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Growth pattern to the end of the mating period influences the reproductive performance of Merino ewe lambs mated at 7 to 8 months of age

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Highlights

- A 5 kg greater live weight at the start of the mating period increased the reproductive rate (foetuses per 100 ewes joined) of Merino ewe lambs mated at 7 to 8 months of age by about 20%.
- Regardless of their live weight at the start of the mating period, gaining an extra 100 g/day of live weight during the mating period further increased the reproductive rate of Merino ewe lambs mated at 7 to 8 months of age by about 20%.
- Merino ewe lambs from sires with higher Australian Sheep Breeding Values for fat measured post-weaning achieved a higher fertility and reproductive rate regardless of nutritional treatment.
- The effects of managing growth pattern until the end of the mating period and sire genetics on fertility and reproductive rate were additive.

- Survival of twin born progeny from ewe lambs was lower than survival of single born progeny (68 vs 93%; P<0.001), so only 70% of the gains in reproductive rate due to improved feed allowance until the end of the mating period translated into extra progeny at weaning.

Abstract

The reproductive performance of Merino ewe lambs is highly variable and generally poor in comparison to older ewes. In this study, we determined the impacts of growth pattern to the end of the mating period and sire genetics on the reproductive performance of Merino ewe lambs. Five hundred ewe lambs with full pedigree records were managed under commercial conditions from weaning and weighed 43.5 kg at the start of the mating period with an average age of 224 days. The ewe lambs were offered a moderate or high feed allowance to achieve target growth rates of 100 or 200 g/day during a 46-day mating period. They were then recombined and scanned for pregnancy status 60 days after the mating period. At the individual animal level, a 5 kg greater live weight at the start of the mating period increased reproductive rate (foetuses per 100 ewes joined) by about 20% (P<0.001). Regardless of their live weight at the start of the mating period, gaining an extra 100 g/day of live weight during the mating period further increased their reproductive rate by about 20% (P<0.001). Ewe lambs from sires with higher Australian Sheep Breeding Values for fat measured post-weaning achieved a higher fertility (P<0.05) and reproductive rate (P<0.01) regardless of feed allowance treatment. The effects of sire fatness was significant even when the sire breeding values for live weight measured post-weaning were included in the model. The effects of managing growth pattern and sire genetics were additive, so improving the reproductive performance of Merino ewe lambs mated at 7 to 8 months of age requires improving their feed allowance and rate of live weight gain until the end of the mating period and using sires with higher breeding values for fatness.

Key words: Merino; ewe lambs; fertility; reproductive rate; genotype; feed allowance

Introduction

The proportion of Merino ewe lambs joined at 7 to 8 months in Australia is less than 5% and the reproductive performance of ewe lambs is highly variable and generally poor in comparison to older ewes regardless of breed (Fogarty et al., 2007; Rosales Nieto et al., 2013a,b, 2015; reviewed by Kenyon et al., 2014a). Ewe lambs that are heavier due to improved nutrition pre- and post-weaning or 'genetic propensity for growth' consistently achieve puberty at a younger age, are more fertile and have a higher reproductive rate. Nevertheless, at the same live weight at the start of the mating period, there is still a large range in fertility and reproductive rate between different experiments and between individual sheep within experiments, indicating that other environmental, nutritional and genetic factors are also involved (Rosales Nieto et al., 2013a,b, 2015; Paganoni et al., 2014a). Increasing nutrition and live weight gain during the mating period are known to increase the ovulation rate of adult ewes (Gunn and Maxwell, 1989) and the fertility and reproductive rate of ewes lambs (Rosales Nieto et al., 2015). However further work is still needed to define the optimum combinations of live weight at the start of the mating period and live weight gain during the mating period to enable development of cost-effective management strategies to improve the reproductive performance of Merino ewe lambs.

A number of genetic parameters affect the reproductive performance of ewe lambs and there is clear variation between and within breeds in fertility and reproductive rates (Fogarty et al., 2007; Bunter and Brown, 2013; Kenyon et al., 2014; Newton et al., 2014). Merino ewe lambs with higher breeding values for growth, or from sires with higher breeding values for growth, attain puberty earlier and achieve a higher reproductive performance than those with lower breeding values for growth (Rosales Nieto et al., 2013a,b; Paganoni et al., 2014a). The proportion of fat in the body is known to play an essential role in reproductive processes in mammals, and the reproductive performance of adult ewes is positively related to their condition score at mating (reviewed by Kenyon et al., 2014) and their own breeding values for fat (Ferguson et al., 2010). Rosales Nieto et al. (2013b) also reported a positive relationship between the ewe lambs own breeding values for fat

measured post-weaning (7 to 10 months old) and their reproductive performance. However, the ewe lambs own breeding values include both phenotypic and genetic components and in a related study the sires breeding values for fat were not related to the reproductive performance of their daughters when mated at 8 to 10 months of age (Paganoni et al., 2014a). It is reasonable to expect that animals that are genetically fatter would be physiologically more mature at the same weight (Robelin, 1986; Rosales Nieto et al., 2018), however the effect of genetic fat on the reproductive performance of Merino ewe lambs is not entirely clear and little is also known of the interactions between genetic and management factors.

