Lamb Wastage and its Association with Ewe Body Condition

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Abstract of a Dissertation submitted in partial fulfilment of the requirements for the Degree of Bachelor of Agricultural Science with Honours

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The effect of ewe body condition and live weight, and change in these factors, on lamb wastage was examined in a composite (principally Coopworth) flock of small- or large-framed ewes. Approximately equal sized flocks of small- and large-framed ewes, balanced for age and condition were selected from 9 commercial farms, and transported to Lincoln University's Ashley Dene Pastoral Systems Research Farm where they were managed as one mob until pre-lambing in 2002, where the multiple bearing ewes remained for the following year's trial (2003). Small-framed ewes in 2002 (n = 310) had significantly (P < 0.001) lower LW and GR (LW = 61.6 ± 0.73 kg; GR = 8.23 ± 0.26) compared with large-framed (n = 296) ewes (LW = 71.2 ± 0.75 kg; GR = 8.74 ± 0.26). Small-framed ewes in 2003 (n = 323) also had significantly lower (P < 0.001) average mating LW (52.4 ± 0.62 kg) compared with large-framed ewes (60.8 ± 0.63 kg). Crayon-harnessed Coopworth rams (n = 14) were introduced to all ewes on 11 April 2002 (n = 614) and 9 April 2003 (n = 643) and crayon-marked ewes were drafted once weekly for the first three weeks for determination of ovulation rate (0, 1, 2, 3, and 4) by laparoscopy. Pregnancy rates (0, 1, 2 or more fetuses) were recorded by use of transabdominal ultrasonic scanning on 4 July (2002) and 22 July (2003). Non-pregnant ewes and ewes with 1 fetus were sent back to original owners. Ewes were fully recorded at lambing. There was significantly (P < 0.001) higher embryonic mortality up to scanning (23 & 19%, in 2002 & 2003 respectively) compared with losses from scanning to lambing (1 & 3%, in 2002 & 2003 respectively). There were highly significant (P < 0.001) differences between GR and LW of ewes at mating in 2002 (GR = 8.48 ± 0.22; LW = 66.29 ± 0.60 kg) compared with 2003 (GR = 4.81 ± 0.21; LW = 56.56 ± 0.59 kg) that were attributable to climatic effects. As a result ewes in 2002 had a significantly higher OR (1.89 *vs* 1.74), scanning (165 *vs* 155%), and lambing percentage (207 *vs* 150%), than in 2003, respectively. There was a significant (P < 0.001) positive linear correlation between mating live weight and OR up to 3 CL in 2002 and up to 4 CL in 2003. Exclusion of non-pregnant ewes from the scanning data resulted in a positive relationship between number of lambs scanned and LW and GR. In 2002 ewes with embryo losses had a significantly (P < 0.05) lower reduction in GR (2.52 ± 0.35) compared with ewes that maintained their pregnancy (3.05 ± 0.19); however there was no effect of change in GR in 2003. Change in LW had a larger effect on embryo wastage than static weight did. It was concluded that ewes have higher embryonic losses up to scanning compared with after scanning, and that change in ewe body condition and LW have a greater effect on these embryo losses compared with static ewe body condition and live weight at mating.

Keywords: Lamb wastage, body condition, live weight, ewe, embryo survival, ovulation rate, reproduction, nutrition

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Abbreviations

BCS	body condition score
OR	ovulation rate
LW	live weight
CL	corpus luteum
CIDR	controlled internal drug release

Chapter 1

Introduction

Embryo wastage is a major constraint in the livestock industry through decreasing economic and production efficiency. Reproductive output for sheep is affected by ovulation rate and embryonic survival, both of which are associated with genotype and nutrition (Vinoles *et al.,* 2012). Many improvements have been made in recent years to increase ewe reproduction performance; however there is still an estimated loss of 20 to 30% of all fertilized sheep ova up to Day 30 of gestation (Edey, 1969), with few losses past this point (Gunn, Doney and Russel, 1972; Mattner & Braden, 1967; Smith & Knight, 1998; Quinlivan, Martin, Taylor & Cairney, 1966; Vinoles *et al.* 2012). Despite many studies concluding similar embryo losses, all embryonic mortalities are only estimations of the true losses, because there is no direct method of measuring fertilised eggs in live animals, and therefore no way of knowing exactly how many of these have perished. Some studies, including the current, have used observation of the number of corpora lutea to estimate embryonic losses; however this does not count failed luteal development, therefore losses of pre-implanted embryos are still largely unknown (Smith & Knight, 1998). Other studies have used estimated embryo survival through slaughtering ewes at various times post-mating and calculating total embryos present (Quinlivan *et al*., 1966); although this technique uses flock averages (Edey, 1969) and therefore is not a direct method either.

In multiple-ovulating ruminants, ovulation rate has been inversely related with embryo survival (Cumming, 1972; Hanrahan, 1994, as cited in Diskin & Morris, 2008, p. 262; Hanrahan 1980 & 2003; O'Connell et al., 2015; Shorten et al., 2013; Quinlivan et al., 1966). Lamb wastage is as a result of either failure of the embryo to survive or as a result of the maternal system unable to sustain the pregnancy (Edey, 1969; Shorten et al., 2013); however the precise cause of most losses during pregnancy is largely unknown. There is some evidence that embryo migration, to allow for enhanced spacing between multiple embryos, contributes towards embryo mortalities (Scaramuzzi & Downing, 1997), although some literature contradicts this theory (Shorten et al., 2013). Many studies have also found an effect of nutrition on embryo survival (Coop, 1962 & 1966; Cumming, 1972; Cumming *et al.,* 1975; Edey, 1969; Gunn *et al.,* 1972; Parr *et al.,* 1987; Rutherford, Nicola & Logan, 2003; Shorten *et al.,* 2013). It is well recognised that flushing, increasing ewe nutrition for a short period prior to mating, results in increased ewe body condition and increased ovulation rate (OR), and thus, the number of lambs born (Coop, 1966). However it is less clear what impact ewe body condition and live weight, and the changes in either post mating have on either OR or embryo survival.

Research over the previous decades has established embryo deaths are significant (20 - 30%) in early gestation (first 30 Days), which may be affected by ewe body condition and live weight, and change in either post mating; creating a large opportunity cost for sheep farming. The objective of the current study is to examine the association between ewe body condition and LW at mating, along with change in body condition and LW on lamb wastage, in particular embryo losses from mating to scanning.

Chapter 2

Literature Review

2.1 Live weight and body condition score

It has been found that many farmers rarely weigh their ewes to manage nutrition, as it is seen to be of 'little value, time consuming and/or expensive' (Van Burgel *et al*., 2011). LW requires adjustment for many factors including body composition, fleece weight, mature size, physiological state (e.g. pregnancy), feed quality/type and, most importantly, time off grazing prior to weighing, which affects gut fill (Kenyon *et al.,* 2014). Due to these issues, along with often expensive technology required for weighing, a simple, quick and cost-effective method for evaluating nutritional status of a ewe was created, body condition scoring as described by Jefferies (1961). Body condition is assessed through manual palpation of the lumbar region, on and around the backbone directly behind the last rib, to observe the sharpness or plumpness. Strong, positive relationships have been found between BCS and LW (Kenyon *et al.,* 2014).

Overall BCS is thought to be a better indicator of body reserves than LW; therefore ewe body condition has been the focus in this review.

2.2 Successful pregnancy

To completely understand embryo wastage and issues caused during pregnancy, first there must be an understanding of the normal, successful pregnancy process. Peri-implantation is a crucial stage for pregnancy success, as this period is when the highest wastage occurs, through either inadequate uterine environments, incompetent corpora lutea (CLs), insufficiency of embryo to survive, signal pregnancy and/or inability to undertake attachment and placentation (Bazer *et al.,* 2012; Spencer *et al.,* 2004).

The general view is that ewes produce CLs in association with oestrus, which occurs around every 17 days. To begin a new pregnancy, first any CLs that are present must undergo luteolysis (death of the CLs) to commence a new oestrous cycle. Luteolysis produces a decrease in circulating levels of progesterone, thus removing the major negative feedback signal, and this leads to an increase in pulse frequency of gonadotrophin releasing hormone (GnRH) and, ultimately, of follicle stimulating hormone (FSH) and luteinizing hormone (LH). This change in secretion of FSH and LH stimulates development of ovarian follicles which produce an increase in pre-ovulatory oestradiol levels, causing a change in ewe behaviour that enables mating to occur. The elevation of oestradiol production also leads to the pre-ovulatory surge of GnRH which causes a corresponding surge of FSH and LH around the period of oestrus, and eventually leads to ovulation of mature follicles.

After successful mating, fertilisation occurs through the fusion of the spermatozoan pronucleus and that of the oocyte to form single-celled 'zygote' embryo (Senger, 2004). The embryos undergo a number of mitotic divisions (cleavage divisions) which generates a multi-celled embryo called a morula (Senger, 2004). Up to this stage, any one of the individual cells of an embryo (called blastomeres) contained in the morula has the potential to develop into separate offspring, e.g. identical twins can be produced from the division of a two-celled embryo (Senger, 2004). The morula moves into the uterus (day 4 to 5) and then forms into a blastocyst by day 6 to 8 (Senger, 2004; Spencer *et al.,* 2004). At Day 7-8 the blastocyst sheds its zona pellucida, which surrounds the oocyte plasma membrane, and becomes a free-floating embryo (now called a hatched blastocyst) which is entirely dependent on the uterine environment for survival (Senger, 2004; Spencer *et al.,* 2004).

To maintain a successful pregnancy, the blastocyst produces interferon-tau (IFN-τ), the 'maternal pregnancy recognition' signal which seems to be essential for maintaining high levels of progesterone and inhibiting luteolysis   This signal is present from around Day 13-21 after ovulation (Senger, 2004; Spencer *et al.,* 2004). From Day 11-16 of pregnancy the blastocyst elongates to a filamentous form, which is comprised of an inner cell mass surrounded by the filamentous trophoblast. This adheres to the endometrial luminal epithelium (LE) at day 16 (Spencer *et al.,* 2004), about which time binucleate cells differentiate in the trophoblast, followed by their migration and fusion with the endometrial LE to form syncytia (Spencer *et al.,* 2004).

Implantation of blastocysts into the uterine epithelium has evolved, in association with viviparity, to allow for continual efficient nourishment and protection of the fetus during pregnancy. To ensure successful embryo implantation, four key stages must be undertaken: (1) embryonic development within the confines of the zona pellucida; (2) blastocyst hatchment from the zona pellucida; (3) maternal recognition of pregnancy; and (4) development of extra-embryonic membranes (Senger, 2004). Signalling must occur between the developing conceptus (embryo/fetus and accompanying placental membranes) and maternal uterus during peri-implantation to enable recognition of pregnancy, implantation, control of gene expression by uterine epithelial and stromal cells, placentation and transfer of nutrients and gases (Bazer *et al.,* 2012).

