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The birthweight and survival of Merino lambs can be predicted from the profile of liveweight change of their mothers during pregnancy

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Abstract. The single largest influence on the survival of lambs in the first few days of life is their birthweight. Fetal growth and birthweight are regulated by genotype of the fetus, maternal genotype, maternal nutrition and the external environment. In this paper we report the extent to which the changes in maternal liveweight during pregnancy and lactation (liveweight profile) of Merino ewes can be used to predict the birthweight and survival of their progeny to weaning. At two sites [Victoria (Vic.) ~700 ewes and Western Australia (WA) ~300 ewes] in each of 2 years, a similar experiment used adult Merino ewes to explore effects of nutrition from joining to Day 100 of pregnancy and from Day 100 of pregnancy to weaning. The average difference between extreme treatments at Day 100 of pregnancy were 7 kg in ewe liveweight and 0.7 of a condition score (CS) and at lambing 11.9 kg and 1.3 of a CS. This resulted in average birthweights of progeny from different treatments ranging from 4.0 to 5.4 kg and survival to weaning ranging from 68 to 92%. Across the four experiments between 68 and 85% of all lamb deaths to weaning occurred within 48 h of birth. Lambs born to ewes in CS 2 at Day 100 of pregnancy were lighter ($P < 0.05$) in both years at the Vic. site than those from ewes in CS 3 at Day 100 of pregnancy. Lambs born to the ewes grazing a feed on offer of 800 kg DM/ha during late pregnancy were also lighter than those from other levels of feed on offer between 1100 and 3000 kg DM/ha at the Vic. site in both years and at the WA site in 1 year ($P < 0.001$). Lambs from the 800 kg DM/ha treatment during late pregnancy at the Vic. site had a lower survival than other treatments, especially in the second year. There were no significant effects of treatments on lamb survival at the WA site; however, the results were in the same direction. The birthweight of individual lambs was significantly related to the liveweight profile of their mothers. Their liveweight at joining, change in liveweight to Day 100 of pregnancy and change in liveweight from Day 100 to lambing all contributed ($P < 0.05$) to the prediction of the birthweight of their lambs. The responses were consistent across experimental sites and years, lamb birth rank and sex, and confirmed that the effects of poor nutrition up until Day 100 of pregnancy could be completely overcome by improving nutrition during late pregnancy. At the Vic. site, survival to 48 h was most influenced by the birthweight of the lamb and survival was significantly higher in single- than twin-born lambs and female than male lambs after adjusting for differences in birthweight. A higher chill index during the 48 h after birth reduced survival of both single and twin lambs to a similar extent, but reduced survival of male lambs more than female lambs. There were no effects of birthweight or chill index on lamb survival at the WA site where most lambs weighed more than 4 kg at birth and climatic conditions during lambing were less extreme. Overall, these results supported our hypothesis that improving the nutrition of Merino ewes during pregnancy increases birthweight and this leads to improved survival of their progeny.

Introduction

Twin lambs are lighter at birth than singles and female lambs are lighter than males (Wallace 1948; Knight *et al*. 1988; Gardner *et al*. 2007). Restricting the level of nutrition to the pregnant ewe can reduce lamb birthweight dependent on the timing and severity of the restriction (Holst *et al*. 1986), although others suggest changes in ewe liveweight were not associated with effects on birthweight (Fogarty *et al*. 1992). Nonetheless, where there are adverse effects of nutrition during early and mid pregnancy they can be overcome by adequate nutrition during late pregnancy (Taplin and Everitt 1964). More than 85% of fetal growth occurs during the last third of pregnancy and therefore good levels of nutrition are required to meet the demands for this growth (Mellor 1983; Kelly and Newnham 1990).

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Birthweight has a direct effect on survival of lambs and the ideal birthweight range appears to be between 3.5 and 6.0 kg. The relationship follows a quadratic shape with maximum survival at ~4.5 kg (Merinos, Atkins 1980; Romney, Knight *et al*. 1988). Survival is therefore lower in very small or very big lambs, irrespective of the source of the variation in birthweight.

Some studies have linked the average liveweight of flocks at key times to lamb birthweight and survival. About 50% of the variation in mortality rates of lambs between farms was associated with the average liveweight of the flock ~Day 100 of pregnancy (Kelly 1992). The nutrition of ewes is reflected in changes in their maternal liveweight during pregnancy and lactation (liveweight profile of the ewe; Ferguson *et al*. 2011) and the liveweight profile of ewes can be used to predict the quantity and quality of their wool production (Ferguson *et al*. 2011) and that of their progeny (Thompson *et al*. 2011). In this paper we tested the hypothesis that the liveweight profile of Merino ewes affects the birthweight of their progeny and that these effects on birthweight can be used to reliably predict lamb survival.

