. In contrast, the high CS treatments generally lost both liveweight and CS from lambing to weaning (Figure 2 and 3). These changes resulted in a convergence of liveweight and CS between CS treatments by weaning even though there were still significant differences in both CS and liveweight between some of the treatments at weaning.

Across site analysis of birthweight, survival, marking and weaning weight

Condition score treatment had a significant effect on birth weight (P<0.001), lamb survival to marking (P=0.001), lamb weight at marking (P<0.001) and lamb weight at weaning (P<0.001) across all sites (Table 2). Birth weight significantly increased by 0.67 kg (0.64 kg singles and 0.71 kg multiples) when ewes were subjected to the highest CS treatment compared to the lowest CS treatment. This effect was also reflected in significant effects (P<0.001) on marking weight (2.3 kg all lambs, 2.5 kg singles, 2.6 kg multiples) and weaning weight (2.0 kg all lambs, 2.7 kg singles, 2.5 kg multiples).

Survival to marking for all lambs was improved with increasing CS treatment by 5.5% units from the CS 2.4 to CS 3.8 treatment (Table 2). However, this trend was largely a function of the survival of multiple born lambs which had an 11.1% unit improvement in survival. In contrast, single born lambs achieved similar survival when the CS target was 2.4, 2.8 and 3.2. Survival trended lower at the highest CS treatment (3.6) where there was 6.3% unit reduction in single lamb survival compared to the CS 3.2 treatment (P<0.1).

There was a significant effect of research site (P<0.001, data not shown) on each measured weight trait when the data was analysed across sites for single and multiple birth type lambs. There were significant interactions between the research site and the CS treatment for birthweight in multiples (P<0.05), marking weight for singles (P<0.05) and multiples (P<0.05) and weaning weight (P<0.01) in single born lambs, although, the interaction was not significant for birthweight in singles or weaning weight in multiples. There was no significant site by CS treatment interaction for survival to marking in singles and multiples. The interaction became significant where individual sites showed a larger effect due to CS on the measured trait. For example, the Hamilton site showed larger effects on marking weight and weaning weight in single born lambs. However, the level of significance of all the interaction terms was less than that of the main effects for CS treatment and site. In all instances, the mean values for individual sites also showed the same trend as the across site trend due to the CS treatment.

Individual Site Analysis

Lamb birth weight

Lambing at the Hamilton site occurred from 4 August to 1 September 2014 (excluding one premature birth detected on the 23 July 2014). At Pigeon Ponds lambing occurred from the 27 June to 8 July 2014, whilst lambing at Mount Barker was over the period 3 July 2014 to 4 August 2014.

Lamb birth weights across all lambs were significantly increased by CS treatment (Table 3). The effect of CS treatment on single born lambs was significant at Pigeon Ponds (<0.001) but not at Mount Barker (*P*>0.05) or Hamilton, although *P* was equal to 0.056 for the effect of CS treatment at the latter site. The reduction in birth weight at lower CS treatments was significant for multiple born lambs at all sites (*P*<0.05). This includes the effects of CS treatment on the birth weight for triplet born lambs at the Hamilton site (*P*<0.01). The average difference in birth weight between extreme CS treatments was 0.61 kg (range 0.5 kg to 0.7 kg) for single born lambs and 0.70 kg (range 0.44 kg to 0.85 kg) for multiple born lambs. On average, multiple/twin born lambs were 1.1 kg lighter than single born lambs (4.8 *vs*. 5.9 kg) although this difference varied between sites.

Gestation Length

The gestation length of ewes at the Pigeon Ponds site was significantly (*P*<0.05) affected by CS treatment with the mean length of all birth types being 148.4, 148.1, 147.6 and 147.0 days for the CS 2.4, 2.8, 3.2 and 3.6 treatments respectively (LSD=0.71). For ewes with single born lambs gestation length was around 1 day shorter for the CS 3.2 and CS 3.6 treatments compared to the CS 2.4 and 2.8 treatments (147.4 and 147.2 days *vs.* 148.5 and 148.4 days respectively, *P*<0.001, LSD=0.347). For ewes with multiple born lambs only the highest (146.8 days) and lowest (148.3 days) CS treatments were significantly different (*P*<0.05, LSD=1.066).

Lamb survival

There was a varied response of lamb survival to CS treatment across sites and birth types (Table 3). Only Hamilton showed significant increasing trend in lamb survival over all lambs born (*P*<0.001). This effect was largely driven by the survival of twins which was significantly reduced (22% units) by the lowest CS treatment compared to the highest treatment. Twin lamb survival increased linearly (*P*<0.01) with increasing ewe CS at lambing at Hamilton. In contrast, the effect on single born lambs was not significant at this site with single lamb survival greater than 90% for all treatments. The Mount Barker site also showed a trend for improved weaning survival of multiple born lambs (*P*=0.061). The data for multiple born lamb survival tended to be in the same direction for Pigeon Ponds but the effects at this site were not significant. The overall survival of multiple lambs was around 77% across all sites and there was an average 13% unit difference across the range of CS treatments. In contrast, single lamb survival was largely unaffected by the CS treatment with the overall survival of single born lambs averaging around 92%. However, single lambs did have lower survival (*P*=0.034) at the highest CS treatment at Mount Barker and this trend was also present at Pigeon Ponds although not significant (*P*>0.05).

Causes of lamb death and lamb rectal temperature

At Hamilton, the low CS treatments had a greater percentage of dystocia (c) or hypoxia related deaths than the higher CS treatments ($P<0.05$; Table 4). There was no effect of CS treatment on any other death category. The average rectal temperature of lambs born at Hamilton were lower ($P<0.05$, LSD=0.23) in the CS 2.4 and 2.8 treatments (38.7°C, 38.7°C) than those born in the CS 3.2 and 3.6 treatments (39.0°C and 38.9°C).

Lamb birth weight in relation to survival

Lamb birth weight was strongly related to lamb survival ($P<0.001$) at all sites with a quadratic relationship being the form of the relationship (Figure 4, Table 5). The shape of the relationship and coefficients for birth weight and birthweight^2 were similar across sites. Across all sites single and twin born lambs were equally likely to survive at the same birth weight. There was no effect of sex at two of the three sites with only Mount Barker showing a significant effect of sex, where males had lower survival than females at the same birth weight ($P<0.05$). At Hamilton and Pigeon Ponds, lamb survival of 90% or more was achieved when birth weight was greater than 4 kg (Figure 4). This threshold increased to approximately 5 kg for the Mount Barker.

Lamb growth during lactation

Across all lambs CS treatment had a significant effect on growth rate from birth to marking at the Hamilton ($P<0.001$) and Mount Barker sites ($P<0.01$) due to slower growth in the two lower CS treatments (Table 6). Despite a similar trend the effects were not significant at Pigeon Ponds site. The effect was in the order of 25 g/day to 55 g/day across all lambs and sites when comparing the highest and lowest CS treatments. Together with the starting differences in birth weight between treatments these differences in growth rate result in differences in the order of 2.3 kg (1.4 kg to 3.2 kg) at marking between CS treatment extremes for all lambs (Table 6). For single lambs the effect on marking weight was significant at Pigeon Ponds ($P<0.05$) and Hamilton ($P<0.01$) and close to significant at Mount Barker ($P=0.06$). For multiples the difference was significant at Mount Barker ($P<0.01$) and Hamilton ($P<0.05$).