Progesterone is vital to sustain pregnancy for uterine functions which support implantation and placentation. Elevated circulating progesterone concentrations during the early luteal phase, around Day 12 post insemination, have been used as a means of determining pregnancy of ewes. Production of progesterone over this period is a key determinant of pregnancy success due to its impact on secretory activity of the reproductive tract, where it influences embryonic growth and secretion of IFN-τ (Vinoles *et al*., 2012).

If implantation or any other steps in the early pregnancy process are not successful this results in the death of the CL, and reduction in circulating progesterone concentrations, along with consequent pregnancy failure.

2.3 Optimal ewe mating LW to maintain pregnancy

It is well recognised that ewes must be a certain pre-mating weight to maximise ovulation, conceive and then continue to maintain that pregnancy. It has also been well documented that this increased nutrition prior to mating leads to increased ovulation and number of lambs born (Coop, 1966). However the weight a ewe is required to be at mating to optimise ovulation and pregnancy maintenance is less well known.

Shorten *et al.* (2013) found a highly significant positive linear relationship between pre-mating ewe LW with mean ovulation rate and litter size. However litter size was significantly reduced in ewes weighing 85-95 kg compared with 75-85 kg, suggesting a maximum ewe LW limit for optimum reproduction (Shorten *et al.,* 2013). Rutherford *et al.* (2003) suggested the optimum weight for joining was around 67.5 kg, with significantly lower ovulation rates in small- (1.72) compared with large-framed ewes (1.92); large-framed ewes were on average 10 kg heavier (Table 1). It was stated that the difference in OR was predominantly due to the significantly higher proportions of single CL in small- (0.28) compared with large-framed ewes (0.17) (Rutherford *et al.,* 2003).

Table 1: Predicted ovulation rate and number of lambs born for a range of ewe joining live weights (kg). (Source: Rutherford, Nicol & Logan, 2003)

Average joining LW (kg)	**Ovulation rate at 50**	**Ovulation rate at 60 kg**	**Ovulation rate at 70**	**Lambs born at 50**	**Lambs born at 60 kg**	**Lambs born at 70**	**Source**
71.3	1.91	1.92	1.92	1.78	1.76	1.73	Large ewes, this study
66.4	1.66	1.77	1.89	1.54	1.62	1.71	All ewes, this study
61.5	1.54	1.76	1.98	1.44	1.63	1.82	Small ewes, this study
				0.93	1.18	1.43	Coop, 1962

Despite Rutherford *et al.* (2003) finding differences in OR due to ewe size, no significant difference in total ewes displaying oestrus due to ewe size (0.81 for small- and 0.87 for large-framed ewes) was found. However mean date of first obvious oestrus was three days early ($P < 0.05$) for large- compared with small-framed ewes.

Interestingly Shorten *et al.* (2013) suggest that ovulation rate is more influenced by static weight than changes in weight; therefore indicating that current nutrition level is less important compared with body reserves. In partial agreement Coop (1962; 1966) concluded live weight alone is a crucial factor influencing reproduction twinning performance; Coop (1962) found twinning increase by on average 6% for each 4.5kg. However it was indicated that change in live weight also has major impacts on reproduction, particularly flushing, although only in poor conditioned ewes (Coop, 1966).

It has been established that ewe weight can influence OR, although maintenance of pregnancy may also require ewes to maintain a certain condition, which may differ from initial weight for conception to take place. Shorten *et al.* (2013) indicated optimum weight to maintain pregnancy was 65kg, either higher or lower weights resulting in significantly reduced probabilities of maintaining pregnancy. In contrast Cumming (1972) cited research indicating ewe weight around mating did not appear to significantly influence embryo survival. Coop (1962), in partial agreement, found an average of 6% barren ewes independent of ewe LW, though only if ewes were above 40.5-45.5kg, below these weights percentage of ewes barren increases dramatically. Coop (1962) study only reviewed number of dry ewes as a percentage of ewes mated, therefore it is unclear whether these barren ewes did not conceive or lost foetuses. To maximise embryo survival, Shorten *et al.* (2013) found optimal ewe premating weight increased with OR which they suggested was due to increased body reserves required to maintain a larger number of embryos or the duration of gestation.

It appears ewe live weight at joining is only crucial for OR and pregnancy preservation if ewes are below a certain threshold weight or are giving birth to multiple offspring. This threshold weight will likely differ between breeds and frame size of ewe. Pre-mating weight, as stated above, also has a large influence on OR, however more information is required to quantify the effect of mating weight on maintaining pregnancy.

2.4 Nutrition

Nutrition is a vital component of all living beings; therefore it is a crucial factor in agricultural operations to ensure maximum production and profitability. It has been well established that nutrition prior to mating (flushing) has a positive correlation with OR and lambing percentage (Coop, 1966). However there is less information regarding nutrition during and immediately post mating and its impact on embryonic losses.

Gunn *et al*. (1972) reported higher embryonic mortality in ewes with a low BCS, of 1.5, compared with those with a high BCS of 3.0 at mating (50% *vs* 15%, respectively). Embryo survival was recorded through randomly selecting alternate ewes, half from each feeding and BCS group, which were slaughtered 26 ± 2 days post mating, and corpus lutea and embryos were counted and checked for viability. The remainder ewes were allowed to lamb, enabling average lambs born to be estimated from average number of viable embryos present in the slaughtered group; allowing average embryo loss to be calculated. While there was no significant difference in embryonic mortality between high and low plane post-mating nutrition, there was a significant interaction between BCS and post-mating nutrition on the embryonic mortality rate; high plane nutrition showing a greater difference between low and high BCS (63 *vs* 12%), compared with low plane diets (36 *vs* 17%). Post-mating nutrition did not seem to have an effect on embryo survival past Day 26 ± 2.

In contrast Parr *et al.* (1987) recorded lower pregnancy percentages (48%) in ewes fed at 200% of maintenance requirement during mating, compared with ewes fed at 25% or 100% of maintenance (67% and 68%, respectively). Reduced pregnancy rates, shown in ewes fed at the high level, were able to be corrected with progesterone supplementation (CIDR at 8-14 days post mating) as shown in Table 2.

Table 2: Level of Nutrition and CIDR (Days 8 - 14 post mating) on percentage of ewes pregnant and foetuses per pregnant ewe. (Source: Parr *et al.*, 1987).

Level of Nutrition	**Ewes pregnant (%)**		**Fetuses/ewe (%)**	
	Control	**CIDR**	**Control**	**CIDR**
High	48	76	132	132
Medium	68	65	135	150
Low	67	60	129	148

Cumming *et al.* (1975) showed reduced embryo survival with both severe sub-maintenance and above maintenance nutrition fed from Days 2-16 post mating. Merino and Merino-cross ewes fed at 25%, 100% and 200% of maintenance diets resulted in 1.12, 1.19 and 1.04 embryo survival, respectively, with the maintenance diet being significantly higher compared with ewes fed on the 200% diet. Differences in embryo survival were reasoned to be due to breed variation, with Merino ewes only maintaining 0.93 embryos on the 200% of maintenance diet, decreasing the treatment average. Likewise Cumming (1972) found embryo survival and returns to service were significantly influenced by nutrition prior to mating in Border Leicester x Merino ewes. Ewes that lost weight around the time of mating, signifying embryonic death up to, and including Day 18 of pregnancy, showed lower embryo survival and higher return to service. Reductions in two year-old ewe lambing percentages resulted from severe under-nutrition in the first 90 days of pregnancy, compared with mature ewes which were not affected by the same treatment, were noted by Edey (1969). Starved two-tooth ewes lost an average of 24% of their body weight during the reduced nutrition phase, while control ewes gained 15%; lambing percentages were 18.8% and 65.6%, respectively.

The reviews by Edey (1969) concluded that a high level of feeding and supplementation, along with increased body weight, results in increased OR and greater embryo mortality; indicating there may be an association between these two factors. Increased embryo mortalities with severe sub- and exceptionally above-maintenance diets in early pregnancy (up to 2 weeks post mating) has been associated with increased progesterone clearance rate, resulting in lower circulating concentrations of progesterone and increased embryonic losses (Cumming *et al.*, 1975; Diskin & Morris, 2008; Parr, 1992; Parr *et al.,* 1987; Vinoles *et al*., 2012), described below.

Gunn *et al.* (1972) concluded that high embryo mortalities, resulting from high post-mating nutrition, were influenced by variation in distribution of ova shed singly and in multiples. Multiple shed ova had a mortality rate of 43% compared with 18% for single shed ova; which was noticeably affected by high post-mating nutrition (53% vs 19%) compared with low-plane diets (33% *vs* 17%). However caution is required with these results due to differences associated with ewe BCS. A large proportion of the single ova were produced from ewes in BCS 1.5, compared with multiples from ewes in higher BCS, which may have confounded the results.

Mechanisms causing increased embryo losses with increased nutrition post-mating are, as yet, not well understood. However it has been suggested that increased embryo losses may be due to raised clearance rates of plasma progesterone through the liver, this being the primary site for progesterone catabolism (Parr, 1992), with up to 96% of progesterone cleared from the blood after one passage through the liver as a consequence of high metabolic activity resulting from high planes of nutrition. Understanding the association between nutrition, quantity and timing of feed changes, is crucial to ensure ovulation rate is reflected by number of lambs born.

2.5 Embryonic losses and progesterone

Progesterone is crucial for successful implantation of fertilised ova and embryo survival. It is produced by the corpus luteum (CL) and is the key chemical component for maintaining pregnancy. Formation of the CL occurs during every oestrus cycle, which occurs every 17 days for ewes. If a ewe does not become pregnant the CL regresses within 10 days of oestrus, however if mating takes place during the oestrous cycle, the CL continues to produce progesterone past Day 10 maintaining the pregnancy.

Associations between low embryonic survival and conception rates have been established with circulating concentrations of progesterone during the cycle directly before insemination, as well as during early stages of the luteal phase following insemination (Diskin & Morris, 2008). Circulating peripheral progesterone levels have been found to be inversely correlated with embryo survival. Parr *et al.* (1987) established that a concentration of 2-5 ng progesterone/ml plasma is required for successful conception, and 4-5 ng ml^{-1}, on Day 12, appeared to be the optimal concentration for maximum pregnancy rates (80%). Above this concentration embryo mortalities increased; stated to be likely associated with under-nutrition (Parr *et al.*, 1987). Low concentrations of progesterone during the oestrous cycle, below 2 ng ml^{-1}, have also been associated with deceased fertilisation rate and/or poor embryonic survival (Parr *et al.,* 1987). Diskin and Morris (2008) found that an under-supply of progesterone may result in delayed growth and development of embryos, through control of uterine secretion of proteins and growth factors essential for embryonic development; therefore increasing the risk of embryo mortality.