Materials and methods

All procedures reported in this paper were conducted according to the guidelines of the Australian Code of Practice for the Use of Animals for Scientific Purposes and received approval from the Western Australia and Victorian Department of Agriculture Animal Ethics Committees.

Experimental sites and design

A total of four experiments were conducted in 2001 and 2002 at sites located on commercial properties near Hamilton in Victoria (Vic.; 141.7°E/41′25s, –37.6°S/36′1s) and Kendenup in Western Australia (WA; 117.6°E/37′25s, –34.5°S/29′13s). Both sites experience predominantly winter–spring rainfall, and dry, hot summers, with a long-term average annual rainfall of 590 and 540 mm for the Vic. and WA sites. Actual rainfall received at the Vic. site was 717 and 548 mm for 2001 and 2002 and for the WA site was 522 and 466 mm for 2001 and 2002. The pasture on the Vic. site was based on both perennial grasses (*Lolium perenne* and *Phalaris aquatica*) and annual grasses (*Lolium rigidum*) whereas the pasture at the WA site was based only on annual grasses, subterranean clover and broad-leaf weeds.

Further details of experimental sites, treatments, pasture management and measurements, and ewe management and measurements are provided by Ferguson *et al*. (2011). In brief, a factorial design was used with three (Vic.) or two (WA) replicates of 10 treatments. Adult Merino ewes in condition score (CS) ~3.0 (Jefferies 1961) at artificial insemination (Day 0) in late summer–autumn were: (i) managed using a combination of stocking density and hand feeding to achieve CS 2 or 3 at Day 100 of pregnancy; and then (ii) grazed on five target amounts of feed on offer of the new season's green pasture [800, 1100, 1400, 2000 or 3000 kg DM/ha from Day 100 of pregnancy until weaning (Vic.) or when pasture growth could no longer maintain targets for feed on offer (WA)]. The lambs at the WA site were weaned ~30 days after removal from plots. The ewes were artificially inseminated using semen from four fine wool Merino bloodlines with ~20 sires used at each site each year. The two sites were linked by sires both within and between years.

Experimental sheep, management and measurements

At the Vic. site, plots were grazed with 303 single- and 375 twin-bearing ewes in 2001 and 467 single- and 219 twin-bearing ewes in 2002. At the WA site 320 single-bearing ewes were used in each experiment. Feed on offer for each plot was maintained near target levels by adding and removing additional dry sheep (Vic.) or adjusting the area grazed by experimental sheep (WA). Feed on offer was assessed at 1–2-week intervals from the break of season until the end of the experimental period by calibrated visual assessment (Thompson *et al*. 1994), and pasture composition was estimated three to five key times during pregnancy and lactation in each experiment using the 'toe-cut' method (Cayley and Bird 1996).

Ewes were weighed and condition scored monthly at the Vic. site and every 2 weeks at the WA site during pregnancy and lactation, except for a 5–6-week period immediately following artificial insemination when ewes were not handled. Liveweight was adjusted for conceptus weight and the weight of greasy wool estimated using the dyeband technique as described by Ferguson *et al*. (2011).

Lambing commenced in late August at the Vic. site and late July at the WA site. All lambs were tagged within 24 h of birth and their birthweight, sex and dam recorded. The day of death was recorded for all lambs and surviving lambs were weighed 2–4 weekly until weaning at 12–16 weeks of age. Chill index was estimated from average temperature, rainfall and wind speed measured daily using the equations reported by Donnelly (1984).

Statistical analyses

All statistical analyses were performed using GENSTAT (GENSTAT Committee 2008). In the first analysis the method of Restricted Maximum Likelihood was used to fit progeny birthweight data with target ewe CS at Day 100 of pregnancy, target feed on offer during late pregnancy and lactation, ewe age, progeny sex and birth type as fixed effects. Year, replicate, plot and sire were fitted as random effects. All possible models were examined with statistical significance of terms and interactions thereof accepted at $P < 0.05$.

A second analysis of data generated from the four experiments was conducted to determine whether the maternal liveweight or change in maternal liveweight of ewes or feed on offer during specific periods could be used to predict the birthweight of progeny. Many models were explored to ensure the final modelling provided a statistically sensible parsimonious explanation of the data, in a biologically sound framework. The Restricted Maximum Likelihood model that best predicted the birthweight of progeny used the liveweight of the ewe at joining, change in liveweight of the ewe between joining and Day 100 of pregnancy, and change in liveweight of the ewe from Day 100 of pregnancy until lambing. Ewe age, and birth type and sex of progeny were fitted as fixed effects where appropriate, and year, replicate, plot and sire were fitted as random effects. All possible models were examined with statistical significance of terms and interactions thereof accepted at $P < 0.05$.

