# An epidemiologic investigation of wastage and productivity of ewes in a sample of New Zealand commercial flocks

A thesis presented in partial fulfilment of the requirements for the degree of Doctor of Philosophy in Veterinary Science at Massey University, Palmerston North, New Zealand

**Kate Jade Griffiths**

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## Abstract

Until recently, little was known about ewe wastage in commercial New Zealand ewe flocks, or indeed, internationally. This PhD was undertaken with the broad objective of establishing the extent, timing and cause (premature culling or mortality) of ewe wastage in New Zealand ewe flocks, while also identifying factors associated with increased ewe wastage including pre-mating body condition score (BCS), failure to rear a lamb and, linked with the latter, impact of ewe udder defects on productivity.

To the authors' knowledge, this is the first study that reports both lifetime wastage and detailed annual wastage in a sample of New Zealand commercial flocks. Of the 13,142 enrolled ewes, 50.4% exited their respective flocks due to premature culling (where a ewe is culled from the flock prior to the potential end of her productive lifespan) and 40.0% due to on-farm dead/missing, giving a total of 90.4% that exited due to wastage. In all years, pre-mating BCS could be used as a predictor of ewe wastage with odds of wastage lower with increasing BCS.

In Year 1, wastage for each cohort ranged from 7.6% - 45.4% of ewe lambs enrolled, while wastage due to dead/missing accounted for 26.8% - 100.0% of ewe lamb wastage across cohorts, and premature culling was primarily due to poor reproductive performance (dry at pregnancy diagnosis or dry at docking when 3-6-week-old lambs are yarded for ear marking, tail removal and castration of males). Hence, other than the cull sale-value for those that were prematurely culled, the farmer received no productive or economic benefit from these wasted ewe lambs. Ewe lambs with heavier conceptus adjusted liveweight (CALW) and those that gained greater CALW between pregnancy diagnosis and pre-lambing were less likely to be dry at docking. Similarly, for two-tooth ewes (18-months of age at breeding), heavier ewes and those that gained CALW were less likely to be dry at docking than lighter ewes or those that lost CALW.

Pre-mating udder palpation scores of hard or lump were associated with increased odds of lambs not surviving to weaning compared with normal scores. Additionally, surviving offspring of ewes with pre-mating udder palpation scores of hard had lower growth to weaning.

Commercial farmers can use the information presented in this thesis to identify ewes within their flocks that have increased risk of wastage or poor productivity. They can then alter management of these at-risk ewes to both improve ewe productivity and reduce likelihood of wastage.

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# List of Publications

## Journal Publications

**Griffiths KJ, Ridler AL, Heuer C, Corner-Thomas RA, Kenyon PR.** The effect of liveweight and body condition score on the ability of ewe lambs to successfully rear their offspring. *Small Ruminant Research* 145, 130-135, 2016

**Griffiths KJ, Ridler AL, Heuer C, Corner-Thomas RA, Kenyon PR.** Associations between liveweight, body condition score and previous reproductive outcomes, and the risk of ewes bred at 18-months of age being dry at docking. *New Zealand Veterinary Journal* 66, 290-296, 2018

**Griffiths KJ, Ridler AL, Compton CWR, Corner-Thomas RA, Kenyon PR.** Associations between lamb survival to weaning and dam udder and teat scores. *New Zealand Veterinary Journal* 67, 163-171, 2019

**Griffiths KJ, Ridler AL, Compton CWR, Corner-Thomas RA, Kenyon PR.** Associations between lamb growth to weaning and dam udder and teat scores. *New Zealand Veterinary Journal* 67, 172-179, 2019

## Additional Publications

**Griffiths KJ.** Investigating longevity and wastage in New Zealand commercial ewe flocks. *Proceedings of the Society of Sheep and Beef Cattle Veterinarians of the NZVA*, 113-115, 2016

**Griffiths K, Ridler A, Kenyon P.** Longevity and wastage in New Zealand commercial ewe flocks - a significant cost. *The Journal: The Official Publication of The New Zealand Institute of Primary Industry Management Incorporated* 21, 29-32, 2017

**Griffiths K, Ridler A, Heuer C, Corner-Thomas R, Kenyon P.** Investigating longevity and wastage in New Zealand commercial ewe flocks. *International Sheep Veterinary Congress Proceedings*. Harrogate, UK, 2017

**Griffiths KJ, Ridler AL, Rout-Brown G, Spooner J, Maloney F.** Udder defects in New Zealand commercial ewes. *Proceedings of the Society of Sheep and Beef Cattle Veterinarians of the NZVA*, 2019