The growth rate from marking to weaning was largely unaffected by CS treatment (Table 7) with only Hamilton showing a reduced growth rate for single and triplet born lambs in the low CS treatments ($P<0.01$). CS treatment had a significant effect on weaning weight at the Hamilton and Mount Barker sites ($P<0.05$) due to the lower weaning weights in the lower CS treatments.

Twin lambs were on average 3.6 kg lighter at marking and 5.9 kg lighter at weaning than single born lambs across all sites with some variation between sites.

Prediction of birth weight and weaning weight

Ewe joining weight, and ewe liveweight change in early pregnancy and late pregnancy all had a significant effect on birth weight (Table 8) when analysed at a site ($p<0.01$) or across sites ($P<0.001$). The coefficients for ewe joining weight effects on birth weight were similar across the Pigeon Ponds and Hamilton sites (0.031 and 0.036) but was smaller for joining weight at Mount Barker (0.013; Table 8). The coefficients for the effects of ewe liveweight change from joining to Day 90 on birth weight indicate that a 10 kg change in ewe liveweight would result in 0.25 to 0.43 kg difference in birth weight. The coefficients for liveweight change from day 90 to lambing were larger and a 10 kg change in ewe liveweight during this period would result in 0.32 to 0.58 kg difference in birth weight. There was a significant (P<0.001) effect of sex with males being heavier across all sites and birth type also reduced lamb birth weight (P<0.001). The effects of sex and birth type were similar in magnitude across sites. Ewe age also influenced the prediction of birth weight at the Hamilton (P<0.001) and Pigeon Ponds site (P<0.05), whilst sire had an interaction effect with birth type at the Pigeon Ponds site (P<0.01).

The effects of joining weight and ewe liveweight change on the prediction of weaning weight reflected the prediction of birth weight with all three factors significant (Table 9) in predictions at a site (P<0.05) and across sites (P<0.001). A 10 kg change in ewe liveweight from joining to Day 90 would result in 1.8 to 2.0 kg difference in weaning weight. In contrast, the effect of 10 kg change in late pregnancy from day 90 to lambing would result in a 0.7 kg to 1.8 kg change in weaning weight. Joining weight also had a significant influence on weaning weight with a 1.0 to 1.7 kg increase in weaning weight for a 10 kg increase in joining weight. Birth type and rear type effects on weaning weight were substantial (P<0.001) ranging from -4.7kg to -8.4 kg for twin born and twin reared lambs. Sex effects (P<0.001) also influenced weaning weight with males being of 1.0 to 2.1 kg heavier compared to female lambs. The age of the ewe was a significant factor at the Hamilton site (P<0.01). A sire and sire by birth type and rear type interaction was present at the Pigeon Ponds site (P<0.05).

Discussion

Changes in CS and maternal liveweight of composite ewes during pregnancy were associated with changes in birthweight, weaning weight and lamb survival. The birthweight and weaning weight responses for twin bearing ewes were linear, when examined across all sites. The CS treatments providing undernutrition resulted in lower birthweight and weaning weight when CS was below 3.0, and improved nutrition increased weight when CS at lambing was greater than 3.0. These results contrast the findings of the review by Rooke *et al.* (2015) that showed more variable responses from nutrition above maintenance requirements during pregnancy. Birthweight was also strongly related to survival at all sites. The consistency of the data and relationships observed across the three research sites conducted in multiple environments indicates that birthweight, survival and weaning weight responses to ewe liveweight change are predictable, supporting our first hypothesis.

The size of the coefficients to predict birthweight and weaning weight from ewe liveweight and liveweight change were similar to those predicted from previous experiments for Merinos (Oldham *et al.* 2011, Thompson *et al.* 2011) and BLM ewes (Paganoni *et al.* 2014, Hocking Edwards *et al.* 2018) and thus our second hypothesis that the coefficients for maternal composite ewes would be significantly different to those of Merino derived ewes was not supported. However, our coefficients for the prediction of weaning weight from liveweight at joining and in early pregnancy were smaller than those found in Paganoni *et al.* (2014). The reasons for these differences are not clear but could be due to the different experimental designs. In our experiments, we manipulated the nutrition of replicate flocks of ewes to generate different liveweight profiles to lambing, whereas the study by Paganoni *et al.* (2014)

utilised between animal variation from within single flocks at different research sites to provide a range in liveweight profiles. The latter study also examined breed and crossbred effects on weaning weight that were significant.

Birth weight

Across all sites a range in ewe live weight and CS at lambing of 13.7 to 19.1 kg (average 16.4 kg) and 1.1 to 1.5 of a CS (average 1.24) resulted in an increased birth weight of about 0.7 kg. The differences in birthweight between the lowest and highest CS treatments were smallest at the Pigeon Ponds site (~0.5 kg) compared to Hamilton (~0.7-0.8 kg) and Mount Barker (~0.6-0.8 kg). This is most likely in part due to a smaller range in ewe liveweight at lambing for Pigeon Ponds but may also be due to the low CS treatments having an increased gestation length. The use of artificial insemination at the Pigeon Ponds site enabled a shorter period of lambing in which lambs in the higher CS treatments would have been born earlier and the low CS treatments later in the period. This could reduce the difference in birthweight between high and low CS treatments, since gestation length is positively related birth weight (Holst and Allan 1992). In contrast, at sites where natural mating was practiced the conception and birth dates were more spread out and thus any effect of gestation length would be more distributed across the lambing period. Nevertheless, the coefficients predicting the impact of joining liveweight and liveweight change during pregnancy on birthweight were largely consistent, particularly for the Hamilton and Pigeon Ponds sites for which the ewes were of similar breeding history. The coefficients from an across site analysis of all the data in our experiments predicts changes of 0.247 kg, 0.327 kg and 0.429 kg for 10 kg difference in joining liveweight or liveweight change from day 0 to 90 or day 90 to lambing respectively. The results at Mount Barker were somewhat different with this site having a lower effect due to joining liveweight. The results and prediction coefficients indicate that the impact of maternal liveweight change on birthweight in maternal composite ewes is similar to that of Merinos (Oldham *et al.* 2011) and that manipulation of ewe nutrition can result in significant changes in lamb birth weight over the range of liveweight or CS change tested in our experiments.

Lamb Survival

The strong relationship between lamb birth weight and lamb survival was consistent across all sites and was in accord with previous experiments including those on the precursor breeds for the maternal composites and those on Merino ewes and BLM ewes (Dalton *et al.*1980, Knight *et al.* 1988, Oldham *et al.* 2011, Hinch and Brien 2014; Hocking Edwards *et al.* 2018). Lamb survival was significantly reduced at low birthweights but survival at the highest birthweights was not markedly reduced, although an increased risk of mortality is suggested by the lower confidence limits of the predictions at Hamilton and Pigeon Ponds and for the survival of males at Mount Barker. For Hamilton and Pigeon Ponds, there appeared to be a broad 4.4 kg to 7.5 kg range for lamb birthweight in which lamb survival was greater than 90%. At Mount Barker, the range was narrower from 6 to 7 kg for male lambs but 4.8 kg to 8 kg for female lambs.