Nutrition has been associated with circulating progesterone levels, and therefore embryonic survival. Parr *et al.* (1987) showed that peripheral progesterone concentrations are inversely correlated with the level of nutrition. Ewes on a high plane of nutrition recorded significantly lower peripheral progesterone concentration (50%) compared with ewes on a low plane of nutrition on Day 12 post mating. Deficiencies were able to be corrected with use of intravaginal progesterone-releasing devices (CIDRs) inserted for 8-14 days post mating (Table 2). Similar results were reported in cattle by Diskin and Morris (2008), who found that low peripheral progesterone concentrations, and subsequent increased embryo mortalities, were associated with an increased plane of nutrition. This has been linked to increased metabolic clearance rates (MCR) of progesterone from passage of blood through the liver, the primary site for progesterone catabolism (Parr, 1992; Diskin & Morris, 2008).

Parr (1992) found that ewes were highly sensitive to changes in peripheral progesterone levels over a 48-hour period on Days 11 and 12 when injected with 50 mg of an enzyme inhibitor (Epostance), to stimulate reduction of peripheral plasma progesterone levels. When ewes were injected with 250 mg Epostance per day on Days 9, 10 and 11 post-mating, progesterone concentration was severely reduced and all embryos died.

A review by Smith and Knight (1998) supported the findings of Parr *et al*. (1987) who found that progesterone supplementation, by use of CIDRs or progestogen-sponges from Day 5-10 post mating increased pregnancy rates (by 15-28%) and increased multiple births (by 20-26%). However a review by Edey (1969) indicated conflicting results, with injection of progesterone during pregnancy having either negative, positive or no effect depending on dose rate and timing of injection. Smith and Knight (1998) suggested that because of the large variability associated with this practice, it is not recommended to use this method to reduce prenatal losses. More research is required to clarify these findings.

In contrast, Vinoles *et al.* (2012) found little association between embryo losses and progesterone concentration when looking at different lupin grain feeding regimes. Two justifications have been given for this inconsistent result: (1) substantially higher nutritional variations were used in the study conducted by Parr (1992) i.e. 25% and 200%, compared with ewes fed at maintenance; or (2) blood samples were taken after 12 hours of fasting in the Parr (1992) study. Inverse relationships between progesterone concentration and concentrations of progesterone receptors have been indicated. Vinoles *et al.* (2012) suggested that nutritionally induced change in progesterone are only temporary;

concentrations were able to recover within 13 hours after feeding a diet which provides 200% of maintenance, signifying any decrease resulting from a high clearance of progesterone is short-term and may not have a negative effect on uterine environment as first thought. Therefore it was proposed that circulating concentrations of progesterone may not be the best indicator of the effectiveness of progesterone. It was also concluded that progesterone concentration, above 2.3 ng ml^{-1}, was not an accurate measure of pregnancy in this trial, compared with > 0.1 ng mL^{-1} used as the 'gold standard'. It was suggested more research is required to design an improved early pregnancy diagnostic test.

2.6 Body condition score, oestrus and return to service

Studies conducted by Gunn *et al.* (1972) showed there was a substantial difference in the occurrence of oestrus between ewes at BCS 3.0 and 1.5 at mating, with 75% and 44% of ewes mated in the first 7 days, respectively. Gunn and Doney (1975) studied the effects of change in BCS over five weeks before mating on synchronised oestrus and conception rates. Results are shown in Table 3 below; groups were separated by BCS five weeks prior to mating (*x*/) and at mating (/*x*).

Table 3: Number of ewes showing oestrus at expected time and either held to first service or returned to service, and the number of ewes which either showed delayed oestrus or had not exhibited overt oestrus by Day 19 post expected time. (Source: Gunn & Doney, 1975)

Group	Oestrus at expected time		Oestrus delayed by 7-19 days	No oestrus by day 19 after expected time
	Held to service	Returned to service		
3/3	27	2	0	0
3/2.5	19	7	0	0
2/2.5	21	1	0	0
2/1.5	10	8	5	2
1/1.5	5	9	7	9

Results show ewes with a higher BCS at mating have a higher conception rate (hold to first service). At moderate to high BCS (2.5 and 3.0), ewes gaining condition had a higher conception rate compared with ewes losing condition. In contrast ewes with an initially low BCS and increasing (1/1.5) had lower conception rates and higher proportion of delayed or no oestrus compared with ewes which were in initially higher BCS and reducing condition, showing ewes still required to be in a certain condition to conceive and retain pregnancy. Contraception rates in ewes in BCS 1.5 were low, with a high number of ewes returning to service (30%), having either delayed oestrus (23%), or not displaying oestrus at all (30%). Likewise Gunn *et al.* (1972) also showed low BCS ewes (1.5) had significantly lower rates of holding to first service; 63% compared with 94% in ewes with BCS 3.0. It is not clear in these studies whether a return to service is due to loss of embryos, absorption of foetuses prior to Day 13, or due to non-conception. Likewise, Cumming (1972) found sub maintenance feeding resulted in a significantly greater proportion of ewes returning to service after, and including day 18; this is indicative of early embryonic death. However, further experiments are required to define the period in early pregnancy at which the developing embryo is most severely affected as a result of poor nutrition.

Returns to service rates could also be affected by the number of times a ewe is served. Mattner and Braden (1967) found 62.3%, 73.7% and 91.7% of Merino ewes served once, twice or three times or more, respectively, were deemed pregnant; therefore with increased number of services ewes are more likely to become pregnant. Although currently available data regarding nutrition, BCS, onset of oestrus and return to service rate are limited and in some cases contradictory, there seems to be a general effect of BCS on conception, with higher BCS ewes at mating holding to first service better and with oestrus occurring at the expected time post synchronization. There is a positive correlation between well-conditioned ewes which were gaining or maintaining body condition at mating, (BCS 3.0 and 2/2.5), with high rates of ewes holding to first service. However similar effects were not observed for low conditioned ewes increasing BCS (1/1.5), with high rates of return to service (30%), delayed oestrus (23%) and no oestrus displayed 19 days after expected time (30%). All ewes which experienced a reduction in BCS by 0.5 in the 5 weeks prior to mating resulted in a negative effect on return to service and oestrus. With these results, however, it is difficult to isolate the reason for returns to service, which may be due to non-fertilization or from loss of embryos. Contrary to the positive effect of high body condition on apparent conception rates, the evidence discussed above suggests that increased levels of nutrition around mating may result in lower levels of progesterone in the peripheral circulation, leading to a decrease in embryo survival (Diskin & Morris, 2008; Parr, 1992; Parr *et al.,* 1987). At present there are no data sets available to assess these differences and their association with ewe body condition status.

2.7 Body condition score and ovulation rate

Ovulation rate is a key performance indicator of an animal's potential fecundity and has been associated with BCS in ewes. Increased OR leads to greater probability of producing multiple offspring, increasing production output, efficiency and therefore profitability.

Positive relationships between BCS and OR have been reported for the majority of studies reviewed (Table 4). Rhind *et al.* (1984a) concluded that 'very fat' ewes, average BCS at mating of 3.35, compared with 'moderate fat' ewes (2.74) had a higher mean OR (3.36 *vs* 2.33, respectively). In agreement Gunn *et al.* (1972) concluded ewes with higher BCS (3.0 *vs* 1.5) had significantly higher OR (1.83 *vs* 1.07). Rhind *et al.* (1984b) also found a higher OR (1.8 *vs* 1.1) in well-conditioned ewes (BCS 2.75 - 3.0) compared with low BCS ewes (1.5 - 1.75), respectively. In contrast, Vinoles *et al.* (2012) found no effect of feeding supplementary lupin grain on ovulation, conception or pregnancy rates in

Australian Merino ewes. Differences found by Vinoles *et al.* (2012) may be explained by: (1) nutritional background, ewes were provided 60% of maintenance requirements in this study compared with severe sub- and above-maintenance nutrition in other studies; (2) differences in breed; or (3) mating commencing in spring, outside the 'normal' breeding season, in this study.

Table 4: Summary of studies showing relationship of BCS and nutritional treatment on ovulation rate. (Based on Kenyon *et al.* 2014)

Reference	Timing of tested & BCS	Nutritional treatment(s) during experimental period	Breed	BCS & OR
Gunn *et al.* (1972)	Breeding, 1.5-3.5	Fed to maintain BCS	Scottish Blackface	+
Gunn & Doney (1975)	Breeding, 1.0-3.0	Low, maintenance, high	Scottish Blackface	+
Rhind *et al.* (1984a)	Pre-breeding, 2.5-3.0 & 3.25-3.75	Fed to maintain BCS	Scottish Blackface	+
Rhind *et al.* (1984b)	Breeding, 1.8 & 2.8	Fed to maintain BCS	Scottish Blackface	+
Kleemann & Walker (2005)	Breeding	Commercial conditions	Merino	+
Vinoles *et al.* (2012)	Breeding, 2.9	Pasture, Pasture + lupin grain Day-7 to -2 pre mating, lupin grain Day-7 to -2 pre mating & Day 1 to 15	Merino	-
Cumming *et al.* (1975)		25%, 100%, 200% maintenance	Merino & Merino x Border Leicester	+

Despite Rhind *et al.* (1984a) concluding ewes in high body condition (3.0 <) had significantly higher OR, these ewes were also found to have reduced potential number of lambs per ewe (1.10 *vs* 1.42), along with a higher proportion of ova lost (0.41 *vs* 0.23) compared with moderate BCS ewes. Higher rates of reproductive wastage were recorded in this study, particularly in ewes with BCS above 3, compared with other studies reviewed in Edey (1969); it was suggested that this could possibly be due to ewes in the study being treated with prostaglandin prior to mating, impacting on lamb wastage. Gunn and Doney (1975) also found ewes with higher condition scores had higher total ovulations, along with increased number of multiple ovulations; 73.33% (66.67% with 2 ovulations), compared with 13.33% in poor conditioned ewes (Table 5). In agreement Rhind *et al.* (1984b) also found higher multiple ovulations and higher embryo survival rates (0.89 *vs* 0.80) in good conditioned ewes compared with under nourished ewes. Cumming *et al.* (1975) showed that ewes which had two corpora lutea had higher mean LW and BCS, compared with those that had only displayed one CL.