Therefore, we tested the hypothesis that in addition to the effects of improving live weight at the start of the mating period, the reproductive performance of Merino ewe lambs mated at 7 to 8 months would be increased by feeding to gain more live weight during the mating period. Furthermore, we expected that reproductive performance could be increased by selecting ewe lambs from sires with higher breeding values for both growth and fat and that these effects of sire and rate of live weight gain during the mating period would be additive.

Materials and methods

This work was done in accordance with the Australian Code of Practice for the Care and Use of Animals for Scientific Purposes and was approved by the Animal Ethics Committee of the Department of Agriculture and Food, Western Australia (AEC number 6-10-43).

Animals and experimental design

This experiment used 500 Merino ewe lambs from the Moojepin Multi-Purpose Merino stud located at Katanning, Western Australia (33°63'S, 117°89'E). The ewe lambs were generated from two artificial insemination programs that were 40 days apart, had full pedigree records and Australian Sheep Breeding Values (ASBVs, Brown et al., 2007), and weighed 29.3 kg (range 16 to 43 kg) when they were weaned on 28-Oct-2011. They were managed to gain live weight after weaning and weighed 43.5 kg (range was 31 to 59 kg) at the start of the mating period on 09-Mar-

2012 (Day 0). The average age of the two cohorts of ewe lambs at the start of the mating period was 200 and 240 days (average 224 days). At the start of the mating period they were allocated into two treatments varying in feed allowance, balanced for sire of ewe lamb and the lambs age, own birth type (born as a single or twin) and live weight, and fed to achieve target growth rates of 100 (moderate) or 200 g/day (high) during the mating period. The feed allowance treatments were achieved by manipulating grazing pressure and access to a commercial pellet with a metabolisable energy content of 11.5 MJ/kg of dry matter and a crude protein content of 14.5%. Each group of ewes was syndicate mated with five mature Merino rams for 46 days and then recombined until the end of the experiment when they weaned their own lambs.

Animal measurements

The ewe lambs were weighed at least once per week from weaning until the end of the mating period and then monthly until pre-lambing in August. The ewes were also body condition scored at the start and end of the mating period and pre-lambing (Jefferies 1961). The numbers of fetuses were determined by ultrasound scanning about 60 days after removal of rams, and the scanning data were used to calculate fertility (percentage of pregnant ewes per 100 ewes mated) and reproductive rate (number of fetuses in utero per 100 ewes mated). All pregnant ewe lambs were marked for identification using side-branding just prior to the start of lambing and during the lambing period their progeny were weighed, tagged, recorded as single or twin born and had their sex determined within 24 hours of birth. The date of conception was calculated from the date of birth and assuming a 147-day gestation period. The progeny from the ewe lambs were weighed at weaning and the identification of lambs present at weaning was used to derive lamb survival.

Statistical analysis

All statistical analyses were performed using GENSTAT (GENSTAT Committee, 2008). Live weight, body condition score, live weight change over the mating period and feed allowance treatment were analysed using Residual Maximum Likelihood to fit each trait with the ewe lambs

own birth type and relevant covariates as fixed effects. Sire of ewe lambs was fitted as a random effect. Live weights are uncorrected for wool and conceptus weights.

Estimates of fertility were assessed separately by fitting General Linear Mixed Models. The approach used a logit-transformation and binomial distribution in additive models. Logits were predicted as a function of relevant effects, live weight at the start of the mating period, growth rate during the mating period, Australian Sheep Breeding Values of the sire of the ewe lamb for weight (PWT), fat depth (PFAT) and eye muscle depth (PEMD) measured post-weaning and feed allowance group, where relevant, fitted as fixed effects either individually or in combination. Sire of ewe lambs (removed for sire breeding values) was fitted as a random effect. Reproductive rate (dry, singles and twins) were analysed as a function of the same variables as above, either individually or in combination using a generalised linear model with a multinomial distribution and logit link function, and adjustment for sire of ewe lambs where relevant.

The birth and weaning weight of progeny from the ewe lambs were analysed using REML. Within this procedure the birth type and sex of the progeny, feed allowance treatment or live weight at the start of mating and all interactions were fitted as fixed effects. Dam, sire of ewe lambs and date of birth were fitted as random effects. Survival of their progeny to weaning was assessed by fitting Generalized Linear Mixed Models. The approach used a logit-transformation and binomial distribution. Logits were predicted as a function of relevant effects and sex were fitted as fixed effects with and dam, sire of ewe lambs and date of birth were fitted as random effects.