Estimates of lamb survival were assessed by fitting General Linear Mixed Models (GENSTAT Committee 2008). The approach used a logit-transformation and binomial distribution. Using additive models, logits were predicted as a function of target ewe CS at Day 100 of pregnancy, target feed on offer during late pregnancy and lactation. Progeny sex and birth type were fitted as fixed effects with year, replicate, plot and sire fitted as random effects. A model was then developed to predict lamb survival to 48 h in terms of lamb birthweight, feed on offer at lambing, chill index, and birth type and sex as fixed effects and year, replicate, plot and sire as random effects.

The effect on lamb survival from the ewe liveweight profile was based on the effects of the profile on the birthweight of the lamb and the subsequent effect of birthweight on survival. This form of modelling allows for more control of factors affecting survival.

Results

The effects of nutritional treatments on ewe liveweight profile to weaning

A full description of the liveweight profiles of the various treatments can be found in Ferguson *et al.* (2011). In brief, the average liveweight and CS of the ewes at or just before joining (Day 0) in 2001 and 2002 were 46 kg and 2.7 and 45 kg and 3.0 at the Vic. site and 46 kg and 2.9 and 47 kg and 2.5 at the WA site. The treatments imposed generated a wide range of ewe liveweight and CS profiles at the Vic. and WA sites in both years. Across all experiments, the average difference in ewe liveweight achieved by Day 100 of pregnancy was 7.0 kg (range 4.7–8.7 kg) and difference in CS was 0.7 (range 0.6–0.9). All ewes gained significant liveweight and CS immediately following introduction to the plots, especially those lower in CS at Day 100 of pregnancy and grazing higher levels of feed on offer. Overall, grazing different amounts of feed on offer from Day 100 of pregnancy amplified the spread in ewe liveweight and CS such that the average difference between extreme treatments (CS treatment 2, feed on offer treatment 800 and CS treatment 3, feed on offer treatment 3000) were 11.9 kg (range 4.9–17.8 kg) and 1.3 of a CS (range 0.5–1.7) at lambing. The differences in liveweight between feed on offer treatments increased during lactation and were 13.9 kg (range 8.8–22.7 kg) and 1.4 of a CS (range 0.9–2.3) at weaning.

Factors influencing the birthweight of lambs

A total of 1970 lambs were born at the Vic. site and 720 lambs at the WA site over the 2 years. Overall the mean birthweight of single lambs across both sites and years was 5.1 kg and did not differ between sites. The average birthweight of twin lambs at the Vic. site was 3.8 kg, which was significantly less ($P < 0.001$) than the birthweight of single lambs. The estimated mean gestation length was 151 days at both sites, with no significant effect ($P > 0.05$) of ewe nutritional treatments, lamb birth type or lamb sex on this trait.

At the Vic. site, ewe nutrition from joining to Day 100 of pregnancy and from Day 100 to lambing both influenced lamb birthweight (Table 1). Lambs from ewes fed to achieve a target of CS 2 at Day 100 of pregnancy were lighter at birth than those from ewes fed to a target of CS 3 at Day 100 of pregnancy ($P < 0.05$). Lambs from ewes that grazed the lowest feed on offer treatment between Day 100 of pregnancy and lambing were also significantly lighter ($P < 0.05$) than those from the other treatments. There was no significant interaction ($P > 0.05$) between the nutritional treatments from joining to Day 100 of pregnancy and from Day 100 of pregnancy to lambing. The effects of ewe nutritional treatments on lamb birthweight were less evident at the WA site, the only significant effect being that the lowest level of feed on offer from Day 100 of pregnancy to lambing reduced lamb birthweight in 2001 ($P < 0.05$).

Table 1. The effect of maternal body condition to Day 100 of pregnancy and level of feed on offer (FOO) from Day 100 to lambing as well as birth rank and gender on lamb birthweights at the Vic. and WA sites in 2001 and 2002. Progeny were from single ewes at the WA or single- and twin-bearing ewes at the Vic. site that were differentially fed to achieve condition score (CS) 2 or 3 at Day 100 of pregnancy and then grazed a range of FOO (kg DM/ha) levels until weaning

Level of significance; $P < 0.05$ (*), $P < 0.01$ (**) and $P < 0.001$ (***). Different letters within CS and FOO treatments and between birth type and gender comparisons differ at the probability shown. n.s., not significant

Factor	Vic. 2001	Vic. 2002	WA 2001	WA 2002
CS treatment 2	4.34a	4.37a	5.20a	5.29a
CS treatment 3	4.45b	4.51b	5.13a	5.27a
Level of significance	*	*	n.s.	n.s.
FOO treatment 800	4.18a	4.02a	4.68a	5.19a
FOO treatment 1100	4.37b	4.52b	5.25b	5.22a
FOO treatment 1400	4.43bc	4.50b	5.37b	5.26a
FOO treatment 2000	4.45bc	4.54b	5.18b	5.38a
FOO treatment 3000	4.53c	4.61b	5.34b	5.33a
Level of significance	***	***	***	n.s.
	Birth type			
Single	4.95a	5.03a	–	–
Twin	3.84b	3.85b	–	–
Level of significance	***	***	–	–
	Sex			
Male	4.51a	4.52a	5.27a	5.43a
Female	4.28b	4.36b	5.06b	5.11b
Level of significance	***	**	*	***