Single lamb survival was not affected by the lower CS treatments at any of the research sites which is consistent with the high average birth weight of single lambs (5.4 kg to 6.3 kg) being in the optimum range for survival. In contrast, multiple birth type lambs had lower survival at Hamilton and Mount Barker sites for the lower CS treatments, while the survival at Pigeon

Ponds trended lower but was not significant. The average birth weight for twin and multiple born lambs subjected to the lowest CS treatment was 4.0 kg, 4.3 kg and 4.9 kg for the Hamilton, Pigeon Ponds and Mount Barker sites respectively. To achieve greater than 90% survival in both single and twin lambs the critical birth weight ranged from around 4.4 kg to 5 kg across the sites. Comparing the site treatment means with these thresholds a significant population of lambs from the lowest CS treatments would be below the critical weights to optimise survival.

In contrast to the findings in Merinos (Oldham *et al.* 2011) and crossbred ewes (Hocking Edwards *et al*. 2018), the effect of birth type, single or twin, was not significant across all sites meaning that the relationship between birth weight and survival and the risk of mortality was not necessarily modified by being born a single or twin from maternal composite ewes. This response is also consistent with the finding of Dalton *et al.* (1980) that birth rank effects were explained by birth weight. These results imply a possible genotype based advantage for maternal ewes when rearing multiple lambs which could be due to improved ewe behaviour and increased lamb vigour given the increased selection these ewes have had for reproductive success and maternal behaviour. The practical implication of this result is that for twin bearing maternal composite ewes achieving critical birth weight for their lambs should alleviate many of the losses associated with twin lambs. In our experiments the near maximum lamb survival was achieved for twin bearing ewes when their CS at lambing was 3.2 or greater at which point lamb survival was similar to single born lambs.

Anecdotally, feedback from the Lifetime Ewe Management course participants has indicated that high CS in maternal composite ewes can lead to higher rates of mortality of single-bearing ewes due to increased birth weight and birthing difficulty. The Mount Barker site showed such an effect for their highest CS treatment (achieving an average CS 4.0 at lambing) where birth weight averaged 6.3 kg and lamb survival was consequently reduced to 83% compared to 89% to 94% in the lower CS treatments. For Mount Barker, the risk of lower survival at high birthweights was particularly evident for male lambs. The risk of high birthweight arising from high CS and subsequently lower lamb survival was also partially supported by the across site analysis and the modelled relationships between birthweight and survival at other sites. This suggest an upper limit for CS at lambing and ewe liveweight gain in single bearing ewes. Across sites the highest CS treatment averaged CS 3.6 to 4.0 at lambing. However, there were insufficient ewe deaths in our experiments to confirm a relationship between CS and ewe mortality and therefore the CS levels that increase risk for ewes at lambing require further definition.

Causes of lamb death

Lamb necropsies were only performed at the Hamilton site, where the low CS treatments increased the proportion of lamb deaths categorised as dystocia causing hypoxia. In many studies the most common form of lamb mortality in Australian flocks is due to starvation/mismothering but many of these studies have not examined lambs for evidence of hypoxia and dystocia that does not necessarily result in the more classical expression of significant oedema and birth trauma (Hinch and Brien, 2014). The Hamilton site clearly shows that low nutrition results in higher risk of more difficult birthing for lambs even when they are small and have a lower birthweight indicating that the effect may be mostly via the ewe through reduced energy supply and reserves for the lambing process. Changes in ewe-lamb bonding behaviour due to under nutrition will also affect the rearing success for these lambs

(Dwyer *et al.* 2003) and the higher number of lambs categorised into the starvation/mismothering category for the lowest CS treatment supports the classical susceptibility of low birthweight lambs to this cause of death (Hinch and Brien, 2014). The lambs born from the lowest CS treatments also had a lower rectal temperature by 0.3°C which is most likely linked to birthweight, reserves of brown adipose tissue, hypoxia and changes in lamb and ewe behaviour and lamb viability (Dwyer *et al*. 2003, Dwyer and Morgan, 2006, Dutra and Banchero 2011, Dwyer *et al.* 2016). The gestation length of ewes in the low CS treatment was also longer at the Pigeon Ponds site. This result which is similar to that reported by Holst *et al.* (1986) suggests that in utero maturation of lambs in nutritionally restricted ewes takes longer. Collectively, the results suggest that improvements in the nutritional status of the ewe acts to improve lamb survival by increasing birthweight, reducing dystocia causing hypoxia, reducing gestation length and reducing the risk of starvation and mismothering in the days post-lambing. The mechanisms are multi-factorial (Dwyer et al. 2016) but attaining a target CS of 3.2 or greater appears to substantially reduce lamb losses due to these issues in multiple bearing maternal composite ewes.

Marking and weaning weight

Marking and weaning weight were significantly affected for one out of three sites for single lambs and two out of three sites for twin/multiple born lambs, however, trends in the mean values at the Pigeon Ponds site were also present and the lack of significant difference may reflect a lack of statistical power at this site to discern effects rather than the absence of an impact. For example, the Pigeon Ponds site showed a 1.9 kg range in average weaning weight for twins and 1.7 kg range for singles. In addition, when marking weight and weaning weight were analysed across all sites the effects of CS treatment were highly significant. Restricted nutrition during mid to late pregnancy significantly depressed weaning weight for singles and twins in our experiments and the coefficients for liveweight at joining, joining to Day 90 and Day 90 to lambing were all significant. As weaning weight is a pre-cursor and strongly related to slaughter weight these impacts are important as they signify a potential economic impact on the prime lamb producer, if birth weight is reduced at lambing. A key feature of these results is that the impacts were largely present by lamb marking with the differences in growth rate between marking and weaning contributing little to the impacts on weaning weight. This suggests that the differences in marking and weaning weight appear to be largely a function of birth weight but because all sites maintained nutritional treatments to the end of lambing which was 1-2 weeks prior to marking it is also possible that late pregnancy and early lactation nutrition affected milk production and growth to marking and weaning (Treacher 1970 and Thompson *et al.* 2011). However, some experiments have shown no effect of late pregnancy nutrition on milk yield and lamb growth rate (Gibb and Treacher 1982, Geenty and Sykes 1986), particularly when herbage allowances during lactation were adequate. It is therefore not clear if high levels of FOO during lambing and early lactation could mitigate effects on birth weight and these liveweight effects at marking and weaning.

The regression coefficients relating ewe liveweight profile to lamb weights at birth, marking and weaning suggest that late pregnancy liveweight gain can be used to offset early pregnancy reductions in foetus weight. However, as most maternal prime lamb systems operate on a lambing time when feed is restricted, achieving high CS at joining and allowing a moderate reduction and then maintenance of ewe CS to lambing is likely to optimise use of feed resources, optimise birth weight and increase survival. It is likely that twin bearing ewes will need to reach higher CS or liveweight targets to optimise survival through birth weight increases, whilst singles may be allowed to lose weight provided weaning weight is not reduced to a large degree.