Gunn and Doney (1975) concluded single shed-ova were not affected by level of pre-mating nutrition, however were significantly affected by change in BCS; increased mortalities were associated with reducing body condition. In contrast, multiple shed-ova were not affected by BCS; however ova deaths were significantly increased in ewes with BCS 2.5 after low feed intake. Likewise Cumming (1972) found delayed ovulations and unmated ewes only occurred in ewes with BCS below

2.0 (Table 5). Ewes which had an increase in BCS from 2 to 2.5 had a higher mean OR compared with those that decreased BCS from 3 to 2.5 (1.64 *vs* 1.58, respectively) (Gunn & Doney, 1975). Similarly Vinoles *et al.* (2012) found ewes which maintained body condition from Day -17 to Day 5 (pre- and post-insemination) tended to have higher OR (1.28 *vs* 1.21) compared with ewes which lost condition.

Table 5: Number of ewes with 0-3 ovulations displayed at expected time post first mating, delayed after mating 7-19 days and unmated ewes post Day 19 after first mating. (Source: Gunn & Doney, 1975).

Time of mating	**Ovulations at expected time**					**Delayed ovulation 7-19 days**		**Unmated at 19 days**	
Group	3/3	3/2.5	2/2.5	2/1.5	1.5/1	2/1.5	1/1.5	2/1.5	1/1.5
No. of ovulations									
0	0	0	0	0	0	0	0	1	6
1	4	12	8	15	14	5	7	1	3
2	23	13	14	3	0	0	0	0	0
3	2	1	0	0	0	0	0	0	0
Total no. of ovulations	56	41	36	21	14	5	7	1	3
Total no. of ewes	29	26	22	18	14	5	7	2	9
Mean ovulation rate	1.93	1.58	1.64	1.17	1.00	1.00	1.00	0.50	0.33

It is evident that ewes in moderate to high body condition, along with those increasing BCS at time the time of mating, will have higher ovulation rates, at the expected times, and increased incidence of multiple ovulations compared with those that are in poor condition. Ovulation rate does, however, decrease if body condition is lost, even in those which are in initially high condition; therefore best practices is to maintain or increase nutrition prior to and during mating.

2.8 Effect of ovulation rate on embryo survival

It has been well established that ewes in higher body condition often have higher number of CL (Cumming *et al.,* 1975; Gunn & Doney, 1975; Rhind *et al.,* 1984b); however these ewes may also exhibit higher embryonic mortalities. As noted above, Rhind *et al.* (1984a) proposed that despite significantly higher OR in ewes in better condition, these ewes also had lower potential number of lambs and increased ova lost. It is important to understand the interaction between ewe condition, OR and number of lambs born to optimise production.

The probability of embryo survival has been negatively correlated with increased OR (Diskin & Morris, 2008; Hanrahan 1980 & 2003; Shorten *et al.,* 2013); Table 6. Likewise, Cumming (1972) and Quinlivan *et al.* (1966) also found higher embryonic losses in ewes that produced 2 CL compared with 1 CL. Furthermore Cumming (1972) established that as nutritional deprivation continued, the number of ewe with no viable embryos increased. In contrast Gunn *et al.* (1972) found significantly higher ova mortalities in single- compare with multiple-ovulating ewes (43% *vs* 18%). Interestingly more ova perished in ewes which were receiving high (53% *vs* 18%) compared with low post-mating nutrition (33% *vs* 17%) in single- and multiple-shed ova, respectively. Gunn *et al.* (1972) advised that the high loss of single-shed ova was mainly due to most of these being from poor conditioned ewes (1.5) compared with high multiple-shed ova from ewes in BCS 3.0. Likewise Gunn and Doney (1975), regardless of pre-mating nutritional intake or BCS, found mean mortalities of single- and multiple-shed ova were 42% and 40%, respectively. However it was indicated that these losses were much higher compared with other literature reviewed, possibly due to ewes having been housed in individual pens, leading to increased stress and higher ova deaths (Gunn & Doney, 1975). Cumming (1972) found similar results with response to pre-mating nutrition and losses of single- and multiple-ova.

Table 6: Probability of embryo survival as a function of ovulation rate in naturally mated ewes. (Source: Hanrahan, 1994, as cited in Diskin and Morris, 2008, p. 262; Hanrahan, 1980).

No. of corpus luteum	**Probability of embryo survival**		**No. of ewes involved in trial**	
	Hanrahan (1994)	Hanrahan (1980)	Diskin & Morris (2008)	Hanrahan (1980)
1	0.88	N/A	N/A	N/A
2	0.82	0.84	5069	2642
3	0.74	0.75	884	345
4	0.65	0.66	270	75
5	0.55	0.65	91	19
6	0.45	0.47	38	10
7	N/A	0.34	N/A	14

Hanrahan (1994) as cited in Diskin and Morris (2008, p. 262), concluded this negative relationship was primarily due to the number of embryos entering the uterus, rather than problems associated with embryo quality, timing of ovulation or the uterine environment. Shorten *et al.* (2013) indicated a maximum expected litter occurs at an OR of 4, with diminishing expected number of lambs past this point; largely identified to be due to uterine capacity, either competition between embryos or reduced oocyte viability.

Despite the decrease in probability of reduced embryo survival with an increase in number of CL, there is still an increase in overall number of lambs born (Table 6); therefore it is beneficial to have more corpora lutea. No evidence was found to indicate that the relationships between ovulation rate and embryo survival are physiological or genetically heritable; therefore external factors, such as management and environmental factors should be studied as potentially having direct impacts on embryo survival (Diskin & Morris, 2008).

There is contradicting literature regarding the probability of embryo survival compared with the number of corpora lutea between one and two CL. However, it appears reports are in agreement with each other that when ewes have higher than 3 or 4 CL, embryo survival is negatively correlated with increased number of CL. Even though a higher number of lambs are born with increased CL, it is not generally advised to breed for above 3-4 lambs for most sheep farmers due to high lamb and ewe losses.

2.9 Body condition score and embryonic loss

2.9.1 Embryo mortality up to Day 30 post mating

It has been determined that between 20 and 30% of all fertilized sheep embryo losses occur in the first 21-28 days of pregnancy, with few deaths recorded past Day 30 (Edey, 1969).

Smith and Knight (1998) concur with the review by Edey (1969), who established that Day 18 of pregnancy was the most vulnerable time for embryo survival. Quinlivan *et al.* (1966) found an overall embryonic loss of 24% between Days 2-18 in Romney Marsh ewes that conceived to first service and were slaughtered at 2-, 18-, 30-, 140- days post mating, along with a control group which were allowed to lamb. Embryo losses were estimated from CL counts, excluding non-fertilized embryos. Because ewes did not return to service, these losses refer to partial loss, most likely loss of one out of two embryos (Mattner & Braden, 1967). Similar results have also been found in dairy cattle, in which the majority of embryo losses occur prior to Day 16 post artificial insemination (Diskin & Morris, 2008). The high vulnerability of embryo survival around, and up to, Day 18 could be due to failure of implantation, as firm adhesion occurs around Day 16 (Brazer *et al.,* 2012; Spencer *et al.,* 2004), therefore prior to this date the embryos have not fully attached to the uterus wall making them vulnerable to atresia.

Table 7: Loss of conception from Day 10-17 and Day 17-30 post AI in ewes that had at least one ovulation on Day 10 (based on progesterone concentrations on Day 17, cut-off level 1 ng mL^{-1}) and at least one embryo on Day 30. (Source: Vinoles *et al.,* 2012)

Group	TL 10-17	TL 17-30	Total loss to Day 30	Total losses Day 30-60	Total
Control	27	12	39	12	103
Lupin6	23	12	35	7	100
Lupin6+15	17	21	38	7	109

In agreement with other studies, Vinoles *et al.* (2012) found highest total embryo losses up to Day 30, 35-38%, with only 6-12% lost from Day 30-60 (Table 7). Total losses between feeding groups were similar; however the timing of losses differed. Both the Control (grazed on pasture only) and Lupin6 (supplemented with lupin grain from Day -7 to Day -2 pre-mating) groups had higher losses up to Day 17 (45-69%) compared with Lupin6+15 (supplemented with lupin grain from Day -7 to Day -2 then from Day 1 to 15 post-mating) which had the highest losses from Days 17-30 (55%).

Ewes in the Vinoles *et al.* (2012) trials had higher overall embryo losses compared with ewes in other studies reviewed. This could be due to a number of reasons: (1) losses in ewe LW and BCS that was detected in all groups prior to insemination; (2) use of Merino ewes, which generally have low prolificacy and fertility and high embryo mortalities (7-46%), (Kleemann & Walker, 2005); or (3) the ewes were mated in spring, late non-breeding season, which could also distort results.

Gunn *et al.* (1972) found low BCS ewes had a higher percentage of ova not represented by viable embryos on Day 26 ± 2 compared with high conditioned ewes (15% *vs* 50%); indicating greater embryo mortalities in the poor conditioned group. Gunn and Doney (1975) also found higher total embryo loss in poor conditioned ewes (1.5) compared with moderate-to-good (2.5) and good (3.0) conditioned ewes. In contrast, Rhind *et al.* (1984b) found no differences between embryo survival rates up to Day 14-16 post mating between high (2.80) and low (1.77) conditioned ewes; 0.86 *vs* 0.81, respectively . These contradictory results, however, may be due to ewes being slaughtered between 14-16 days post mating; differences may have occurred if ewes had been slaughtered 4 weeks post mating. Cumming *et al.* (1975) also found no influence of BCS on embryo survival up to Day 26-30.

Ewes which lose all embryos early, and are able to return to service, are not of great economic significance considering the likelihood of ewes getting pregnant in their second cycle as oestrus is not greatly reduced compared to its level in the first cycle (Mattner & Braden, 1967). More important are ewes that lose one out of two embryos; i.e. a partial loss, which would result in large productive and economic losses.

2.9.2 Fetal mortality from Day 30 to parturition

Edey (1969) and Hanrahan (2003) both concluded embryo mortalities are highest in early pregnancy, up to day 30 and during the oestrus cycle, respectively. Smith and Knight (1998) agree with these findings, indicating an embryo loss of only 6-14% post Day 30. Similarly Quinlivan *et al.* (1966) found total losses of 1.3% and 5.3% in parous and non-parous ewes two-tooth ewes, respectively, from Day 30-140, i.e. much smaller percentages compared with pre-Day 30.

Gunn *et al.* (1972) compared number of viable embryos present at slaughter, on Day 26 ± 2, with total number of lambs born; allowing embryo mortalities to be estimated and found BCS was associated with fetal mortality. Ewes with high BCS (3.0) had a slight increase in barrenness from ovulation to Day 26 ± 2 (0% up to 7%); however ewes in poor condition (1.5) had substantial increases in barrenness from ovulation to Day 26 ± 2 (7% up to 48%). Both low and high conditioned ewes showed little increases in barrenness from Day 26 ± 2 and up to parturition.

Studies have shown late embryo losses, post Day 30, are statistically much lower compared with early embryonic losses; however late fetal mortality can result in higher economic losses due to it being too late to return ewes for a subsequent service (Diskin & Morris, 2008).