Male lambs were on average 0.2 kg heavier than females at both sites ($P < 0.05$) and single-born lambs were on average 1.1 kg heavier than twin-born lambs at the Vic. site ($P < 0.001$). These effects of lamb gender and or birth type were independent of ewe nutrition from joining to Day 100 of pregnancy or from Day 100 of pregnancy to lambing, as the interactions with nutritional treatment were not significant ($P > 0.05$).

Prediction of lamb birthweights

For all site by year combinations, lamb birthweight could alternatively be predicted from the liveweight profile of the ewe. Ewes that were heavier at joining or gained more weight between joining and Day 100 of pregnancy or from Day 100 to lambing produced lambs that were heavier at birth (Table 2). These aspects of the ewe liveweight profile were significant when fitted together and each explained additional variance in lamb birthweight. There were no significant ($P > 0.05$) interactions with year, so data from different years at each site was combined. At both sites, an extra 10 kg of ewe liveweight at joining increased lamb birthweight by ~0.25 kg. A loss of 10 kg in ewe liveweight between joining and Day 100 of pregnancy reduced lamb birthweight by ~0.33 kg, whereas gaining 10 kg from Day 100 to lambing increased birthweight by ~0.45 kg. The

Table 2. Regression coefficients (±s.e.) of Restricted Maximum Likelihood models that predict birthweight (kg) of individual progeny from ewe liveweight at joining (LW_{D0}; kg), ewe liveweight change from mating to Day 100 of pregnancy (LWC_{D0-100}; kg) and Day 100 of pregnancy to lambing (LWC_{D100-L}; kg) and progeny sex and birth type. Data represents a combined analysis for 2001 and 2002 at the Vic. and WA sites

All possible models were examined with statistical significance of terms and interactions thereof accepted at $P < 0.05$

Term	Coefficient (±s.e.)	
	Vic. site	WA site
Constant	3.7 ± 0.16[A]	3.9 ± 0.24[B]
LW_{D0}	0.027 ± 0.0033	0.025 ± 0.0044
LWC_{D0-100}	0.033 ± 0.0044	0.032 ± 0.0069
LWC_{D100-L}	0.045 ± 0.0038	0.048 ± 0.0066
Twin	–1.1 ± 0.03	–
Female	–0.2 ± 0.03	–0.3 ± 0.05

[A]The birthweight constant is for single male progeny.
[B]The birthweight constant is for male progeny.

responses were consistent across birth type and confirmed that the effects of poor nutrition up until Day 100 of pregnancy on the birthweight of single and twin lambs could be completely overcome by improving nutrition between Day 100 and lambing. Exhaustive exploration of other combinations of short periods (≥2 weeks WA, ≥4 weeks Vic.) failed to find other periods of change in the liveweight of individual ewes that was related to the birthweight of their lambs.

Factors influencing the survival of lambs

Overall, 75 and 79% of lambs born survived until weaning at the Vic. and WA sites, respectively. Of the lambs that died, 84% (Vic.) and 95% (WA) did so within 48 h of birth. There was no further concentration of deaths between 48 h and weaning. Only the lowest feed on offer treatment from Day 100 in Vic. significantly decreased survival to 48 h (Table 3). However, more twin-born lambs died than single-born lambs ($P < 0.001$) and more male lambs than female lambs ($P < 0.05$) died during the first 48 h in both years (Table 3). None of the interactions between ewe nutritional treatments and progeny gender or birth type were significant (all $P > 0.05$) for lamb survival to 48 h.

The CS of ewes at Day 100 of pregnancy had no effect on the survival of lambs from 48 h after birth to weaning at either site in both years (Table 4). At the Vic. site, feed on offer from Day 100 to weaning decreased the survival of lambs at levels ≤1400 kg DM/ha in 2001 ($P < 0.05$) and 800 kg DM/ha in 2002 ($P < 0.01$). In 2002, survival was greater in single-born lambs ($P < 0.001$). Neither nutritional treatment of the mother nor the sex of the lamb influenced survival at the WA site in either year.