Limitations of the current experiments

These experiments were limited to the profiles of ewe liveweight managed and the lambing conditions experienced at the time which were generally mild for the year at Pigeon Ponds and Mount Barker. The Hamilton site had higher chill conditions earlier in the lambing period but was also milder than normal weather in the later part of the lambing period. Some caution should therefore be observed in translating the high level of survival achieved in these experiments to commercial farming sites under more challenging environmental conditions, such as those experienced in other experiments (e.g. Hocking Edwards *et al.* 2018).

Additionally, ewes were restricted in nutrition until the end of lambing potentially conserving the size of the effects due to birth weight, although results from our second series of experiments (Thompson *et al.* 2018) indicate limited potential to mitigate gestational birth weight effects through higher FOO post-lambing. Nevertheless, due to the seasonal conditions, FOO levels at lambing for some sites were below those that would normally be recommended (e.g. 600-800kg DM/ha vs. 1200-1800kg DM/ha) and this may have influenced survival particularly in low CS treatments as low FOO has been associated with reduced survival in other experiments (Oldham *et al.* 2011).

The experiment also used supplementation of cereal grains (oats, barley) and hay to achieve CS and liveweight change during the experiment. Feeding of barley immediately prior to lambing has been shown to have beneficial effects on the yield and quality of colostrum and can increase lamb survival (Banchero *et al.* 2007, Hawken *et al.* 2012). It may be that some of the effect on lamb survival seen in higher CS treatments was due to the effects of feeding barley or oats rather than liveweight change or CS change per se. In most experiments where barley feeding has been effective in improving colostrum and lamb survival, the feeding has been conducted in the last two weeks prior to a synchronised lambing. The latter practice is different to the natural mating used at the Hamilton and Mount Barker sites that resulted in a greater spread of lambing dates. Feeding barley in late pregnancy and early lactation did not improve survival in the study of Kopp *et al.* (2018) where twin bearing ewes were in good condition and grazing high FOO. In addition, the effect of concentrate feeding in late pregnancy on both lamb performance and indirect indicators of lamb colostrum intake has not been consistent in other experiments (Kerslake *et al.* 2008). It is worth noting that poor ewe nutrition prior to lambing can reduce colostrum and milk production (see review by Banchero *et al.* 2015) and thus effects on colostrum and milk production will be difficult to disassociate from effects of ewe liveweight change as they are biologically intertwined. So, while the mechanisms by which ewe liveweight change effects birth weight and survival in this experiment cannot necessarily be fully attributed to birth weight alone the consistent effect of undernutrition during mid to late pregnancy are in alignment with previous reviews by Kenyon and Blair (2014) and Rooke *et al.* (2015). In contrast, the improvements for multiple lambs in birth weight, weaning weight and lamb survival from improved CS greater than 3.0 and increased ewe liveweight would appear a more consistent finding in our experiments.

Conclusion

Manipulating the nutrition of the maternal composite ewes during mid to late pregnancy resulted in predictable impacts on the birth weight of single and multiple lambs. There was little effect of low CS at lambing (2.5 to 2.6) on the survival of single born lambs, but possible negative effects of a CS greater than 3.5, where ewe liveweight was markedly increased during pregnancy. However, effects of CS management on weaning weight of single lambs should also be considered when formulating optimum guidelines for single bearing ewes as weaning weight was improved by the higher CS treatments. Improving CS at lambing increased survival of multiples at 2 of the 3 sites and the effect was significant when analysed across all sites. The effect was 'near-maximum' with the implementation of the CS 3.2 treatment (CS 3.2 to 3.5 at lambing). Improved ewe CS at lambing also had positive effects on the weaning weight of multiple born lambs. The coefficients for the effects of joining weight, ewe liveweight change from joining to Day 90 and ewe liveweight change from Day 90 to lambing on birth weight and weaning weight were similar across the research sites and to those found in previous experiments in Merino and BLM ewes. The prediction equations from these experiments can now be used to model the optimum ewe CS or liveweight profile to optimise production and survival in maternal composite prime lamb production systems.

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Conflict of interest

The authors declare no conflicts of interest.

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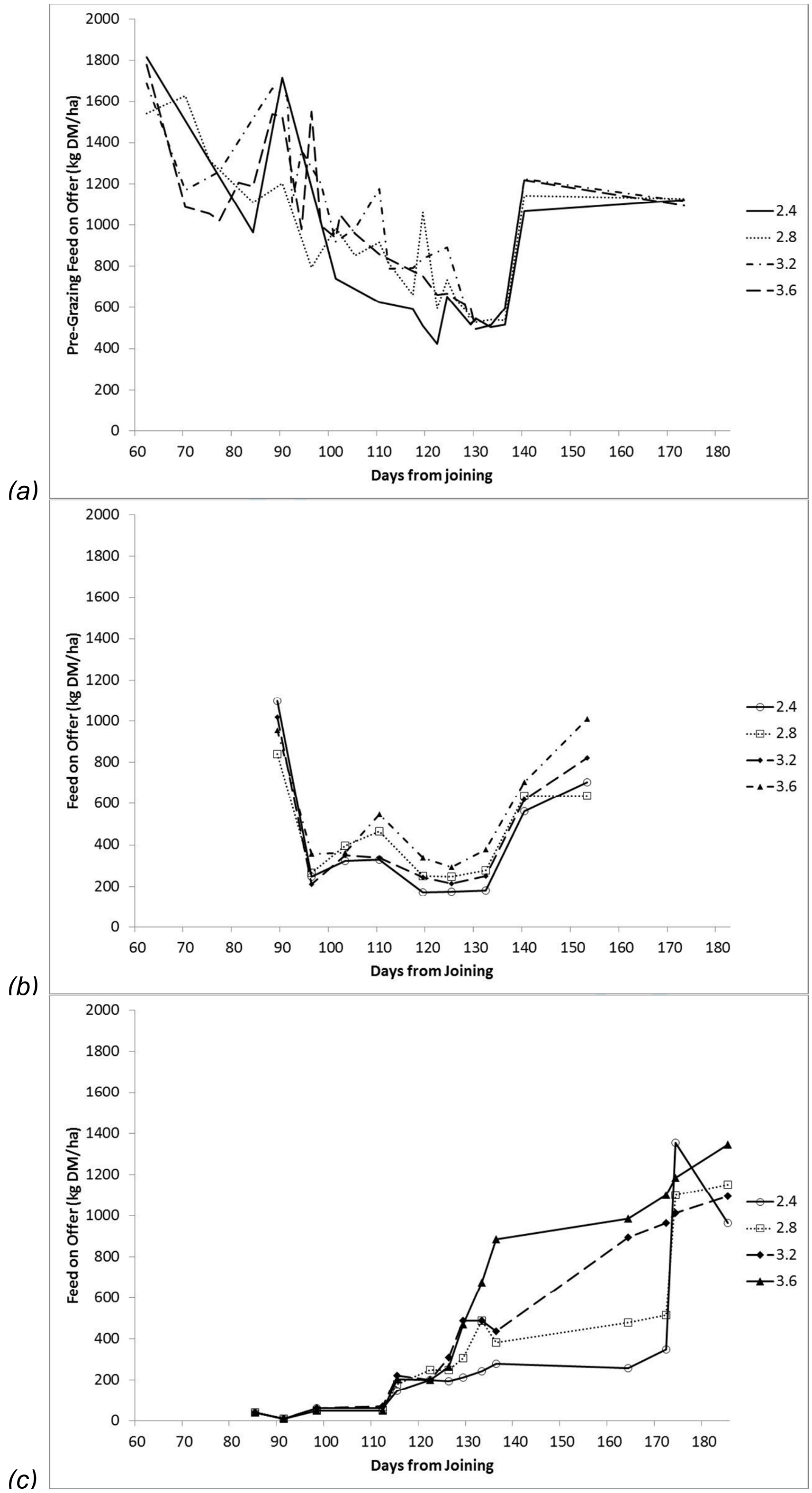