2.10 Conclusion

Lamb wastage has a large impact both on production and profit in the sheep industry. Wide variations in prenatal embryonic losses have been found, varying between 20-30% (Edey, 1969). There is still little understanding of the main causes of embryonic and fetal losses, with Edey (1969) indicating that it could simply be the natural process of eliminating genetic material which is not suitable for survival, due to chromosomal defects, individual genes and genetic variation (Diskin & Morris, 2008). This suggests that there will always be a certain amount of embryonic loss which is unavoidable; however it has been indicated to above there are environmental factors, such as nutrition, which may be able to minimise these losses. More information about nutritional influences during and immediately after mating, may give farmers the ability to decrease lamb wastage leading to increased efficiency and overall profit.

The objective of this dissertation is to examine the effects of change in ewe body condition and LW, post mating, and its effects on lamb wastage during pregnancy, primarily looking at losses during early pregnancy.

Chapter 3
Materials and Methods

3.1 Experimental Data

Data used in this study have been taken from Rutherford *et al.* (2003). In this trial, groups of 25 - 38 small- or large-framed ewes were selected from 9 flocks of 400-500 ewes each. Flocks originated from Southland and north, mid and south Canterbury, New Zealand. Most of the farms were classed as intensive South Island breeding and finishing farms. Six flocks were Coopworth-, two Romney- and one Perendale-based. Ewes were phenotypically chosen for frame size (small- or large-framed ewes; Table 8), although groups were balanced for age and condition (detailed as the estimated manually palpated GR score, tissue depth over the 12th rib midway from the spine to the sternum). All ewes were run as one flock once transported to Lincoln University's Ashley Dene Pastoral Systems Research Farm until pre-lambing in 2002, where the multiple bearing ewes remained for the following year's trial (2003).

Table 8: Ewes phenotypically chosen for frame size with average mating GR score and live weight (kg) for 2002 and 2003

Year	Group	GR	LW	Number
2002	Small	8.23 ± 0.26 *	61.6 ± 0.73 **	310
2002	Big	8.74 ± 0.26 *	71.2 ± 0.75 **	296
2003	Small	4.75 ± 0.34	52.4 ± 0.62 **	323
2003	Big	4.87 ± 0.35	60.8 ± 0.63 **	319

Within each year significance GR (* = $P < 0.05$) and LW (** = $P < 0.001$)

Four harnessed vasectomized rams were used to monitor the onset of the breeding season in a proportion of the ewes (n = 280) from 18 Jan until 4 April 2002, and from 15 Jan until 1 April in 2003. Ram harness crayon colours were changed weekly, and ewe tag numbers recorded twice weekly to determine the commencement date of their breeding season. Crayon-harnessed Coopworth rams (n = 14) were introduced to all ewes (n = 614) on 11 April 2002 and 9 April 2003 (n = 643). In the first 3 weeks after the introduction of the rams, ewes that had been crayon-marked by a ram were drafted off once weekly, and ovulation rate (OR) was measured through laparoscopy the following day after fasting the ewe for a minimum of 12 hours. The number of corpora lutea (CL) were recorded as the OR in ewes displaying at least 1 CL. Ewes were returned to flock after laparoscopy.

Transabdominal ultrasonic scanning was performed on 4 July 2002 and 22 July 2003 to record pregnancy status (0, 1, 2 or more fetuses). All barren ewes, and singleton fetus-bearing ewes in 2002, were excluded from the trial and returned to their original owners. The purpose of excluding singleton-bearing ewes in 2002 was due to the assumption that such ewes give birth to single lambs, and the survival of these was the same for both small- and large-framed ewes (Rutherford *et al.,* 2003). Singleton-bearing ewes were retained in 2003 because they had previously been purchased by Lincoln University in 2002 as multiple bearing ewes. Additional ewes were also purchased in 2003, from the original 9 farms, to replace ewes that were returned to their owners in 2002. The multiple-bearing ewes in 2002, and the additional ewes purchased in 2003, were split into separate groups (n = 25 - 40) of both small- and large-framed ewes that originated from the same farm, and set stocked one week prior to the commencement of lambing. Paddock sizes were kept similar between groups to allow comparable live weight/ha sub-divisions. All ewes were fully recorded at lambing, which included date of birth, sex and birth weight. In both years live weight and GR were recorded at mating, scanning and pre-lambing (approximately 3 weeks prior to lambing), i.e. 3 times to provide the data used in the current report. Full details of the trial are available in Rutherford *et al.* (2003).

Table 9: Distribution frequency of corpora lutea (OR), fetuses (SCANNED) and lambs born (LAMBED) for 2002 and 2003; ewes that were dry (0) or had a single fetus (1) were excluded from the 2002 data.

	OR		**Scanned**		**Lambed**	
	2002	2003	2002	2003	2002	2003
0	11	65	24	74	-	88
1	88	88	180	160	-	166
2	473	443	397	391	375	369
3	39	45	13	18	28	20
4	3	2	0	0	0	0
TOTAL	1163	1117	1013	996	834	964

3.2 Statistical analysis

A one-way analysis of variance (ANOVA) in Minitab, version 17.0 (VSN International), followed by a Fisher's and Tukey pairwise comparison were used to determine if change in ewe GR or LW had significant effects on lamb wastage from laparoscopy to scanning, and from scanning to pre-lambing. The statistical analysis used was ANOVA, rather than regression because the data was not linear. In the 2002 trial, all dry ewes and those with one fetus were excluded from the study; as previously explained in Section 1.1. These analyses were also used to determine the relationship between mating GR and LW on OR, number of fetuses scanned and number of lambs born, along with the effect of OR on embryo survival. The underlying requirements of ANOVA, which are: (1) independence of the observation, (2) data normally distributed, and (3) the variances are approximately equal, have been assumed. However, some of the analyses used here violated these assumptions. It is understood that ANOVA has some degree of robustness that enables it to cope with this (Milliken & Johnson, 1992).

The data records in the Rutherford *et al.* (2003) trial were incomplete, therefore each scenario was performed individually to allow for maximum number of complete records to be included; number of ewes included in each test have been provided in the results. Data that had obvious errors, due to either human or technical faults, underwent data validation. During the validation other available data was used to impute missing values, and edit errors resulting from human or technical faults.

Chapter 4

Results

There were highly significant ($P < 0.001$) differences between GR and LW of ewes at mating in 2002 (GR = 8.48 ± 0.22; LW = 66.29 ± 0.60 kg) compared with 2003 (GR = 4.81 ± 0.21; LW = 56.56 ± 0.59 kg); as this was the starting point for this experiment, all subsequent events are affected by this factor, and therefore 2002 and 2003 were treated as separate experiments.

4.1 Change in ewe GR and LW relationships with lamb wastage

4.1.1 Embryonic and fetal mortality up to scanning

In 2002 lamb wastage was significantly affected by change in ewe GR and LW from mating to scanning (Table 10). Ewes that had lamb losses up to scanning (n = 134; 23%) maintained their condition, that is had significantly lower ($P < 0.05$) reductions in GR up to scanning (2.52 ± 0.35) compared with ewes (n = 457) that had no lamb losses (3.05 ± 0.19). In contrast ewes that lost lambs lost significantly more weight ($P < 0.001$) up to scanning (5.61 ± 0.71 kg) compared with ewes that did not lose lambs (3.82 ± 0.39 kg). Although overall average ewe mating GR and LW were not significantly different between ewes that lost lambs (GR = 8.34 ± 0.39; LW = 66.4 ± 1.38 kg) and those that did not (GR = 8.54 ± 0.21; LW = 66.25 ± 0.74 kg); therefore the effect must be because of the change in ewe weight and condition.

Table 10: Change in ewe GR and LW from mating to scanning effects on embryo losses up to scanning in 2002 and 2003

Year	Loss			No losses		
	GR	**LW**	**Number**	**GR**	**LW**	**Number**
2002	-2.52 ± 0.35*	-5.61 ± 0.71**	134	-3.05 ± 0.19*	-3.82 ± 0.38**	457
2003	-0.45 ± 0.49	2.15 ± 0.77*	56	-0.54 ± 0.24	3.19 ± 0.38*	233

Within each year significance * = $P < 0.05$ and ** = $P < 0.001$

In 2003 there were no significant effects of change in ewe GR from mating to scanning on lamb loss up to scanning. In contrast ewes that had no losses had significantly ($P < 0.05$) higher increases in LW (3.19 ± 0.38 kg; n = 233) up to scanning compared with ewes that had losses (2.15 ± 0.77 kg, n = 56). The percentage of embryonic losses (19%) was also similar to 2002. There was also no significant effect of static average mating weight or body condition (GR).

4.1.2 Fetal mortality from scanning to parturition

In 2002, ewes that lost lambs after scanning (n = 4; 1%), had an average increase in GR = 0.5 ± 1.70 post scanning, compared with a reduction in GR in ewes that had no losses (mean = 2.14 ± 0.18; n = 373); this difference was significant ($P < 0.05$). In contrast, there was no effect of change in ewe LW from scanning to lambing on lamb losses. Changes in GR and LW from mating to scanning showed no significant differences between ewes that lost lambs and those that did not post-scanning. Overall, there were only 4 ewes that lost lambs between scanning and lambing. There were no significant differences between mating mean static GR and LW between ewes with losses and those that did not.

Table 11: Change in ewe GR and LW from scanning to lambing effects on fetal losses post scanning in 2002 and 2003

Year	**Loss**			**No losses**		
	GR	**LW**	**Number**	**GR**	**LW**	**Number**
2002	0.5 ± 1.45 *	3.55 ± 3.16	4	-2.14 ± 0.18*	3.73 ± 0.40	373
2003	-2.00 ± 1.31	12.6 ± 3.00	6	-0.95 ± 0.21	12.6 ± 0.49	223

Within each year significance * = $P < 0.05$

In 2003 there were no significant effects of change in ewe GR or LW from mating to scanning on lamb losses, even when non-pregnant ewes and ewes with a single fetus were excluded. This was predominantly due to the low number of ewes that lost lambs (n = 6; 3%) post scanning in 2003, therefore creating a greater standard error. There was however a significant effect ($P < 0.05$) of average mating GR score between ewes that lost lambs from scanning to lambing (6.67 ± 1.36) compared with ewes that had no losses (4.66 ± 0.29).

4.2 Effect of mating GR and live weight on ovulation rate, scanning percentage and number of lambs born

Data from a total of 1269 ewes were analysed in these results: 614 in 2002 and 643 in 2003; 211 ewes with either none or a single fetus were excluded from the 2002 trial (Table 9). Of the 1269 ewes there were 76 ewes that did not have any corpora lutea present at laparoscopy: 11 in 2002 and 65 in 2003. These ewes were excluded from any further analysis when evaluating lamb wastage. A further 134 ewes in 2002, and 107 in 2003 lost embryos up to scanning, and 85 and 21 fetuses were lost from scanning to lambing in 2002 and 2003, respectively. There were more ewes included in the study in 2003, although 2002 ewes had significantly higher OR (1.89 *vs* 1.74), scanning (165 *vs* 155%), and lamb percent (207 *vs* 150%), compared with 2003 ewes. The higher scanning percentage compared with lambing percentage in 2002 is result of taking non-pregnant and single-scanned ewes out after scanning.