Results

Live weight, live weight gain and condition score

Ewe lambs weighed 43.5 kg at the start of the mating period and their average condition score was 3.2. Ewe lambs born as singles were heavier at the start of the mating period than those born as twins (44.4 *vs*. 42.5 kg; $P< 0.01$) but they did not differ significantly in body condition score. Treatment effects of live weights increased during the mating period. At the average day of

conception, 28 days after the introduction of rams, the difference in live weight between the high and moderate feed allowance treatments was 2.5 kg (48.7 *vs*. 46.2 kg: P<0.001) and this increased to 4.6 kg (51.3 *vs.* 46.7 kg; P<0.001) one week prior to the end of the mating period. The average growth rate in the high and moderate feed allowance treatments during the mating period was 190 and 120 g/day, respectively (P<0.001; Fig. 1). Ewe lambs from the high feed allowance group remained about 2.2 kg heavier pre-lambing than those from the moderate group (61.4 *vs*. 59.2 kg; P<0.05). At the end of the mating period the body condition score of ewes from the high group was 0.3 higher than those from the moderate group (3.8 *vs*. 3.5; P<0.001), but there was no significant difference between treatment groups in body condition score pre-lambing.

[Insert Fig. 1 near here]

Fertility and reproductive rate

Ewe lambs that were heavier at the start of the mating period were more fertile and achieved a higher reproductive rate (P<0.001). On average, reproductive rate increased by 4.0 to 4.5% per 1 kg increase in live weight at the start of the mating period (Fig. 2). Ewes born as single lambs tended to be more fertile (69 *vs.* 61%; P <0.1) and had a higher reproductive rate (95 *vs*. 84; P<0.1) than those that were born as twin lambs, however these differences were not significant when live weight at the start of the mating period was included in the statistical model. There were no significant effects of body condition score at the start of the mating period that was in addition to the effects of live weight. Increasing feed allowance during the mating period also increased fertility (74% *vs.* 55%; P<0.001) and reproductive rate (107% *vs*. 70%; P<0.001), and the effects were evident regardless of live weight at the start of the mating period (Fig. 2). Improving feed allowance during the mating period reduced the proportion of dry ewes (24.7 *vs.* 45.9: P <0.001) and increased twinning rate of pregnant ewes (43.2 *vs.* 29.0%; P<0.001).

[Insert Fig. 2 near here]

The effects of feed allowance treatments on fertility and reproductive rate of ewe lambs were associated with differences in live weight change during the mating period (Fig. 3; $P<0.001$). Across all ewes, regardless of treatment, it was predicted that growing an extra 100 g/day during the mating period increased fertility by between 8 and 18%. Even though the interaction was not statistically significant ($P>0.05$), the effects of live weight change during the mating period on fertility were less apparent at higher live weights as most ewes that were greater than 50 kg at the start of the mating period became pregnant. At the individual animal level, an extra 100 g/day in live weight gain during the mating period improved reproductive rate by about 20% irrespective of live weight at the start of the mating period.

[Insert Fig. 3 near here]

The breeding values for PWT and PEMD of the sire of the ewe lambs did not significantly influence their reproductive performance, despite sire PWT being positively related to the ewe lambs live weight at the start of the mating period and growth rate during the mating period. However the breeding values for PFAT of the sire of the ewe lambs were positively related to both their fertility ($P<0.05$) and reproductive rate ($P<0.01$), even when sire ASBV for PWT was added to the model. On average, the effect of increasing sire ASBV for PFAT by 1 mm resulted in a 13% increase in fertility and a 24% increase in reproductive rate for any given sire PWT (Fig. 4). There was no significant interactions between any of the sire breeding values and feed allowance treatment, so the effects of feed allowance or live weight change during the mating period and breeding value of the sire were additive.

[Insert Fig. 4 near here]

Progeny weights and survival to weaning

There was no significant effect of live weight of ewe lambs at the start of the mating period or their feed allowance during the mating period on the birth weight and survival to weaning of their single or twin born progeny. At the individual animal level, an extra 1 kg in live weight of ewe lambs at the start of the mating period was associated with a 0.13 (± 0.042) kg increase (P<0.01) in the weaning weight of progeny.

Single born progeny from ewe lambs were significantly heavier than twin born progeny at birth (5.4 *vs.* 4.5 kg; P<0.001) and at weaning (21.8 *vs.* 18.8 kg; P<0.001), and survival of single born progeny to weaning was significantly higher than survival of twin progeny (93 *vs.* 68%; P<0.001). The estimated difference in weaning rates between feed allowance treatments was 27% (84% *vs.* 57%; P<0.01).