Figure 1. Mean feed on offer (FOO, kg DM/ha) for the targeted condition score treatments (CS 2.4 ○, 2.8 □, 3.2 ♦ and 3.6 ▲) from the allocation of ewes to plots to the end of lambing at the Hamilton (a), Pigeon Ponds (b) and Mount Barker (c) research sites.

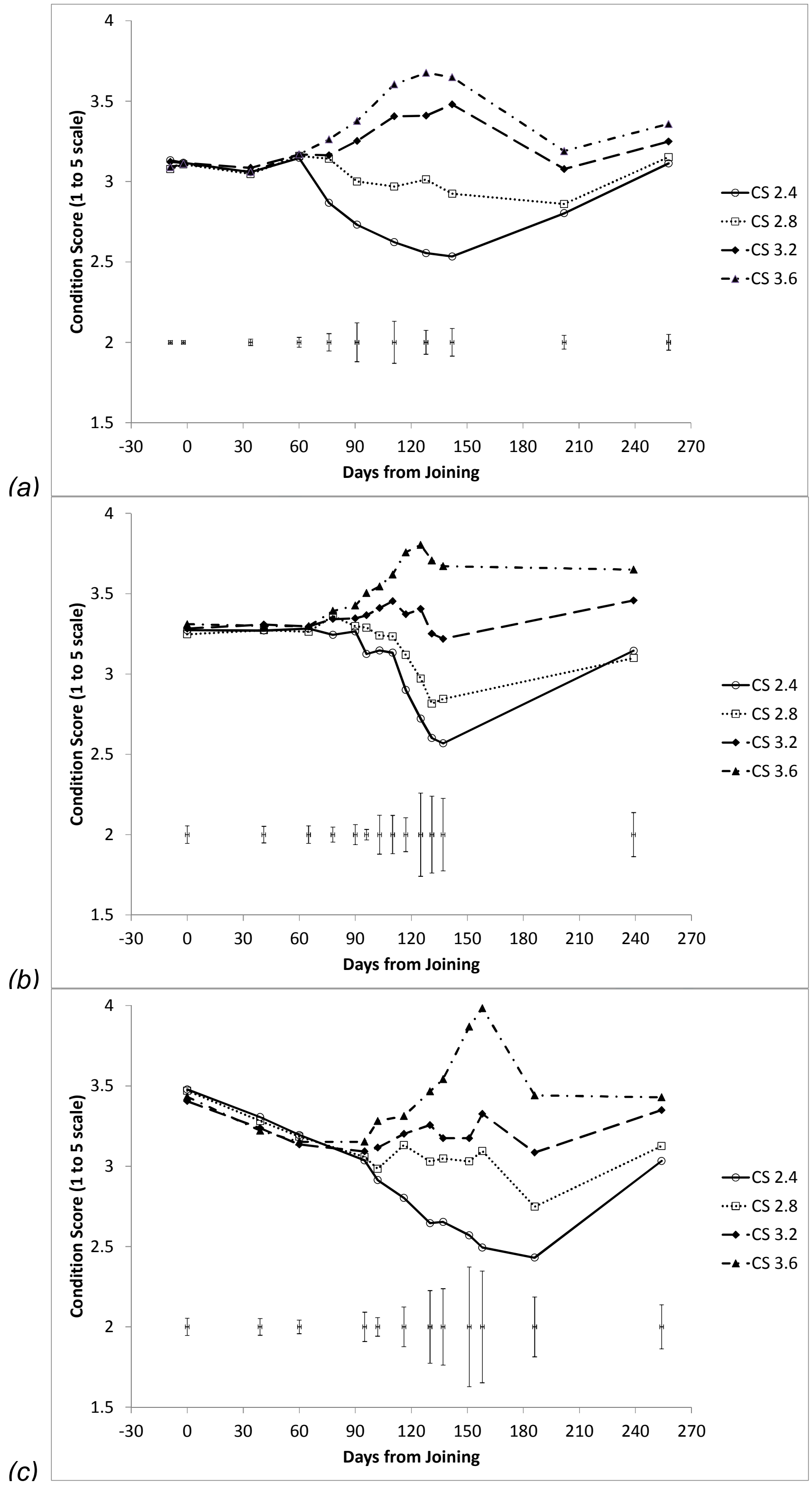
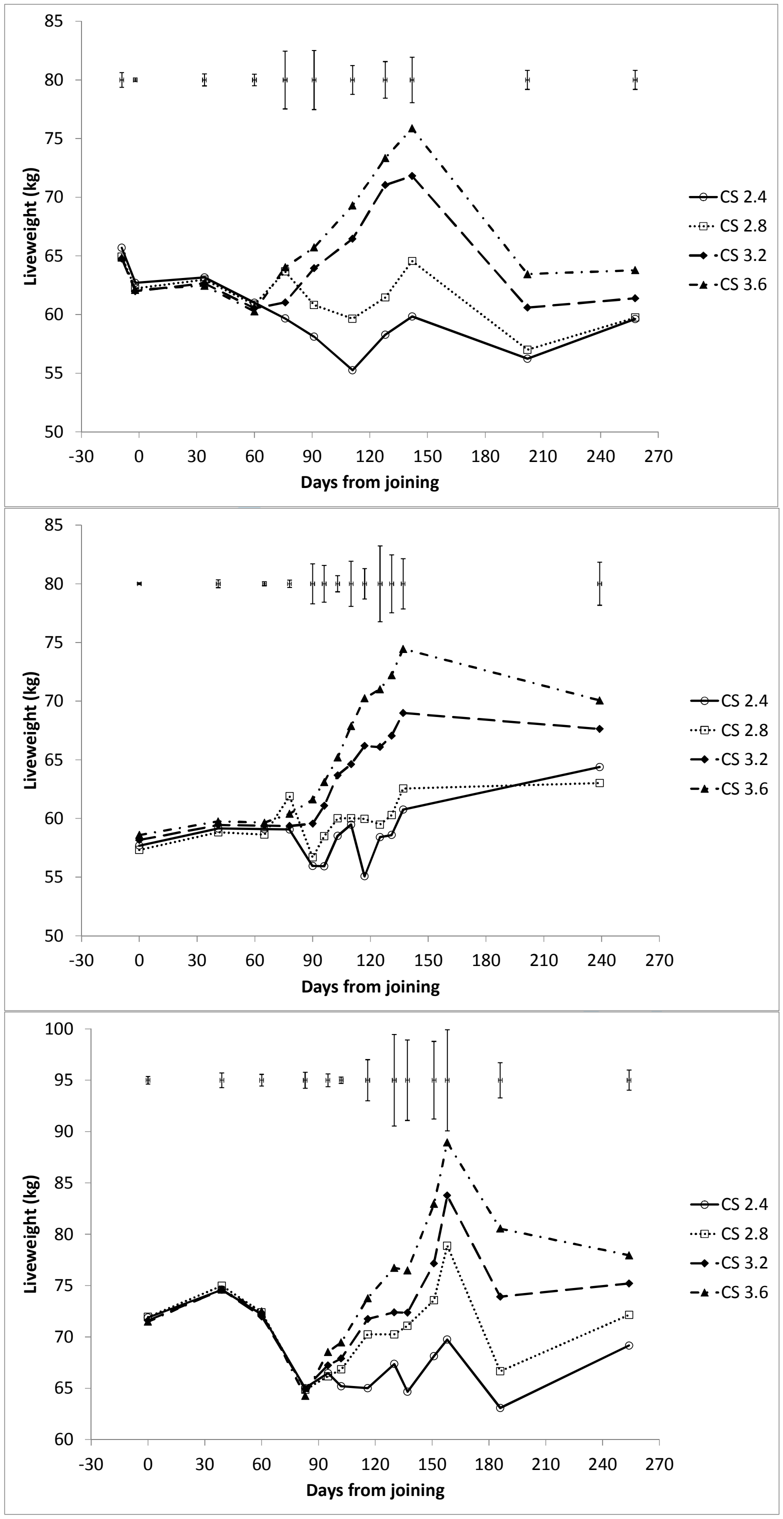