Lamb birthweight and survival

Lambs that died within 48 h of birth at the Vic. sites were significantly ($P < 0.001$) lighter than lambs that survived; the difference was 0.2 kg for single-born lambs (4.8 versus 5.0 kg) and 0.5 kg for twin-born lambs (3.5 versus 4.0 kg). There was no significant difference in birthweight between lambs that died or survived between 48 h and weaning in 2001 (4.3 kg), but in 2002

Table 3. The effect of maternal body condition to Day 100 of pregnancy and level of feed on offer (FOO) from Day 100 to lambing as well as birth type and gender on lamb survival to 48 h (% of lambs born) at the Vic. and WA sites in 2001 and 2002. Progeny were from single ewes at the WA or single- and twin-bearing ewes at the Vic. site that were differentially fed to achieve condition score (CS) 2 or 3 at Day 100 of pregnancy and then grazed a range of FOO (kg DM/ha) levels until weaning

Level of significance; $P < 0.05$ (*), $P < 0.01$ (**) and $P < 0.001$ (***). Different letters within CS and FOO treatments and between birth type and gender comparisons differ at the probability shown. n.s., not significant

Factor	Vic. 2001	Vic. 2002	WA 2001	WA 2002
CS treatment 2	75a	84a	88a	83a
CS treatment 3	74a	87a	88a	85a
Level of significance	n.s.	n.s.	n.s.	n.s.
FOO treatment 800	68a	70a	84a	85a
FOO treatment 1100	76ab	83ab	86a	85a
FOO treatment 1400	74ab	91b	88a	80a
FOO treatment 2000	79b	90b	89a	82a
FOO treatment 3000	74ab	88b	92a	89a
Level of significance	n.s.	**	n.s.	n.s.
Birth type				
Single	85a	92a	–	–
Twin	60b	74b	–	–
Level of significance	***	***	–	–
Sex				
Male	68a	82a	89a	82a
Female	80b	88b	87a	86a
Level of significance	**	*	n.s.	n.s.

Table 4. The effect of maternal body condition to Day 100 of pregnancy and level of feed on offer (FOO) from Day 100 to lambing as well as birth type and gender on lamb survival between 48 h and weaning (% of lambs alive at 48 h after birth) at the Vic. and WA sites in 2001 and 2002. Progeny were from single ewes at the WA or single- and twin-bearing ewes at the Vic. site that were differentially fed to achieve condition score (CS) 2 or 3 at Day 100 of pregnancy and then grazed a range of FOO (kg DM/ha) levels until weaning

Level of significance; $P < 0.05$ (*), $P < 0.01$ (**) and $P < 0.001$ (***). Different letters within CS and FOO treatments and between birth type and gender comparisons differ at the probability shown. n.s., not significant

Factor	Vic. 2001	Vic. 2002	WA 2001	WA 2002
CS treatment 2	98a	90a	91a	92a
CS treatment 3	99a	94a	92a	97a
Level of significance	n.s.	n.s.	n.s.	n.s.
FOO treatment 800	97a	75a	86a	93a
FOO treatment 1100	97a	91b	94a	90a
FOO treatment 1400	97a	96b	97a	94a
FOO treatment 2000	100b	94b	92a	98a
FOO treatment 3000	100b	96b	91a	96a
Level of significance	*	**	n.s.	n.s.
Birth type				
Single	98a	97a	–	–
Twin	99a	84b	–	–
Level of significance	n.s.	***	–	–
Sex				
Male	97a	92a	88a	95a
Female	99a	93a	95a	95a
Level of significance	n.s.	n.s.	n.s.	n.s.

lambs that died after 48 h had significantly lower birthweights than those that survived ($P < 0.05$; 4.1 versus 4.6 kg). At the WA site there was no difference in birthweight between lambs that died or survived to 48 h (5.2 kg) or that died or survived between 48 h and weaning (5.2 kg).

At the Vic. site, birthweight was strongly correlated ($P < 0.001$) with the survival of lambs to 48 h (Table 5; Fig. 1). There was no significant ($P > 0.05$) interaction with year, so data from different years was combined into a single analysis. Lamb survival increased up to a birthweight of 4.5 kg and only declined for single lambs when they weighed more than 6.5 kg at birth. Lamb birth type and gender did not alter the shape of the birthweight versus survival curve ($P > 0.05$), but they did influence absolute survival ($P < 0.05$) at a given birthweight. Single-born lambs were more likely to survive than multiple-born lambs even at the same birthweight ($P < 0.05$). At the same birthweight male lambs also had a lower survival than female lambs during the first 48 h ($P < 0.05$).

Table 5. Regression coefficients (±s.e.) of General Linear Mixed Model analysis that predicts lamb survival to 48 h in terms of lamb birthweight, feed on offer (FOO) at lambing, average daily chill index, and birth type and sex as fixed effects and replicate, plot and sire as random effects. Data represents a combined analysis for 2001 and 2002 at the Vic. site and data was transformed (logit)

All possible models were examined with statistical significance of terms and interactions thereof accepted at $P < 0.05$

Term	Coefficient (±s.e.)
Constant[A]	0.7 ± 1.68
Birthweight (kg)	4.5 ± 0.45
Birthweight squared (kg)	–0.42 ± 0.051
FOO (kg DM/ha)	$1.4 \times 10^{-3} \pm 0.5 \times 10^{-3}$
FOO – squared ($\times 10^{-7}$)	–3.4 ± 1.12
Female	–3.6 ± 1.89
Twin	–0.4 ± 0.17
Chill index (kj/m^2.h)	$-1.1 \times 10^{-2} \pm 0.41 \times 10^{-2}$
Female by chill index[B]	$0.4 \times 10^{-2} \pm 0.18 \times 10^{-2}$

[A]The survival constant is for a single male progeny.
[B]Increased survival of females relative to males with increasing chill index.