Discussion

Merino ewe lambs that were heavier at the start of the mating period at 7 to 8 months of age were more fertile and achieved a higher overall reproductive rate than those that were lighter. The relationship between live weight and reproductive rate was linear over the range 35 to 55 kg and reproductive rate increased by 4.0 to 4.5% for each additional 1 kg in live weight at the start of the mating period. This response is comparable to earlier studies that reported increases of 4.5 to 4.8 extra foetuses per 100 ewes mated (Rosales et al., 2013a, b). These responses are however greater than that observed in a study evaluating the effects of genotype and growth path during the mating period on fertility, fecundity, embryo mortality and peri-natal mortality of lambs (Paganoni et al., 2014a), which could reflect the high rates of pregnancy failure in that study due to the intensive measurement protocol required to accurately quantify embryo losses. Overall, it is likely that the responses in reproductive rate to improved live weight at the start of the mating period are much greater in ewe lambs than in adult ewes regardless of breed (Lindsay et al. 1975; Ferguson et al. 2011). Management to achieve target live weights at mating to optimise reproductive performance will therefore be more important in young growing ewes mated at 7 to 8 months than in adult ewes.

Improving the feed allowance of Merino ewe lambs during the mating period also significantly increased their fertility and reproductive rate when mated at 7 to 8 months of age. These effects of feed allowance during the mating period were evident irrespective of live weight at the start of the mating period, indicating that their effects were additive. The effects of feed allowance during the mating period on fertility and reproductive rate logically reflected differences in live weight gain during the mating period, and the effects of increasing live weight gain on reproductive performance was close to linear across the range from live weight maintenance to nearly 300 g/day. Across all ewe lambs, regardless of treatment, the prediction equations suggest that growing an extra 100 g/day during the mating period had a similar impact on reproductive rate as an extra 5 kg of live weight at the start the mating period. In other words, ewe lambs that weighed 40 kg at the start of the mating period and grew at 200 g/day during the mating period achieved similar reproductive performance to those that weighed 45 kg at the start of the mating period and grew at 100 g/day, or weighed 50 kg at the start of the mating period and maintained weight. These results extend the earlier findings of Rosales et al. (2015) who reported the effects of live weight change during the mating period on reproductive performance of ewe lambs from the same flock as the current study. Whilst the ewe lambs in the Rosales et al. (2015) study were only 40 kg at the start of the mating period, and the low feed allowance group only maintained weight during the mating period, improving nutrition to gain 180 g/day during the mating period increased reproductive rate by 38% (46% *vs*. 8%). Mulvaney et al. (2010) also reported that feeding Romney ewe lambs to gain about 300 g/day increased reproductive rate by about 29% compared to those fed to maintain live weight (86% *vs*. 57%). Collectively, these results indicate a significant opportunity for sheep producers to increase the reproductive rate of their ewe lambs by increasing their live weight gain over the mating period, regardless of ewe breed. This can increase their management options to improve the reproductive performance of ewe lambs, particularly if live weight targets at the start of the mating period were not achieved.

The average day of conception was estimated to be 28 days after the entire rams were introduced, which is consistent with the ewe lambs being stimulated to cycle from the introduction

of rams. The average live weight of ewe at the estimated day of conception is likely to have differed between nutritional groups by only 2 to 3 kg. These differences in live weight at conception would therefore only explain about one-third of the 37% difference in reproductive rate between nutritional treatments, indicating that the main effects of improving nutrition during the mating period are over and above those resulting from gains in absolute live weight. There is limited evidence in adult ewes that live weight gain can influence ovulation rate over and above the effects of live weight *per se*, and studies with larger numbers of adult ewes have generally failed to detect significant effects of live weight change during the mating period on reproductive performance of adult ewes (Adalsteinsson, 1979). Short-term supplementation of lupins for 4 to 6 days prior to conception can also increase ovulation rates in adult ewes, even in the absence of detectable increases in live weight, but these 'acute' effects often increase reproductive rate by less than 10 to 15% (Smith and Stewart, 1990; Vinoles et al., 2012). Regardless of the mechanism, improving nutrition and live weight gain during the mating period had very large positive effects on the reproductive performance of Merino ewe lambs, irrespective of their live weight at the start of the mating period. Similar to the achievement of target live weights at the start of the mating period, it therefore also appears that nutrition during the mating period may be more important for optimising the reproductive performance of ewe lambs compared to adults.

It is likely that a difference in live weight gain during the mating period is a major factor contributing to the variable results regarding the effects of live weight at the start of the mating period on the reproductive rate of ewe lambs. Rosales et al. (2013a) reported a reproductive rate of about 100% from Merino ewe lambs that were 43 kg at the start of mating and gaining more than 200 g/day during the mating period, whereas in a second study a reproductive rate of 50% was achieved when ewe lambs were 48 kg at the start of mating and only gained about 50 g/day during the mating period (Rosales et al., 2013b). A comparison of the data presented in Figure 3 against 14 other data sets indicates that the reproductive performance observed in the current study may represent the upper limit for what is achievable from Merino ewe lambs mated at about 7 to 8 months of age. The average discrepancy between the actual reproductive rate achieved in these 14

data sets and the predicted reproductive rate was 16% and all but three flocks fitted within the 95% confidence limits from Figure 3. This suggests that development of a matrix of live weight at the start of the mating period plus live weight change during the mating period in relation to reproductive rate is feasible, and together with other factors known to influence reproductive rate, should enable the development of decision tools to optimise management prior to and during mating to maximise profits from joining Merino ewe lambs. The optimum strategy will depend on the supply and quality of paddock feed in relation to the time and duration of mating. The cost effectiveness of segregating ewe lambs at or soon after weaning and only feeding a proportion of the flock to be mated also needs to be investigated, given the linear responses between live weight and live weight gain during the mating period and reproductive rate.