Figure 2. Mean condition score (CS) of ewes for the targeted CS treatments (CS 2.4 ○, 2.8 □, 3.2 ♦ and 3.6 ▲) from the start of mating (Day 0) to weaning at the Hamilton (a), Pigeon Ponds (b) and Mount Barker (c) research sites. Error bars indicate the least significant difference (*P*=0.05) for the day of CS measurement. Data represents average of single and multiple bearing ewes.



(a) (b) (c)

Figure 3. Mean liveweight of ewes in targeted condition score treatments (CS 2.4 ○, 2.8 □, 3.2 ♦ and 3.6 ▲) from the start of mating (Day 0) to weaning at the Hamilton (a), Pigeon Ponds (b) and Mount Barker (c) research sites. Error bars indicate the least significant difference (*P*=0.05) for the day of weighing.

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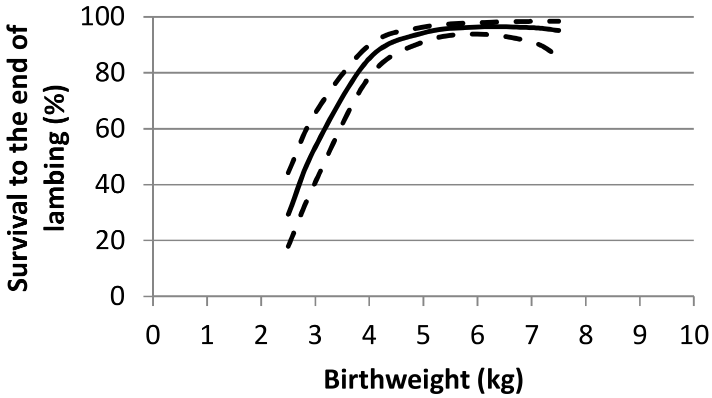
(a)



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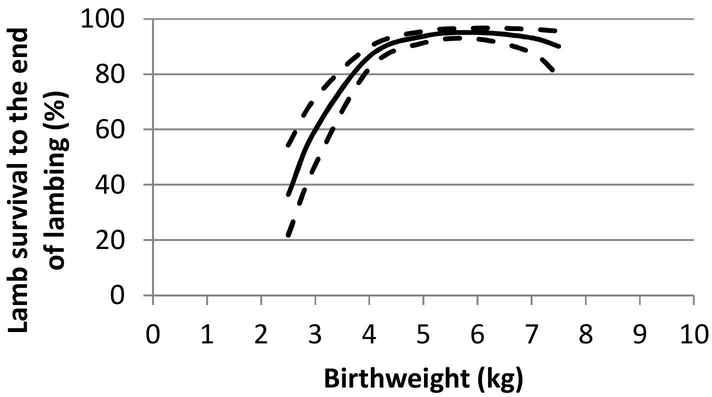

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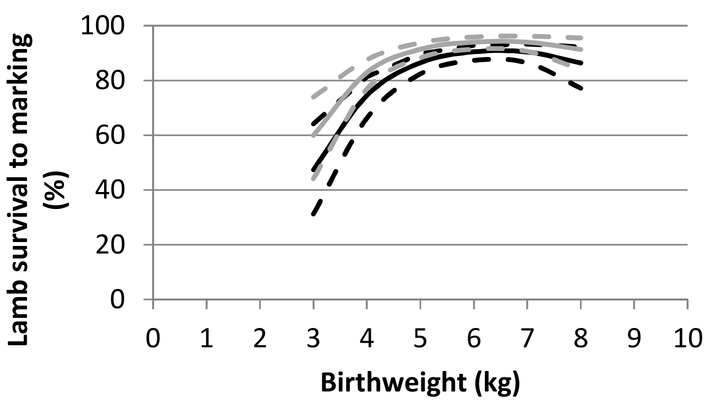

Figure 4. Effect of lamb birth weight on lamb survival to the end of lambing or marking from ewes at the Hamilton (a), Pigeon Ponds (b), and Mount Barker (c) sites. The data is combined across birth types for all sites. The effect of sex at the Mount Barker site is indicated by the grey line for females and black line for males. The dashed lines represent upper and lower 95% confidence limits.

Table 1. Target condition score of ewes at lambing, total number of paddock/plot systems used in each experiment and total numbers of ewes and their foetuses for three research sites. The number of replicates of each treatment is shown in brackets.

Target CS at lambing	Hamilton	Pigeon Ponds	Mount Barker
Treatment targets (and replication)			
Lowest	2.5 (3)	2.4 (3)	2.4 (3)
Med/low	3.0 (3)	2.8 (2)	2.8 (2)
Med/high	3.4 (3)	3.2 (3)	3.2 (3)
Highest	3.8 (3)	3.6 (2)	3.6 (2)
Number of plots and animals			
Total number of paddock/plot systems	12	10	10
Number of ewes allocated per replicate	66	77	75
Total number of ewes	792	770	750
Total number of foetuses scanned allocated	1348	1148	960
Mean potential reproductive rate of ewes (foetuses scanned per ewe pregnant)	1.70	1.49	1.28

Table 2. Mean lamb birth weight, survival to marking, marking weight and weaning weight of lambs from ewes in four condition score (CS) treatment groups analysed across sites (LSD=least significant difference at *P*=0.05).