At the Vic. site lamb survival also increased ($P < 0.05$) as the feed on offer at lambing increased and the effect was independent of birthweight (Table 5). At the average birthweight of singles and twins, survival increased by 3 and 8%, respectively, when feed on offer increased from 1000 to 2000 kg DM per ha at lambing.

At the WA site there was no significant relationship between lamb birthweight and survival to 48 h; however, only 20 of 314 (9%) and 15 of 375 (4%) of lambs born were less than 4 kg in 2001 and 2002, respectively.

Prediction of lamb survival from the ewe liveweight profile via effects on birthweight

At the Vic. site when the liveweight profile of the ewe was used to predict the birthweight of her lamb (coefficients in Table 2) and then the birthweight of the lamb was used to predict its survival (coefficients in Table 5), survival of lambs with low birthweight increased by up to 0.5% per extra kg of ewe liveweight at joining assuming maintenance of liveweight during pregnancy. Similarly, the models predicted that for a 45-kg ewe at joining the survival of twin lambs increases by up to 1.2% per kg change in liveweight to Day 100 of pregnancy and 1.7% per kg change in liveweight during late pregnancy. The effect was most noticeable for twins where most of the lambs were below 4.5 kg.

Effects of chill index during lambing on survival

At the Vic. site the average daily chill value ranged from 940 to over 1400 with a mean of 1043 kj/m^2.h over the 2 years of lambing (Fig. 2*a*). The average daily temperature in both years was ~8.5°C and wind speed ~10.1 km h^{-1}, and the total rainfall during the lambing period was 130 mm in 2001 and 39 mm in 2002. More than 25% of lambs were born on days with a chill index greater than 1100 kj/m^2.h. By comparison, the climatic conditions during lambing at the WA were less severe. The average daily chill value ranged from 889 to 1139 with a mean of 1000 kj/m^2.h over the 2 years of lambing. The average daily temperature over the 2 years was 11.1°C and wind speed 12.2 km h^{-1}, and the total rainfall during the lambing period was 14 mm in 2001 and 28 mm in 2002. Less than 10% of lambs were born on days with a chill index greater than 1100 kj/m^2.h.

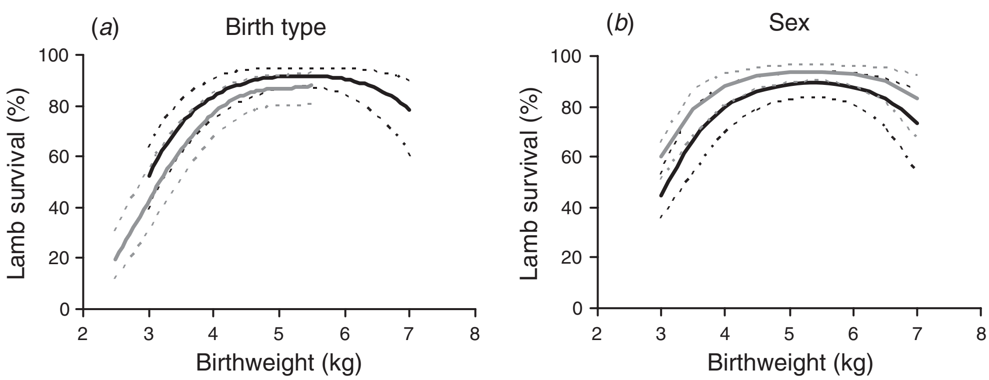

Fig. 1. Effect of lamb birthweight on survival of individual progeny to 48 h at the Vic. site. The data is for progeny born as (*a*) singles (black) or twins (grey) and (*b*) males (black) or females (grey) single-born lambs. The data is combined for 2001 and 2002, based on the average at the average feed on offer and chill index at lambing and the dashed lines represent upper and lower 95% confidence limits.