Ewe lambs from sires with more potential for growth were heavier at the start of the mating period and grew faster during the mating period, but surprisingly the sires ASBVs for PWT was not significantly related to the fertility and reproductive rate of their daughters mated at 7 to 8 months of age. Paganoni et al. (2014a) reported that the reproductive rate of ewe lambs increased by about 7.9% for each 1 kg increase in the ASBV for PWT of their sire, suggesting that the magnitude of the response from selecting high growth sires may vary between flocks for reasons not known. Afolayan et al. (2008) reported moderate positive genetic correlations in ewes between early growth and reproductive performance over their first three breeding seasons, but they did not compare the genetic correlations for ewes mated at 7 to 8 months of age compared to those mated at older ages. The sire breeding values for PFAT were significantly related to the reproductive rate of Merino ewe lambs mated at 7 to 8 months of age, and the effects remained significant when PWT was added to the model. From a biological perspective the effects of extra genetic fat remain large, as a 1 mm increase in sire PFAT resulted in a 24% increase in reproductive rate regardless of PWT. Fat is positively related to fertility and fecundity in adult Merino ewes (Ferguson et al., 2010), but this is the first time the relationship has been identified in Merino ewe lambs. Surprisingly there was no significant correlation between condition score at joining and reproductive performance, as this has been reported previously for cross-bred ewe lambs (Kenyon

et al., 2014). This may suggest that the range of condition scores of the ewe lambs in this experiment at the start and end of the mating period was too small for a significant relationship with fertility or reproductive rate to be established. The results from this study indicate that improving reproductive rate of Merino ewe lambs can be achieved from the indirect selection of sires with higher breeding values for fat measured post-weaning. It also appears that the effects of genetic fat and rate of live weight gain during the mating period are additive indicating that both factors are critical control points to maximising the reproductive performance of Merino ewe lambs mated at 7 to 8 months of age.

Ewes that were born as a single lamb tended to be more fertile and had a higher reproductive rate than those born as a twin. These differences in fertility and reproductive rate were entirely due to single-born ewe lambs being heavier at the start of the mating period than ewe lambs born as twins. Merino ewes born as twins will require preferential management and feeding to increase live weight from weaning to mating at 7 to 8 months of age to enable them to achieve a comparable reproductive performance to those ewes born as single lambs. Further work is also required to establish the effects of age of mating on the reproductive success of Merino ewe lambs, and how this interacts with sire breeding values, live weight at the start of the mating period and live weight change during the mating period. Fogarty et al. (2007) found that ewe lambs mated at an older ages resulted in higher lambing percentages, however in the current study there were two cohorts of lambs from generated by artificial insemination and age at mating was confounded by sire and live weight at mating.

There was no significant effect of live weight at the start of the mating period or nutrition during the mating period on the birth weight or survival to weaning of single or twin born progeny from ewe lambs. Rosales et al. (2015) also found no effect of nutrition during mating on progeny birth weights. While live weight profile of adult Merino ewes during both early and late pregnancy is known to influence lamb birth weights (Oldham et al., 2011; Paganoni et al., 2014b), it is likely that the effects of feed allowance during the mating period on the ewe lambs subsequent live weight profile where insufficient to influence birth weight in the current study. Indeed the changes

in live weight between the average day of conception and pre-lambing were very similar regardless of treatment during mating. The mortality of twin born progeny from ewe lambs was almost 5-fold greater than that for single born progeny, which may be greater than the 2 to 3 fold difference typically observed in adult Merino ewes (reviewed by Hinch and Brien 2014). As a higher feed allowance during the mating period increased fecundity by 50%, and twin-born progeny where much more likely to die, the net effect is that a 37% increase in reproductive rate due to improved feed allowance during the mating period translated into an estimated difference in weaning rates between nutritional treatments of 27%. Further work is needed to develop live weight targets for ewe lambs during pregnancy to maximise the survival of their twin born progeny.