Birth Type	CS2.4	CS2.8	CS3.2	CS3.6	LSD	*P* value
Birth weight (kg)						
All lambs	4.71	4.93	5.19	5.38	0.156	<0.001
Singles	5.51	5.85	6.08	6.15	0.326	0.001
Multiples	4.37	4.53	4.89	5.08	0.108	<0.001
Survival to marking (%)						
All lambs	82.8	83.4	89.1	88.3	4.06	0.001
Singles	94.8	92.4	93.3	87.0	5.63	0.069
Multiples	78.1	80.0	87.8	89.2	5.53	<0.001
Marking weight (kg)						
All lambs	11.5	12.0	13.3	13.8	0.54	<0.001
Singles	13.8	14.5	16.4	16.3	0.79	<0.001
Multiples	10.3	10.9	12.3	12.9	0.60	<0.001
Weaning weight (kg)						
All lambs	28.8	29.3	30.7	30.8	0.76	<0.001
Singles	32.6	33.0	35.7	35.3	0.98	<0.001
Multiples	26.7	27.4	28.8	29.2	0.75	<0.001

Table 3. Mean lamb birth weight (kg) and lamb survival to weaning (lambs alive per lamb born) of maternal composite lambs for each of four condition score (CS) treatment groups (LSD=least significant difference at *P*=0.05).

		Lamb birth weight (kg)						Lamb Survival to weaning (lambs alive per lamb born)					
Site	Birth type	CS2.4	CS2.8	CS3.2	CS3.6	LSD	*P* value	CS2.4	CS2.8	CS3.2	CS3.6	LSD	*P* value
Hamilton	All lambs	4.24	4.49	4.89	5.02	0.326	0.004	0.72	0.79	0.89	0.90	0.060	<0.001
	Single	5.38	5.43	6.13	6.04	0.645	0.056	0.91	0.94	0.95	0.94	0.112	0.838
	Twin	4.02	4.29	4.67	4.87	0.285	0.001	0.69	0.76	0.89	0.91	0.110	0.008
	Triplet	2.83	3.67	4.08	4.41	0.609	0.005	0.41	0.55	0.71	0.80	0.447	0.229
Pigeon Ponds	All lambs	4.76	4.80	5.10	5.21	0.124	<0.001	0.82	0.81	0.85	0.83	0.156	0.835
	Single	5.47	5.69	5.90	6.00	0.274	0.013	0.92	0.93	0.87	0.80	0.222	0.436
	Multiple	4.31	4.24	4.71	4.75	0.131	<0.001	0.76	0.74	0.85	0.84	0.213	0.403
Mount Barker	All lambs	5.18	5.49	5.63	5.98	0.351	0.015	0.86	0.85	0.89	0.89	0.533	0.218
	Single	5.68	6.20	6.26	6.32	0.793	0.190	0.94	0.89	0.93	0.83	0.062	0.034
	Multiple	4.93	5.14	5.40	5.75	0.231	0.002	0.83	0.82	0.87	0.91	0.070	0.061

Table 4. The number of lambs assessed in each death category as a percentage of all lambs born for each of the four condition score (CS) treatment groups at the Hamilton research site (LSD=least significant difference at *P*=0.05).

Death Category	CS 2.4	CS 2.8	CS 3.2	CS 3.6	LSD	*P*-value
Dystocia (a)	3.2% (1.021)	1.6% (0.733)	0.9% (0.537)	1.9% (0.785)	(0.5585)	0.303
Dystocia (b)	0.95% (0.56)	1.2% (0.63)	0.4% (0.36)	0.6% (0.43)	(0.849)	0.860
Dystocia (c)	6.2% (1.425)	5.8% (1.383)	0.7% (0.489)	0.7% (0.481)	(0.6265)	0.014
Infection	0.1% (0.186)	0.0% (0.000)	0.4% (0.359)	0.0% (0.000)	(0.5154)	0.348
Premature or dead in utero	0.6% (0.447)	1.4% (0.684)	0.00% (0.000)	0.6% (0.435)	(0.6354)	0.165
Primary Predation	0.4% (0.375)	0.1% (0.187)	0.2% (0.254)	0.4% (0.359)	(0.5246)	0.795
Starvation/Mismothering	9.1% (1.727)	4.1% (1.154)	4.1% (1.155)	2.8% (0.964)	(0.6189)	0.094
Undiagnosed	0.4% (0.375)	0.4% (0.369)	0.2% (0.253)	0.0% (0.000)	(0.4858)	0.294

*Percentages are back-transformed means for all lambs (singles and multiples). All LSD comparisons are made on the angular transformed data presented in brackets.

Table 5. Coefficients (±s.e.) of a generalized linear mixed model that predicts lamb survival to end of lambing or marking in terms of lamb birth weight (kg) and sex as fixed effects after adjustment for blocking effects (random). (* *P*<0.05, * *P*<0.001).**

	Hamilton	Pigeon Ponds	Mount Barker	Across Sites[B]
Constant	-8.04 ± 1.237	-7.57 ± 1.390	-5.99 ± 1.353[A]	-6.84 ± 0.73[C]
Birthweight (kg)	3.57 ± 0.545 ***	3.56 ± 0.569 ***	2.55 ± 0.478 ***	3.18 ± 0.288 ***
Birthweight Squared (kg^2)	-0.28 ± 0.059 ***	-0.30 ± 0.057 ***	-0.20 ± 0.042 ***	-0.249 ± 0.028 ***
Sex			0.51 ± 0.209[A] *	-0.347 ± 0.120[C] **

[A] The survival constant is for male progeny and the coefficient is for a male lamb at the Mount Barker site.

[B]Model incorporates all sites; fitting site and nesting within site the terms block, plot, sire, lamb date of birth and ewe age as random terms.

[C]The constant for lamb survival is for a female lamb and the coefficient is for male lamb

Table 6. Mean growth rate (g/day) from birth to marking and marking weight (kg) of maternal composite lambs for each of four condition score (CS) treatment groups. (LSD=least significant difference at *P*=0.05).

		Lamb growth rate from birth to marking (g/day)						Lamb marking weight (kg)					
Site	Birth Type	CS2.4	CS2.8	CS3.2	CS3.6	LSD	*P* value	CS2.4	CS2.8	CS3.2	CS3.6	LSD	*P* value
Hamilton	All lambs	207	218	254	259	12.5	<0.001	13.9	14.7	17.0	17.2	0.73	<0.001
	Single	264	288	331	337	21.2	<0.001	17.6	18.4	21.9	21.4	1.59	0.001
	Twin	187	199	239	243	16.8	<0.001	12.6	13.7	16.1	16.4	0.77	<.001
	Triplet	160	119	216	216	66.5	0.035	11.5	9.7	13.9	14.6	3.37	0.044
Pigeon Ponds	All lambs	281	273	314	306	94.8	0.557	9.9	10.0	11.1	11.3	1.91	0.190
	Singles	358	346	388	367	56.8	0.276	11.9	12.0	13.4	13.1	0.85	0.011
	Multiples	227	223	274	269	109.4	0.417	8.5	8.6	9.9	10.1	2.22	0.178
Mount Barker	All lambs	344	350	383	399	27.7	0.009	10.6	11.3	12.0	13.0	0.87	0.005
	Single	389	404	437	441	71.9	0.196	12.1	13.1	14.0	14.5	1.86	0.060
	Multiple	316	322	362	384	48.7	0.033	9.8	10.3	11.3	12.4	1.01	0.005

Table 7. The mean growth rate (g/day) from marking to weaning and weaning weight (kg) of maternal composite lambs for each of four condition score (CS) treatment groups (LSD=least significant difference at *P*=0.05).