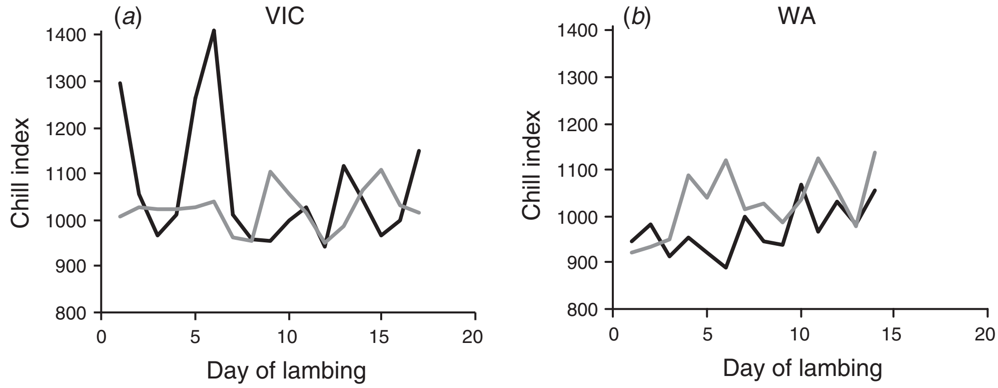

Fig. 2. Estimated chill index (kJ/m^2.h) during lambing at the Vic. (*a*) and WA (*b*) sites during 2001 (black) and 2002 (grey). Chill index was estimated from average temperature, rainfall and wind speed measured daily using the equations reported by Donnelly (1984).

The average chill index accounted for significant variation in lamb survival to 48 h after birth at the Vic. site (Table 5; $P < 0.05$). Chill index did not alter the shape of the birthweight versus survival curve, regardless of lamb birth type but it did significantly influence absolute survival at a given birthweight (Fig. 3*a*; $P < 0.05$). Single- and twin-born lambs were equally susceptible to increasing chill index, but there was a significant chill index by lamb sex interaction (Fig. 3*b*; $P < 0.05$). The survival of male lambs decreased more rapidly with increasing chill index than survival of female lambs. Chill index did not affect lamb survival at the WA site.

Discussion

The liveweight profile of ewes provided an effective tool for predicting survival of their lambs through their effect on birthweight across a range of nutritional scenarios likely to be experienced in commercial flocks. The change in liveweight of ewes in late pregnancy had the largest effect on survival, however their liveweight at joining and liveweight change during the first 100 days of pregnancy were also important (see Table 2). The high repeatability and small errors about the coefficients across sites and years confirms the goodness of fit and predictability of the relationship. Further confirmation of the commercial value of the relationship is provided by the finding that the prediction equations derived from the individual ewes in the present study can also be used to predict the lamb survival of flocks. Behrendt *et al*. (2011) reported survival of both single and twin lambs in a series of paddock-scale experiments conducted on farms across southern Australia. They found a significant relationship between the liveweight of flocks in late pregnancy (Day ~140) and survival of lambs that was similar to the overall effect of liveweight and change in liveweight over pregnancy in the present study. This latter finding builds on the report by Kelly (1992) who found that the mean liveweight of ewes at ~Day 100 of pregnancy in commercial flocks explained ~50% of the variance in lamb survival between flocks. In addition our model used to predict lamb survival was improved by the inclusion of birth type, sex of the lamb, chill index and feed on offer at lambing. The prediction of lamb survival is an important component of the economic impact of the ewe liveweight profile on whole-farm profit (Young *et al*. 2011).

Restricting the level of nutrition to the pregnant ewe reduced lamb birthweight and this effect was dependent on the timing and severity of the restriction and subsequent nutrition. A loss of 10 kg in ewe liveweight between joining and Day 100 of pregnancy reduced lamb birthweight by ~0.3 kg, whereas gaining 10 kg from Day 100 to lambing increased birthweight by ~0.45 kg. The responses were consistent across birth rank, experimental sites and years (Table 2) and were similar to the within- and between-flock relationships reported by Scales *et al*. (1986). The validity of

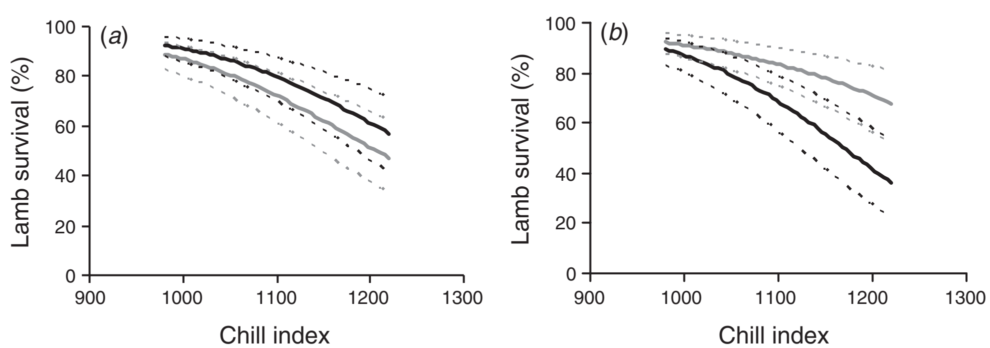

Fig. 3. Effect of average daily chill index (kJ/m^2.h) on lamb survival to 48 h for (*a*) single- (black) or twin (grey)-born lambs and (*b*) male (black) and female (grey) lambs at the Vic. site. The data is combined for 2001 and 2002, is based on the average birthweight for each sex and birth rank and the dashed lines represent upper and lower 95% confidence limits.