4.2.1 Ovulation Rate

It is clear that there are large differences ($P < 0.001$) between 2002 and 2003 mating live weight and GR scores. In 2002 ewes had higher average LW (66.28 ± 0.60 kg) and GR score (8.48 ± 0.22), compared with ewes in 2003 (56.56 ± 0.59 kg and 4.82 ± 0.21, respectively); this was result of climatic effects.

In 2002 there was little difference in mating GR between ewes that scanned 1 to 3 CL; although ewes with 2 CL had significantly ($P < 0.05$; Figure 1) higher average mating GR score (8.61 ± 0.21; n = 467) compared with ewes that had one CL (7.85 ± 0.49; n = 84). Also ewes that had 4 CL had lower average GR score (7.33 ± 2.59; n = 3); although this was not significant due to the low number of ewes. There was also a significant ($P < 0.001$) positive linear correlation between mating live weight and OR up to 3 CL. However, as with GR, ewes with 4 CL had lower average LW (64.9 ± 8.97 kg) compared with ewes that had 2 and 3 CL, although this was not significant. Those ewes with 2 CL (66.7 ± 0.72 kg; n = 247) and 3 CL (69.7 ± 2.49 kg; n = 39) had significantly higher ($P < 0.001$) average live weights compared with ewes with 1 CL (62.3 ± 1.70 kg; n = 84). In 2002 there were 11 ewes devoid of CL at laparoscopy, with average GR score of 6.82 ± 0.50 and LW of 64.7 ± 20.2 kg. These ewes had lower average GR score compared with ewes that had one or more CL and lower LW compared with all ewes except for those with 1 CL. However data from these ewes have been excluded from the analysis which is limited to fertile sheep only.

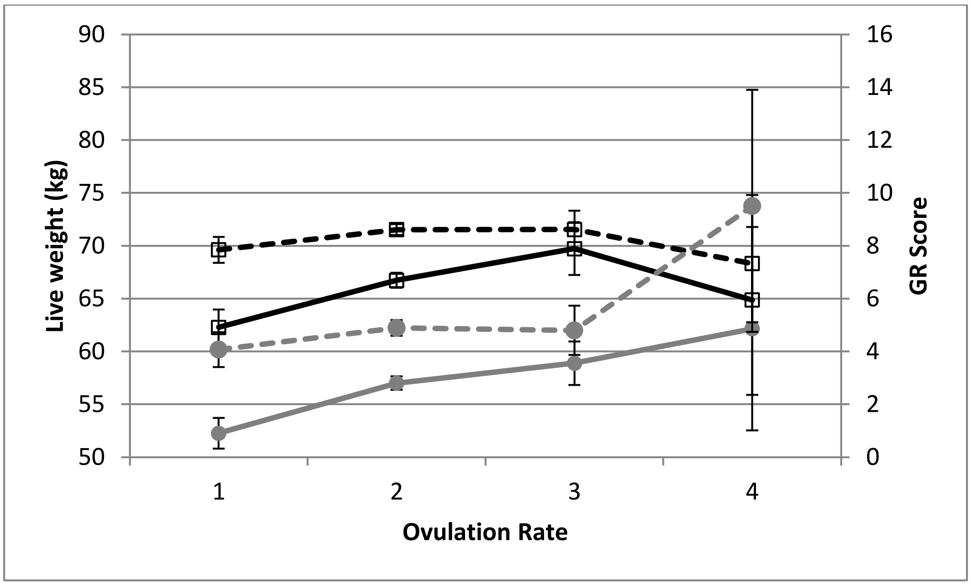

Figure 1: Effect of ewe mating GR score in 2002 (□; dashed line) and 2003 (•; dashed line), and live weight in 2002 (□; solid line) and 2003 (•; solid line) on ovulation rate.

In 2003 there was no significant effect of mating GR score on OR. Figure 1 shows ewes with 4 CL had much higher GR (9.50 ± 4.40; n =2) compared with all other ewes; however this was not significant due to the high variation (large standard error). There was a strong positive linear relationship (y =

3.15x + 49.69; R^2 = 0.97) between average ewe mating live weight and number of CL. Ewes with 1 CL (n = 88) had significantly (*P* < 0.001) lower average live weight (52.2 ± 1.45 kg) compared with all other ewes. No other relationships were significant. There were 64 ewes in 2003 that did not have a CL, with average mating live weight of 57.6 ± 1.70 kg and GR score 5.13 ± 0.77. These ewes had higher GR compared with ewes that had 1, 2 and 3 CL along with higher LW than ewes that had 1 and 2 CL; although as explained above, these data were excluded from the analysis.

4.2.2 Number of lambs scanned

In the 2002 trial, there was an effect of number of lambs scanned and mating GR (*P* < 0.05), once non-pregnant ewes (with a mean GR = 8.62 ± 3.25; n = 13) were excluded (Figure 2). Ewes with 2 fetuses (n = 394) had significantly (*P* < 0.05) higher average mating GR score (8.67 ± 0.12) compared with ewes that had a single fetus (8.10 ± 0.17; n = 176); no other factors were statistically different. There was also a positive relationship between number of fetuses (1 to 3) and ewe live weight. Non-pregnant ewes (n = 13) had higher average LW (8.62 ± 1.25) compared with ewes that had a single fetus (63.8 ± 0.66 kg; n = 176); however this was not significant. Ewes with a singleton fetus also had significantly lower (*P* < 0.001) live weight compared with ewes that had 2 (67.2 ± 0.38 kg; n = 394) or 3 fetuses (70.4 ± 2.68 kg; n = 13).

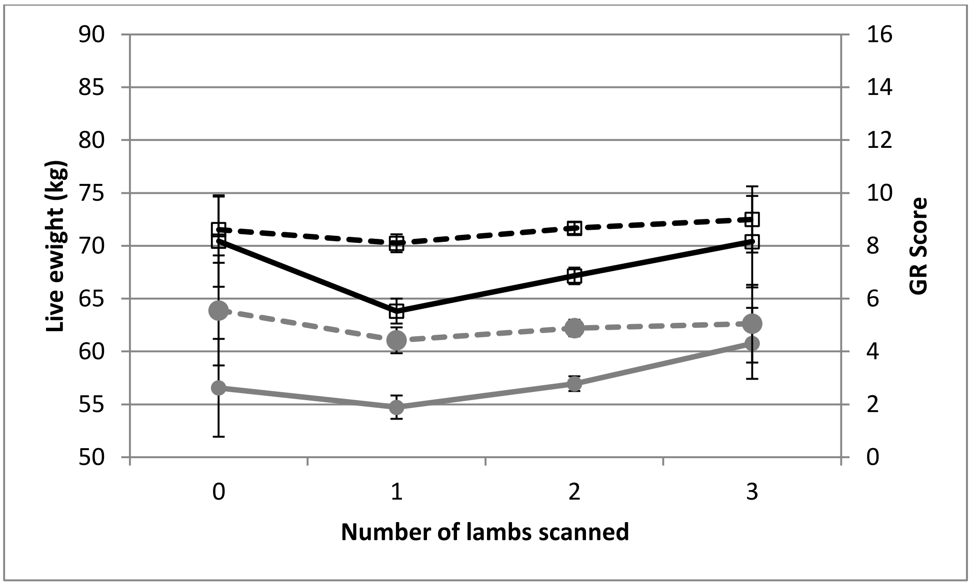

Figure 2: Effect of ewe mating GR score in 2002 (□; dashed line) and 2003 (•; dashed line), and live weight in 2002 (□; solid line) and 2003 (•; solid line) on number of lambs scanned.

In 2003 there was no significant effect of mating GR on number of lambs scanned. In contrast, when non-pregnant ewes (n = 72) were excluded, there was a positive linear relationship between average ewe mating live weight with number of fetuses scanned. Ewes with 1 fetus (n = 160) had lower LW (54.7 ± 0.71 kg; *P* < 0.001) compared with all other ewes. Also ewes with twins fetuses (56.9 ± 0.36

kg; n =390) had significantly ($P < 0.001$) lower live weight compared with ewes that had 3 fetuses (61.4 ± 1.88 kg; n = 18).

4.2.3 Number of lambs born

In 2002 mating live weight and GR score followed a similar trend, with a significant effect of mating GR and LW on number of lambs born. Single bearing ewes (n = 3) had significantly higher mean GR (13.33 ± 2.03; $P < 0.05$) and LW (79.7 ± 3.89 kg; $P < 0.05$) compared with all other ewes; ewes that had 3 fetuses tended to have lower LW compared with single ewes.

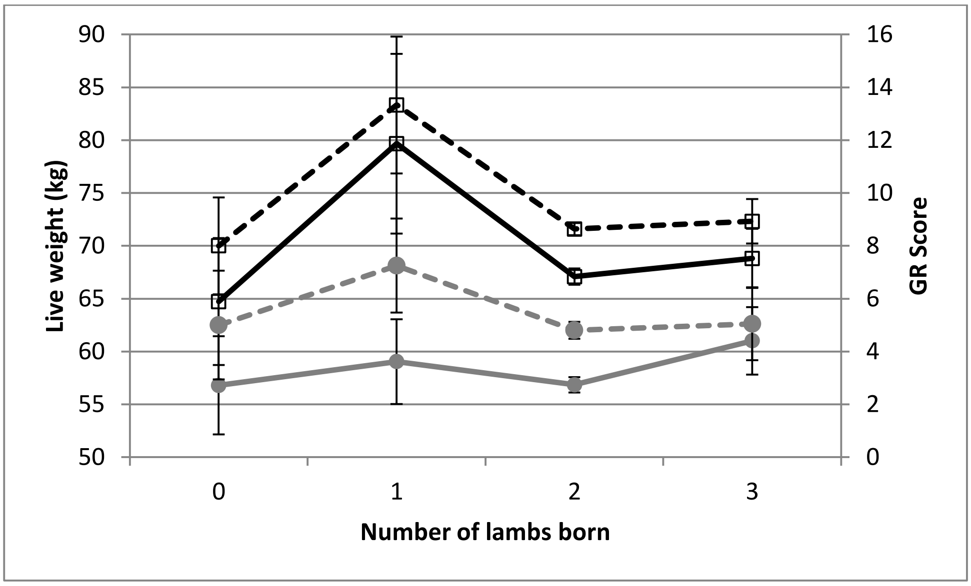

Figure 3: Effect of ewe mating GR score in 2002 (□; dashed line) and 2003 (•; dashed line), and live weight in 2002 (□; solid line) and 2003 (•; solid line) on number of lambs born.