		Lamb growth rate marking to weaning (g/day)						Lamb weaning weight (kg)					
Site	Birth Type	CS2.4	CS2.8	CS3.2	CS3.6	LSD	*P* value	CS2.4	CS2.8	CS3.2	CS3.6	LSD	*P* value
Hamilton	All lambs	165	164	167	168	10.5	0.835	23.2	24.1	26.4	26.5	0.36	<.001
	Single	180	186	203	207	11.8	0.003	27.7	28.8	33.3	33.0	1.43	<.001
	Twin	159	159	158	160	11.1	0.969	21.6	22.7	24.9	25.3	0.69	<.001
	Triplet	124	122	165	145	20.0	0.008	18.9	16.2	23.6	22.7	4.31	0.021
Pigeon Ponds	All lambs	297	300	299	300	18.6	0.965	31.5	32.0	32.6	32.9	2.96	0.580
	Singles	327	329	335	334	17.9	0.505	35.6	35.9	37.5	37.3	2.14	0.097
	Multiples	276	279	281	281	16.7	0.788	28.5	28.9	30.1	30.4	3.13	0.296
Mount Barker	All lambs	327	311	328	312	20.4	0.297	31.4	31.4	32.7	32.6	1.04	0.025
	Single	294	288	295	282	10.7	0.381	34.5	34.2	36.3	35.6	2.67	0.223
	Multiple	305	296	304	290	7.9	0.067	29.7	30.0	31.4	31.5	0.56	<0.001

Table 8. Regression coefficients (± s.e.) that predict the response in lamb birth weight (kg) to ewe joining weight and liveweight change during pregnancy (* *P*<0.05, ** *P*<0.01, * *P*<0.001). Effects are also presented for sex, ewe age, birth type, sire and any interactions where present.**

Model Factor		Hamilton	Pigeon Ponds	Mt Barker	Across Sites[D]
Constant		3.71 ± 0.194[A]	3.53 ± 0.230[B]	4.89 ± 0.302[C]	4.01 ± 0.158[C]
Ewe liveweight at joining (day 0, kg)		0.031 ± 0.0031 ***	0.036 ± 0.0038 ***	0.013 ± 0.0044 **	0.025 ± 0.0021 ***
Ewe liveweight change day 0 to day 90 (kg)		0.031 ± 0.0061 ***	0.043 ± 0.0077 ***	0.025 ± 0.0077 **	0.033 ± 0.0040 ***
Ewe liveweight change day 90 to lambing (kg)		0.046 ± 0.0059 ***	0.058 ± 0.0063 ***	0.032 ± 0.0055 ***	0.043 ± 0.0034 ***
Sex	Male	0.288 ± 0.0385 ***	0.303 ± 0.0430 ***	0.403 ± 0.0601 ***	0.326 ± 0.0268 ***
Ewe Age (Years)	3	0.010 ± 0.0632 ***			
	4	0.291 ± 0.0635	-0.041 ± 0.0550 *		
	5	0.058 ± 0.0820	0.127 ± 0.0570		
Birth type	2	-1.41 ± 0.051 ***	-1.34 ± 0.066	-0.76 ± 0.066 ***	-1.10 ± 0.031 ***
	3	-2.64 ± 0.097		-1.13 ± 0.182	-2.07 ± 0.073
Sire			-0.34 ± 0.071		
Birth class Twin.Sire 120480			0.28 ± 0.090 **		

[A]The birth weight constant is for birth type single, female progeny, ewe aged 2 years.

[B]The birth weight constant is for birth type single, female progeny, ewe aged 3 years and sire 110449.

[C]The birth weight constant is for birth type single and female progeny.

[D] Model incorporates all sites; fitting site and nesting within site the terms block, plot, sire, lamb date of birth and ewe age as random terms.

Table 9. Regression coefficients (± s.e.) that predict the response in lamb weaning weight (kg) to ewe joining weight and liveweight change during pregnancy (* *P*<0.05, ** *P*<0.01, * *P*<0.001). Effects are also presented for sex, ewe age, birthtype, reartype, sire and any interactions when present.**

		Hamilton	Pigeon Ponds	Mount Barker	Across Sites[D]
Constant		20.6 ± 1.09[A]	26.7 ± 1.26[B]	28.1 ± 1.77[C]	25.98 ± 2.200[B]
Ewe liveweight at joining (day 0, kg)		0.154 ± 0.0167 ***	0.168 ± 0.0204 ***	0.100 ± 0.0214 ***	0.123 ± 0.0112 ***
Ewe liveweight change day 0 to day 90 (kg)		0.180 ± 0.0339 ***	0.150 ± 0.0429 ***	0.195 ± 0.0373 ***	0.157 ± 0.0220 ***
Ewe liveweight change day 90 to lambing (kg)		0.075 ± 0.0325 *	0.180 ± 0.0344 ***	0.069 ± 0.0216 **	0.091 ± 0.0203 ***
Sex	Male	1.04 ± 0.201 ***	1.11 ± 0.241 ***	2.12 ± 0.297 ***	1.387 ± 0.1498 ***
Ewe Age (Years)	3	0.591 ± 0.3356 **			
	4	0.801 ± 0.3403			
	5	-0.304 ± 0.4469			
Birthtype.reartype	21	-3.5 ± 0.38 ***	-4.5 ± 0.59	-2.8 ± 0.58 ***	
	22	-8.5 ± 0.26	-8.4 ± 0.38	-4.7 ± 0.33	-6.415 ± 0.172[E] ***
	31	-8.3 ± 1.95			
	32	-11.5 ±0.66			
	33	-14.4 ± 0.99		-5.4 ± 0.93	-9.261 ± 0.451[E]
Sire	120480		-1.18 ± 0.391		
Sire.birthtype.reartype	120480.21		-0.04 ± 0.889 *		
	120480.22		1.25 ± 0.516		

[A]The weaning weight constant is for single birth type and rear type (1,1), female progeny and ewe aged 2 years.
[B]The weaning weight constant is for single birth type and rear type (1,1), female progeny and sire 110449.
[C]The weaning weight constant is for single birth type and rear type (1,1) and female progeny.

[D]Model incorporates all sites; fitting site and nesting within site the terms block, plot, sire, lamb date of birth and ewe age as random terms.

[E]The coefficients are for the effect of birth type only.