the birthweight prediction equations is further strengthened by the findings of Greenwood *et al*. (2010). They reviewed data from 13 studies using a range of breeds and nutritional interventions and reported that on average a 10-kg change in ewe liveweight during the entire pregnancy changed birthweight by ~0.5 kg. Our findings also confirm the findings of Taplin and Everitt (1964) that the effects of poor nutrition up until Day 100 of pregnancy could be completely overcome by improving nutrition during late pregnancy. In addition, there was no evidence in our results that birthweight was consistently related to ewe liveweight change during critical 'windows' of a few weeks during pregnancy, as suggested by Holst *et al*. (1986, 1992).

The birthweight of single (5.1 kg) and twin (3.8 kg) lambs in this study were in the optimum range (3.5–6.0 kg) for survival of Merinos (Atkins 1980; Hinch *et al*. 1985; Fogarty *et al*. 1992). Hence, it was not surprising that the overall survival to 48 h after birth (86% for singles and 65% for twins) was towards the top end of the published data for Merinos (Lax and Turner 1965; Atkins 1980; Fogarty *et al*. 1992). Nonetheless our data showed a typical quadratic relationship, lamb survival increased up to a birthweight of 4.5 kg and only declined for single lambs when they weighed more than 6.5 kg at birth as previously reported by Atkins (1980) and Knight *et al*. (1988). Lamb birthweight was equally sensitive to changes in the liveweight profile of ewes regardless of birth type. However, because twin lambs were ~1.1 kg lighter than single-born lambs, their survival was more sensitive to changes in ewes liveweight especially during late pregnancy. Given these responses, it is not surprising then that scanning ewes for pregnancy status and differentially managing ewes during late pregnancy can improve overall lamb survival and profitability. The benefits of scanning ewes for pregnancy status and litter size were calculated to be $7800 for a typical farm in western Vic. and the optimum management was to feed twin-bearing ewes to gain extra condition from scanning so they were ~0.3 of a CS fatter than single ewes by lambing (J. C. Young, unpubl. data).

Our finding that lambs born as singles weighed more than twins and the survival of singles was greater than that of twins even at the same birthweight is confirmed by Wallace (1948), Knight *et al*. (1988) and Gardner *et al*. (2007). Similarly, the survival of females was greater than males at the same birthweight is confirmed by Lax and Turner (1965), Hight and Jury (1970), Smith (1977), Wiener *et al*. (1983), Knight *et al*. (1988) and Safari *et al*. (2005). At the Vic. site more lambs died in the first 48 h after birth as the average chill index increased (Fig. 3). The effect was similar for both single- and twin-born lambs confirming the observation of Donnelly (1984). However, to our knowledge the differential effect of increasing chill index on the survival of male versus female lambs has not been reported previously. Male lambs are born with finer (less hairy) birth coats than females (Schinckel 1955). In laboratory experiments lambs with hairier birth coats have been reported to be more resistant to hypothermia (Alexander 1962), however this relationship has not been confirmed under paddock conditions (Ponzoni *et al*. 1997) or is at best a small effect (Hatcher *et al*. 2009). A more likely explanation for the difference in sensitivity to cold stress between males and females may be found in the report by Alexander *et al*. (1980) that 'prolonged or difficult births can increase the sensitivity of newborn lambs to cold conditions' as Dwyer (2003) found that males take longer to be born and in some breeds are slower to stand and suckle. In addition, male lambs are more likely to die of dystocia (Scales *et al*. 1986) and twice as likely to be incorrectly presented as females (Dwyer 2003).

Lambs were more likely to survive, regardless of birthweight, when there was more feed on offer for their mothers at the time of lambing (Table 5). For example, at the average birthweight of singles and twins, survival increased by 3 and 8%, respectively, when feed on offer increased from 1000 to 2000 kg DM per ha at lambing. The maximum benefit was achieved at ~2000 kg DM per ha; an amount of feed on offer that has previously been found to maximise growth and wool growth in dry sheep (Thompson *et al*. 1994, 1997; Hyder *et al*. 2002). Lindsay *et al*. (1990) found that survival increased as the time on the birth site increased and the time on the birthsite was increased when ewes were on a higher plane of nutrition during the 6 weeks before lambing and ewes had adequate food and water at the birth site. Hence, while no intensive observations were undertaken of birth in the present study it is tempting to speculate that the effect of feed on offer on lamb survival was acting via effects on maternal behaviour and lamb-ewe bonding linked to the time the ewes remained on the birth site.

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