Ewe live weight and GR score in 2003 followed a similar trend; however there were no significant effects of either LW or GR on the number of lambs born.

4.3 Effect of ovulation rate on embryo survival

There was a highly significant inverse effect of OR on probability of embryo survival in both 2002 and 2003 (Figure 4). In 2002 ewes with 2 CL had significantly ($P < 0.001$) higher probability of lamb survival (0.99 ± 0.01; n = 369) compared with lambs from ewes with either 3 (0.74 ± 0.04; n = 33) or 4 CL (0.63 ± 0.16; n = 2). In 2003 ewes with 1 CL had significantly ($P < 0.001$) higher probability of embryo survival (0.95 ± 0.05; n = 88) compared with ewes that had 2 (0.87 ± 0.02; n = 443) or 3 CL (0.74 ± 0.07; n = 45). Ewes with 2 CL also had higher average probability of embryo survival compared with ewes that had 3 CL. Ewes with 4 CL (n = 2) had lower probability of embryo survival (0.50 ± 0.35); however due to the low number of ewes, this was not significantly different.

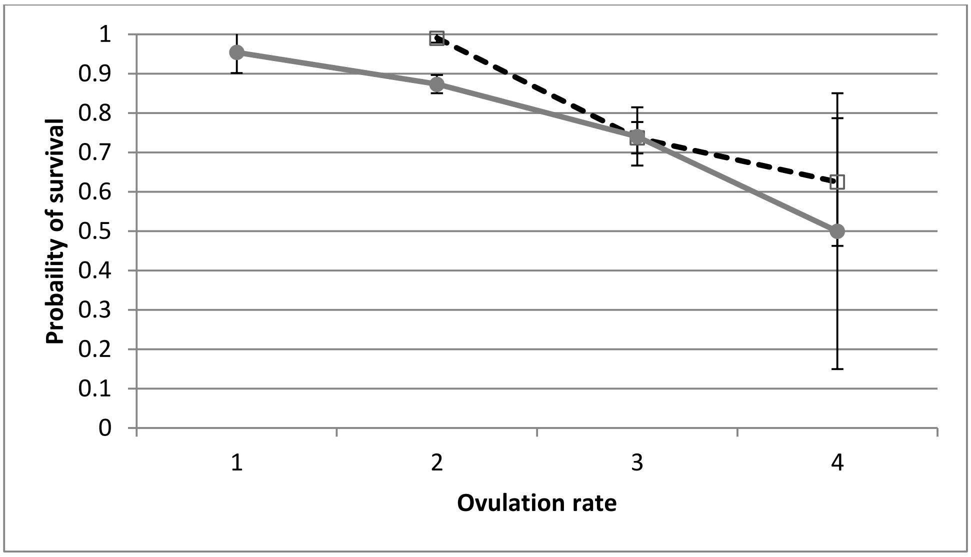

Figure 4: The effect of ovulation rate on probability of embryo survival in 2002 (□; dashed line) and 2003 (•; solid line).

Chapter 5

Discussion

It has been suggested embryo losses are highest in early gestation (up to Day 30), compared with fetal losses later in pregnancy (Edey, 1969; Hanrahan, 2003; Smith & Knight, 1998; Quinlivan *et al.,* 1966; Vinoles *et al*., 2012). Results from the current study confirm this. There were 241 embryos lost up to scanning, and 106 fetal losses from scanning to lambing. Smith and Knight (1998) and Quinlivan *et al.* (1966) both found the time up to- and including Day 18 of gestation was the most vulnerable time for embryo survival; predominantly as a result of failure of implantation, as firm adhesion occurs around Day 16 of pregnancy in ewes (Brazer *et al.,* 2012; Spencer *et al*., 2004). More precisely, O'Connell *et al.* (2015) found most embryo losses occurred between Day 4 and 14 of gestation (12% of ovulated ewes), with 6% of ova lost prior to Day 4, with only 1 % loss from Day 14 to 30. The current study only measured the potential number of embryos available prior to mating, and then the number of fetuses present at scanning (approximately 3 months later), therefore a direct comparison cannot be made with previous studies which found losses were highest up to Day 30, and in particular Day 18 of gestation. Despite the study's limitations, higher embryonic losses were found up to scanning (23 & 19%, in 2002 & 2003 respectively) compared with fetal losses after scanning (1 & 3%, in 2002 & 2003 respectively), these wastage rates were comparable with previous literature.

Despite various studies having found similar lamb wastage rates in early gestation, as previously mentioned, there are no direct measurements of prenatal losses. This would require a sample group of ewes to be slaughtered, around Day 3 of gestation to count the number of viable embryos, with the remainder of the flock allowed to lamb, allowing average embryo mortalities to be counted. Although this is a direct method of counting viable embryos, it requires the assumptions that the sample ewes are a correct representation of fertilisation rate and number of viable ova of the flock; making it less accurate. Large flocks are also required for this measurement making it expensive (Edey, 1969). The method used in the current study to count the number of CL, by laparoscopic examination, is indirect, and therefore limits assumptions such as only a single ovulation occurred or that ewes did not become anoestrus within 40 days of mating (Edey, 1969). Because an indirect measurement was used in the present study to determine number of ova available, there may be some degree of error involved in the calculation of lamb wastage. Unfortunately there is no way to determine lamb wastage precisely.

5.1 Change in ewe GR and LW relationship with lamb wastage

In 2002 ewes with lamb losses up to scanning, and from scanning to lambing, had significantly lower reductions in body condition (GR) compared with ewes that did not lose lambs. This is to be expected because pregnant ewes are supplying nutrients to growing fetuses, and therefore creating food limitations causing ewes to use a proportion of their own body reserves to supplement this process (Kenyon *et al,.* 2014). In contrast, ewes that lost lambs had higher live weight losses up to scanning, and lower live weight gains, from scanning to lambing, compared with ewes that maintained their pregnancies. Likewise with GR, the effect of LW is to be expected; higher LW losses up to scanning and lower LW gains up to lambing are as result of ewes losing their fetus, and therefore have lower overall weight. In 2003 change in GR had no effect on lamb losses up to scanning or from scanning to lambing. Change in LW did however effect lamb wastage; in contrast with 2002, ewes that had no losses up to scanning in 2003, had significantly greater weight gains compared with ewes that lost lambs. There was also no effect of static mating weight or GR score on lamb losses in 2003.

Shorten *et al.* (2013) found that static weight, rather than changes in weight, had the largest effect on OR; suggesting current nutrition was less important compared with ewe condition. This did not hold true in the current study, where static mating ewe LW and GR were not statistically different between ewes that had lamb losses and those that held their pregnancies; therefore the change in weight and body condition (GR) had a large effect on lamb losses than static weight. In contrast Gunn *et al.* (1972) found higher embryo mortalities in Low (1.5) BCS Scottish Blackface ewes compared with ewes in High (3.0) body condition; although no effects after Day 26 of gestation. Likewise Gunn & Doney (1975) concluded that embryo losses decreased as BCS at breeding increased, across a range of BCS (1.5–3.0). In contrast with other literature, and in agreement with the current study, Cumming *et al.* (1975) found no effect of BCS on embryo mortality.

The contradicting findings for change in GR and LW between 2002 and 2003 could be due to the highly significant difference ($P > 0.001$) between mating GR and LW between the two years. In 2002 the majority of ewes had a reduction in live weight, whereas in 2003 most ewes gained weight from mating to scanning; this could have been a result of climatic effects. This was interesting because 2003 was a particularly dry year, and therefore lower levels of feed would have been available, compared with a good growing season in 2002. Small differences between the two years in ewe GR score could also be a result of the GR not being a precise measurement because it was estimated through manual palpation, and therefore a degree of human error is involved. This was minimised by the same assessor used to measure ewe GR score for all stages throughout the experiment and would likely not contribute greatly towards findings.

Shorten *et al*. (2013) also found optimum ewe LW to maintain pregnancy was 65 kg, with lower probability of survival for ewes with either greater or lower LW; this was not entirely consistent with the current study. In 2002 ewes that had embryo losses throughout pregnancy, had an average LW of 64.7 ± 1.07 kg, whereas ewes without losses average mating weight was 67.2 ± 0.81 kg ($P < 0.001$); this was equal to Rutherford *et al.* (2003) from which the current data are taken. In contrast, ewes in 2003 with embryo losses were not significantly heavier at mating compared with ewes with no embryo losses (57.5 ± 1.24 *vs* 56.1 ± 0.66 kg). The differences could be as results of a broad range of effects including breed, climate or management variations.

5.2 Mating GR and LW effect on ovulation rate, number of lambs scanned and born

5.2.1 OR

Ovulation rate is affected by both the genotype and environment (Edey, 1969), and it is well accepted that ewe body condition and live weight can have a large effect on OR (Cumming *et al.,* 1975; Gunn *et al.,* 1972; Gunn & Doney, 1975; Kleemann & Walker, 2005; Rhind *et al.,* 1984a; Rhind *et al.,* 1984b; Table 4). In agreement, the current study found ewes in 2002 had significantly lower percentage of barreness (2 *vs* 10%), and higher mean OR (1.89 *vs* 1.74) compared with ewes in 2003. Coop (1962) also found an increase in barren ewes with lower LW; although above a certain threshold there was no significant effect of LW on number of barren ewes. Likewise Shorten *et al.* (2013) found positive relationships with ewe pre-mating weight and mean ovulation rate; predominantly because higher conditioned ewes were needed to maintain a larger number of embryos throughout gestation. The main cause of the large differences in OR and percentage of barren ewes is assumed to be as a result of ewes in 2002 having significantly higher average mating LW and GR scores compared with ewes in 2003.

There were also significant effects of ewe LW and body condition on OR within each year. In the 2002 experiment, mating GR had a significant effect on OR; ewes that scanned 2 CL had significantly higher mating GR compared with ewes that scanned 1 CL, consistent with previous research. However in contrast with previously literature, ewes with 4 CL had considerably lower mating GR compared with all other ewes. This is thought be because there were only 3 ewes with 4 CL in 2002, and one ewe with significantly lower GR compared with the other two ewes (GR = 5, 8 & 9), which had a significant effect on results due to the low replica number. The trend for LW in 2002 is similar to GR, where ewes with 4 CL had lower average LW compared with ewes with 2 and 3 CL; however this is not a result of one ewe's LW skewing data as all 3 ewes had lower than average live weights.

There was no effect of mating GR on OR in 2003; however ewes with 4 CL had vastly greater GR scores compared with all other ewes. This however is also a result of low replica number (n = 2), and large difference between the ewe mating GRs (6 & 13); and therefore this result cannot be relied upon. There was a strong positive linear trend between ewe LW in 2003 with increasing number of CL which is in agreement with Shorten *et al.* (2013) and Cumming *et al*. (1975).