Conflicts of interest

None

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FIGURES

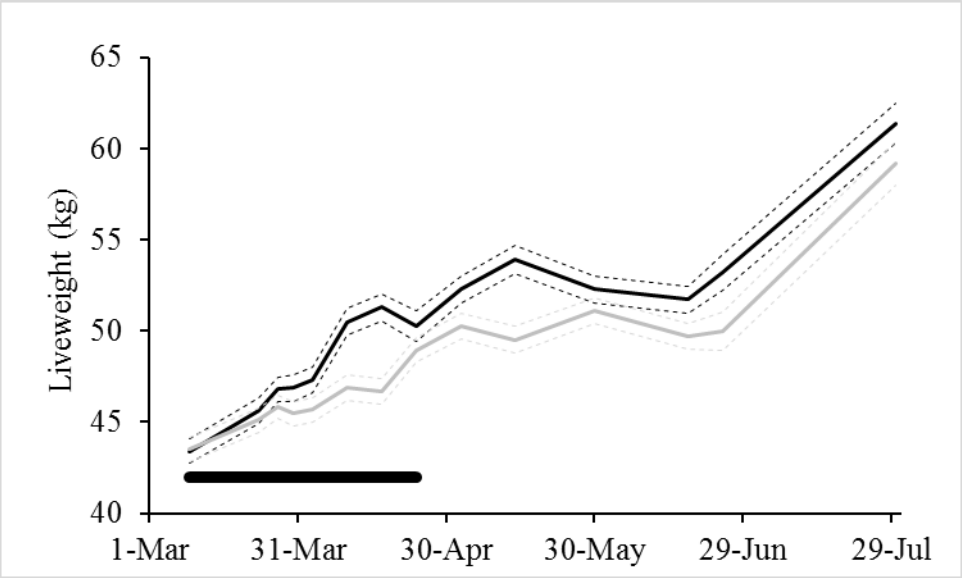
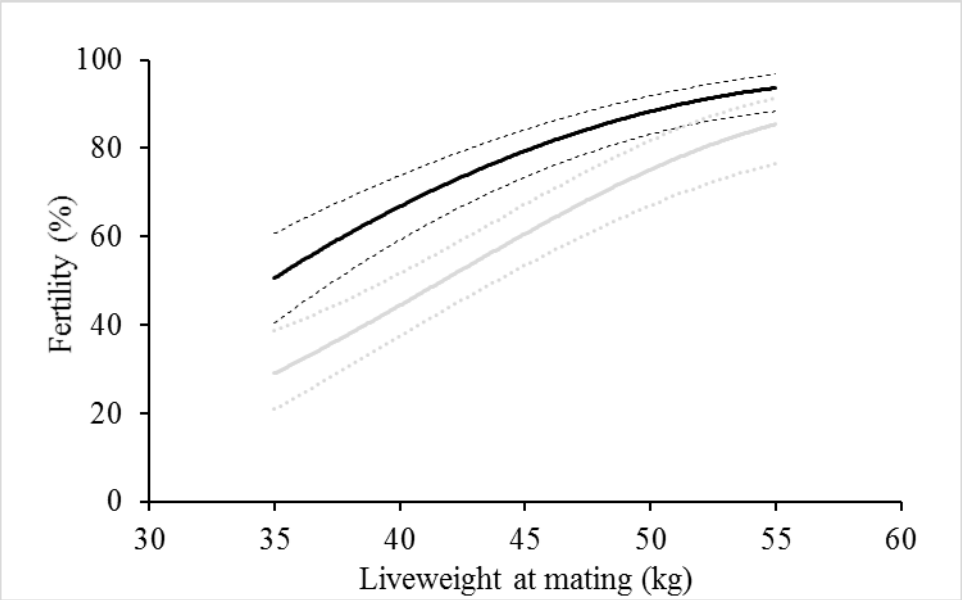


Figure 1. Live weights of Merino ewe lambs offered a feed allowance to achieve fast (black line) or moderate (grey line) growth rates during the mating period. The dashed lines represent the 95% confidence intervals, the horizontal bar represents the mating period and the end of July corresponds with pre-lambing.



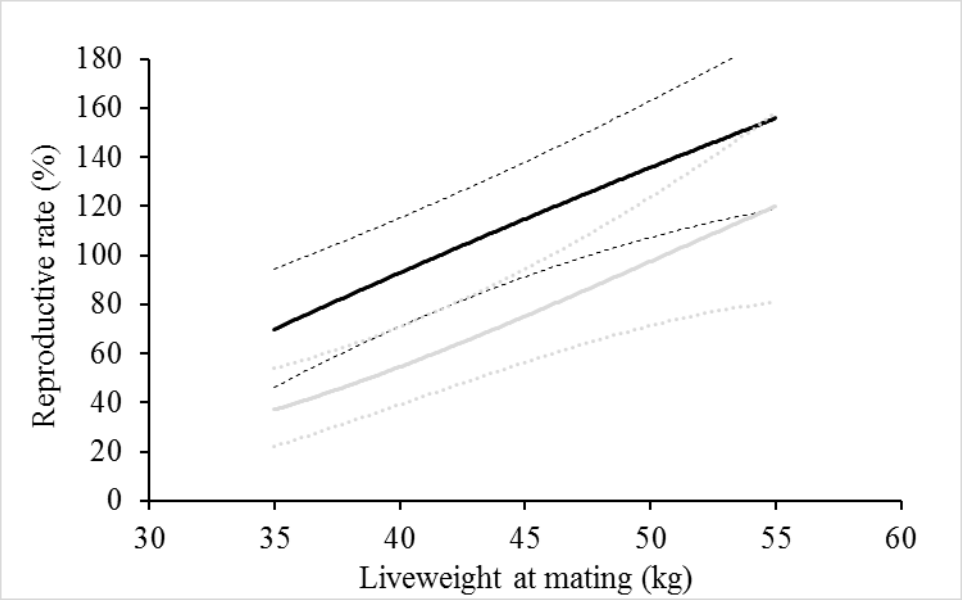


Figure 2. The effect of live weight at mating on fertility (ewes pregnant per 100 ewes mated; top) and reproductive rate (foetuses per 100 ewes mated; bottom) for Merino ewe lambs offered a high (black line) or moderate (grey line) feed allowance during the mating period. The 95% confidence intervals are indicated by dashed lines for each treatment.

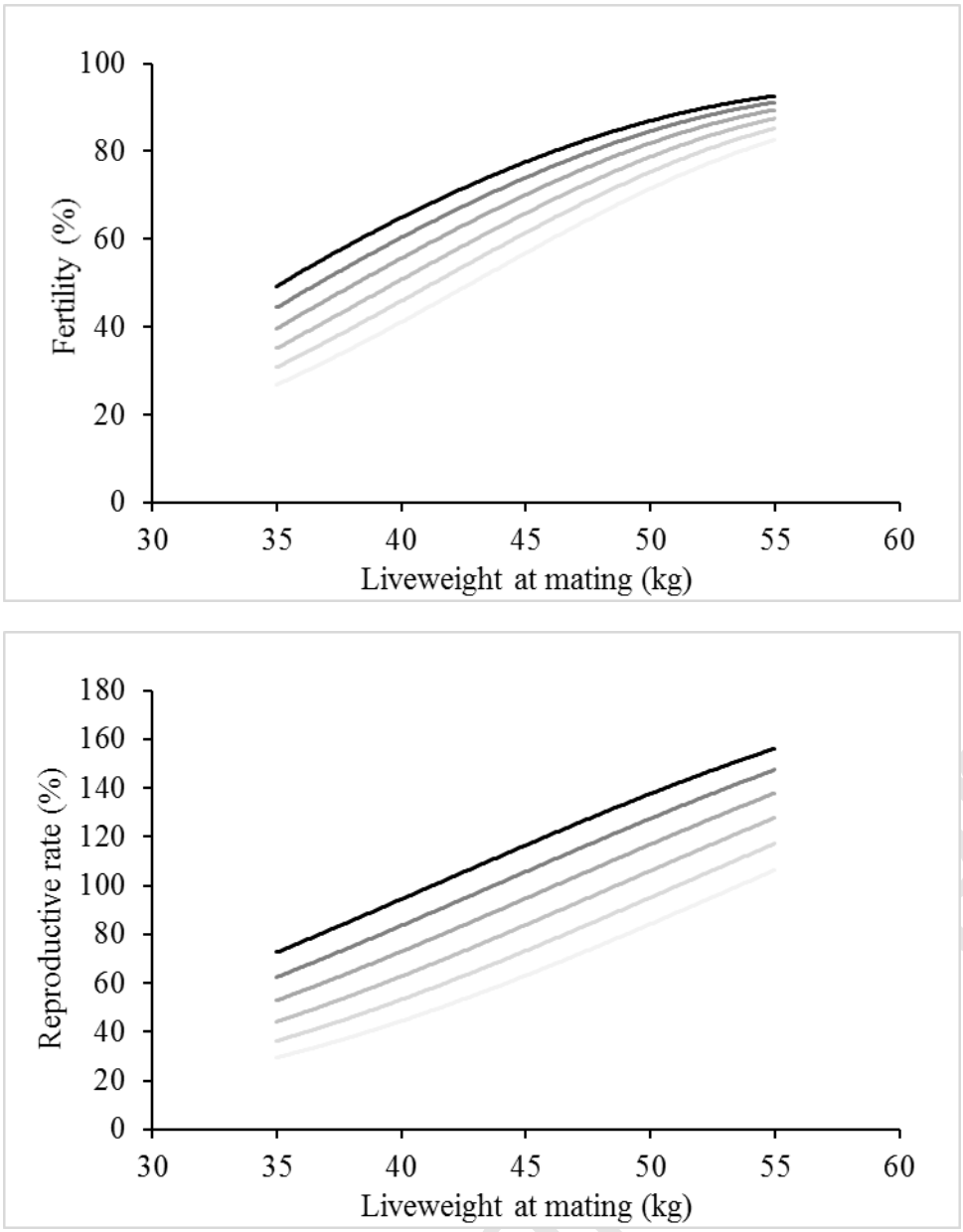


Figure 3. The effect of live weight at the start of the mating period on fertility (ewes pregnant per 100 ewes mated; top) and reproductive rate (foetuses per 100 ewes mated; bottom) for Merino ewe lambs that gained live weight at different rates during the mating period [0 (bottom), 50, 100, 150, 200 and 250g/day (top)]. The average 95% confidence intervals across all scenarios was ±7% for fertility and ±26% for reproductive rate.