Ewes with no OR were excluded from the analysis because it was limited to analysing fertile sheep only. The 2002 data, excluding lower LW of ewes with 1 CL, was consistent with previous literature (Gunn & Doney, 1975; Gunn *et al.,* 1972) that found ewes in higher body condition at mating had higher conception rates. Ewes in 2003 did not follow this trend, although it is unclear the reason for this.

From the literature observed, ewe GR score and LW at mating are positively related with OR. However LW only appears to be crucial below a minimum threshold weight, or if ewes are carrying multiple lambs and this threshold varies between breed and ewe frame size (Shorten *et al.,* 2013).

5.2.2 Scan

As with OR, number of lambs scanned was higher in 2002 compared with 2003 (165 *vs* 155%), and there were also significantly greater embryo losses up to scanning in 2003 compared with 2002 (n = 72 *vs* 11); assumed to be an effect of the significant difference between mating GR and LW between the two years.

Overall average mating ewe GR and LW both had similar positive linear relationships, with number of lambs scanned between 2002 and 2003; when non-pregnant ewes were excluded. In 2002 the linear trend for LW was y = 3.29x + 57.27 (R^2 = 0.99), similar to the linear equation in 2003 where y = 3.02x + 48.42 (R^2 = 0.98). Lambs scanned also followed a similar trend with average ewe mating GR between 2002 (y = 0.45x + 7.23; R^2 = 0.98) and 2003 (y = 0.32x + 3.84; R^2 = 0.94); although similarly with LW, it is apparent ewe GR score in 2002 are much higher compared with ewes in 2003. This shows that when non-pregnant ewes are excluded, the number of lamb scanned increases with both GR and LW which is in agreement with Kleemann and Walker (2005) and reviews conducted by Kenyon *et al.* (2014).

5.2.3 Lamb

Ewes in 2002 had a much higher lambing percent compared with ewes in 2003 (207 *vs* 150%, respectively). This could either be as a result of differences in GR and LW between the two years, in agreement with Shorten *et al.* (2013) who also found positive relationships with ewe pre-mating weight litter size, and/or as a result of the fact that all ewes that scanned either none or one lamb in 2002 were returned to their original owners.

In 2002 single ewes had higher average mating GR and weight compared with all other ewes; although this is as a result of non-pregnant and single ewes being excluded after scanning. There were only 3 ewes, that scanned twins and gave birth to a single lamb, all of which had higher than average LW (79.7 ± 3.89 kg) and GR (13.33 ± 2.03), and therefore distorting the data. When single-birthing ewes are excluded there is a slight positive relationship between mating GR and LW on number of lambs born. There were no significant effects of either average mating GR or LW on number of lambs born in 2003. Since the ewe GR and LW used in the analysis against number of lambs born were mating measurements (approximately 145 days earlier), it is not surprising there are no correlations. Kenyon *et al.* (2014) reviewed similar findings in Merino, Suffolk, Afshari and many other breeds where number of lambs born per ewe was independent of ewe BCS; although this review also mentioned many studies that found relationships between the two factors. Likewise, Rhind *et al.* (1984a) found ewes in high BCS (> 3.0) had lower potential of lambs per ewe compared with ewes in moderate body condition. The contradicting literature could be a result of variations in breed; however Kenyon *et al.* (2014) stated it was more likely to be because the positive correlation between ewe body condition and number of lambs born were curvilinear and not linear; and therefore results depend on the range of BCS analysed. Furthermore, Rhind *et al.* (1984a) found a decline in number of lambs born with high BCS in Scottish Black Face; this apparent decrease in lambing rate at higher BCS has also been observed in other breeds (Kenyon *et al.,* 2014). Combined, these studies suggest a curvilinear relationship between BCS and the number of lambs born, indicating there may be a tipping point for each breed above which there is a negative effect of BCS on lambing rate.

5.3 Effect of ovulation rate on embryo survival

The current findings (Figure 4) are consistent with previous work (Cumming, 1972; Hanrahan, 1994, as cited in Diskin & Morris, 2008, p. 262; Hanrahan 1980 & 2003; Shorten *et al.,* 2013; Quinlivan *et al.,* 1966) that found a decrease in probability of embryo survival with increase in number of corpora lutea (Table 6). The current study showed a higher probability of embryo survival for ewes with 1 (2003) and 2 CL compared with that reported by both Hanrahan (1994, as cited in Diskin & Morris, 2008, p.262) and Hanrahan (1980); although this could either be because of breed variation, or the larger number of ewes surveyed by Hanrahan has provided higher accuracy. In contrast, Gunn *et al.* (1972) found higher embryonic deaths in single- compared with multiple-ovulating ewes; however this was predominantly a consequence of majority of the single-ovulating ewes being in poor condition (BCS 1.5) compared with multiple-ovulating ewes (BCS 3.0). Gunn *et al.* (1972) also found higher embryonic mortalities in ewes that were fed a high diet (35 g kg LW^{-1} per day) of dried grass pellets in bare grass paddocks, compared with ewes on the low diet (5 g kg LW^{-1} per day) which is also at odds with the current findings. The current study showed that ewes in 2002 had a higher probability of survival, for 2 and 4 CL, compared with ewes in 2003 and this is likely to be a result of ewes in 2002 having higher body condition and LW (from higher nutrition) compared with the following year's study.

Shorten *et al.* (2013) indicated a maximum expected litter size occurs with an OR of 4, with diminishing expected number of lambs past this point; predominantly as a result of limited uterine capacity or embryo competition, both of which reduce oocyte viability. No ewes in the current study had more than 4 CL, mainly because of the breeds studied; however it is obvious there is an inverse relationship between number of CL and probability of survival. Hanrahan (1994, as cited in Diskin & Morris, 2008, p.262) concluded that this negative relationship was principally because of the number of embryos entering the uterus, rather than problems associated with embryo quality, timing of ovulation or the uterine environment. There were also no indications of an inherited physiological or genetic relationship between OR and embryo survival, but rather some factor of management and environment.

A further cause of the decreased likelihood of survival with increased CL could be site of ovulation, and embryo migration. Embryo migration, occurring after maternal recognition of pregnancy (Day 14 - 15 of gestation; Nephew, McClure & Pope, 1989), may be required when ova tend to come mainly from one ovary to provide adequate spacing leading to increased ova mortalities (Casida, Woody & Pope, 1966; Scaramuzzi & Downing, 1997). Shorten *et al.* (2014) found a significantly greater OR in the right ovary (1.26 ova/ewe) compared with the left (1.12 ova/ewe) in sheep, which is similar to women in whom it was found that the dominant follicle develops more frequently on the right compared with the left ovary (Fukuda *et al.* (2000). Although, in contrast with Nephew *et al.* (1989), Shorten *et al.* (2013) and Edey (1970) found no significant effects of site of ovulation on embryo survival.

It is apparent that the probability of embryo survival decreases with increased number of CL. However despite the lower chance of survival, there is still an increased number of CL up to a maximum of 4 CL, beyond which the expected number of lambs born decreases. Embryo survival is more likely to be influenced by management practices and the external environment, rather than inherited factors; reinforcing the importance of nutrition and ewe condition for optimum embryo survival.

Chapter 6

Conclusion

In summary, most embryonic mortality of sheep occurs in the first 30 days of gestation (20 - 30%), particularly in the first 18 days as result of failure of implantation, with few embryo losses past Day 30. More recent research has found embryo losses are highest between Days 4 and 14, with few losses from Day 14 to 18, or past Day 18. In spite of abundant research showing similar embryo wastage rates, all measurements are only estimates of true losses because there is no direct method to measure the number of fertilised eggs in live sheep, and therefore no way of knowing accurately how many of these have failed to develop. The current study was limited to measurements of embryo survival at only 3 time points in each year: the potential number of embryos available prior to mating (CL), the number of fetuses present at scanning (approximately 3 months later), and the number of lambs born. Therefore the present study was unable to make direct comparisons with the published literature which had shown that embryo losses were highest up to Day 30, in particular the time between Days 4 and 14 of gestation. Despite its limitations, the present study recorded higher embryonic losses up to scanning (23 & 19%, in 2002 & 2003 respectively), rather than after scanning (1 & 3%, in 2002 & 2003 respectively), which is in agreement with other studies reported in the literature.

Embryonic wastage has a significant economic impact on the sheep industry, and provides a substantial opportunity cost for this agriculture sector if solutions can be found. Lamb wastage is either failure of embryo persistence, or results from a poor ewe uterine environment; although the specific causes are largely unknown. The current study has documented a reduction in embryonic survival with increasing ovulation rate in commercial sheep flocks which contributes to the available evidence. It has been suggested that these high embryo losses in multiple-ovulating ewes are caused by embryonic migration within the oviducts to allow for better spacing of multiple ova; however the evidence for this concept has been equivocable. The present study was not designed to investigate the cause of this increased embryo mortality arising from the higher OR. However, there is no indication that the relationship between increased ovulation rate and embryonic loss is physiological or genetically heritable. Therefore, it is more likely that external factors, such as nutritional management and environmental cues, have direct impacts on embryo survival.

Many studies have found associations between ewe body condition and live weight up to mating and the period after mating on embryo survival. The present study found both ewe GR scores and live weight at mating were higher in 2002 compared with 2003; the between-year differences being probably attributable to climatic effects. This is likely to be a major reason why the sheep in 2002 had higher OR and reduced numbers of barren ewes compared with 2003. Overall there tended to be an increase in OR with increased ewe weight and body condition, and therefore in agreement with pervious literature reported, higher feeding prior to mating results in higher OR. There was also a positive relationship between number of embryos scanned with ewe body condition and weight when non-pregnant ewes are excluded; non-pregnant ewes had higher LW and GR than all single-scanned ewes. There was also a large effect of change in LW and GR on embryo survival compared with static ewe weight and body condition at mating. However changes in ewe LW and GR were not consistent between 2002 and 2003. In 2002 ewes with embryo losses up to scanning had higher LW losses compared with ewes with no embryo losses, although in 2003 ewes with embryo losses had higher weight gain up to scanning compared with ewes that maintained their pregnancies. It was concluded that ewes have higher embryonic losses up to scanning compared with after scanning, and that change in ewe body condition and LW have a greater effect on these embryo losses compared with static ewe body condition and live weight at mating. It is unclear the reason behind this variation, particularly because ewes in 2002 were in better condition resulted from higher feed availability compared with 2003.

Future research on ewe body condition and live weight, and changes in these factors, should focus on specific time periods of embryo losses and nutrition leading up to mating to get background information, especially after mating, to examine the nutritional effects on embryo survival.

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