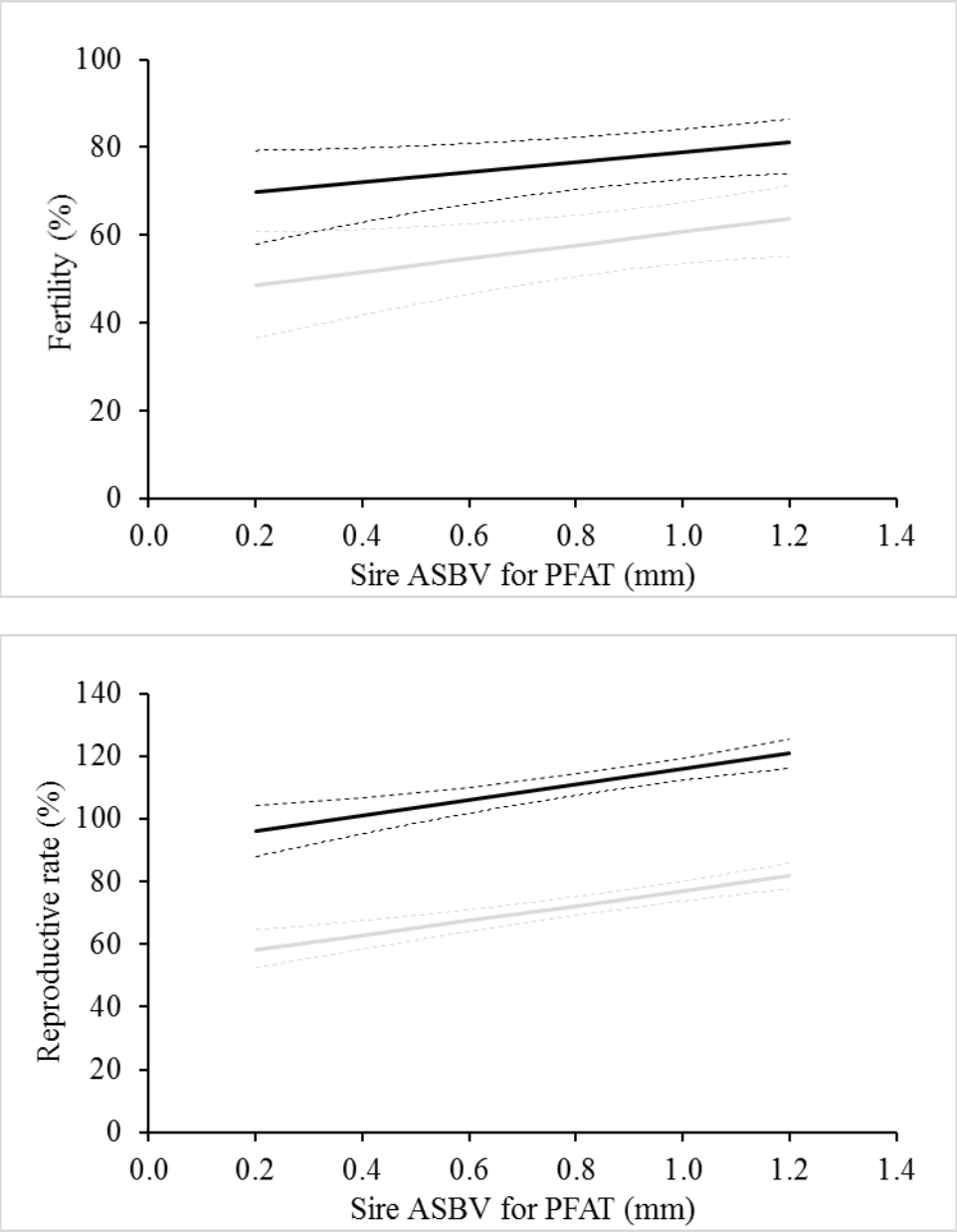


Figure 4. The effect of Australian Sheep Breeding Values for fat depth measured post-weaning (PFAT) of the sire on the fertility (ewes pregnant per 100 ewes mated; top) and reproductive rate (foetuses per 100 ewes mated; bottom) of Merino ewe lambs offered high (black line) or moderate (grey line) feed allowance during the mating period. The 95% confidence intervals are indicated by dashed lines for each treatment.