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# General Introduction

At the commencement of this PhD in 2015 there was very limited published information on ewe wastage in commercial New Zealand ewe flocks, or indeed, internationally. Ewe wastage is a combination of both on-farm mortality and premature culling (Farrell *et al.* 2019). Premature culling is where a ewe is culled prior to the potential end of her productive lifespan (typically six to seven years of age (Farrell *et al.* 2019)); either sold for slaughter, direct sale to another farmer or via slaughter on-farm. Increased ewe wastage results in a reduction in farm productivity and ability to generate profit (Farrell *et al.* 2019), due to a reduced number of lambs available for sale and subsequent lower income from lamb sales (Farrell *et al.* 2019). Replacement ewes should remain within the flock and be productive for a sufficient period to be economically efficient (Conington *et al.* 2001; Douhard *et al.* 2016).

It is somewhat surprising that although ewe mortality and premature culling appear to be frequent topics of discussion within the sheep industry, and are important for overall farm and flock performance, there is very little scientific investigation into either (Farrell *et al.* 2019). Therefore, this PhD study was undertaken with the broad objective of investigating the extent, timing and cause of ewe wastage in a sample of commercial New Zealand ewe flocks, while also identifying factors associated with increased ewe wastage. The first experimental chapter (Chapter 3) utilises data from 13,142 ewes from four cohorts, collected as they aged from replacement ewe lambs to 6-year-old ewes. The data were analysed to investigate the timing, extent and general cause (premature culling or mortality) of ewe wastage. The data were also analysed to assess associations between reproductive outcomes as a replacement ewe lamb and risk of wastage, and associations between pre-mating body condition score (BCS) and risk of ewe wastage in that production year.

The next experimental chapters (Chapters 4 and 5) investigated associations between liveweight, body condition score and previous reproductive outcomes and the risk of ewes being dry (non-lactating) at docking (when 3-6-week-old lambs are yarded for ear marking, tail removal and castration of males), utilising data collected from the ewes described in Chapter 3. The analyses in Chapters 4 and 5 were motivated by three key factors. Firstly, the large number of replacement ewe lambs (7-8 months of age at breeding) and two-tooth (18-months of age at breeding) ewes that were identified as dry at docking from within each of the study cohorts. Secondly, the consequences for farmers (within both this study, and other commercial farmers) of having increased numbers of dry ewes within their flocks, namely reduced flock productivity and increased risk of premature culling as discussed in Chapter 3. Thirdly, the lack of studies that have directly examined factors associated with ewes being dry at docking in New Zealand.

The final experimental chapters (Chapters 6 and 7) report on the description and consequences of poor ewe udder health on lamb survival and lamb growth to weaning. As described in Chapters 3, 4 and 5, failure of ewes to rear a lamb to weaning results in both reduced flock productivity and increased wastage of commercial ewes due to premature culling. In addition, recent survey results indicated that >85% of commercial farmers examined their ewes' udders at least once yearly (Corner-Thomas *et al.* 2016); presumably as a management tool to assist in culling decisions. However, there was no standardised udder scoring method New Zealand farmers could utilise, and there had been very little scientific investigation in the last 40 years into udder health and its effect on productivity in New Zealand commercial ewes.

### Specific objectives of the present thesis

The specific objectives of this thesis are as follows:

- To establish the extent, timing and cause of ewe wastage in commercial New Zealand flocks (Chapter 3)
- To investigate the association between reproductive outcome as a ewe lamb and risk of wastage (Chapter 3)
- To investigate if pre-mating body condition score (BCS) can be used as a predictor of ewe wastage in the following production year (Chapter 3)
- To investigate associations between liveweight and body condition score (BCS) and the risk of ewe lambs (7-8 months of age at breeding) being dry (non-lactating) at docking (Chapter 4)
- To investigate associations between liveweight, body condition score (BCS) and previous reproductive outcomes and the risk of two-tooth (18-months of age at breeding) ewes being dry (non-lactating) at docking (Chapter 5)
- To examine a range of udder and teat traits and to describe the frequency with which different scores occur in a commercial New Zealand flock (Chapter 6)
- To investigate associations between lamb survival to weaning and ewe udder and teat scores (Chapter 6)
- To investigate associations between lamb growth to weaning and ewe udder and teat scores (Chapter 7)

# Chapter 1

## Literature Review: An overview of wastage in commercial breeding ewes, also incorporating relevant measures of ewe health and productivity

# Introduction

The New Zealand Sheep and Beef industry forms an important part of the New Zealand economy, with a large proportion of product exported to overseas markets (Anonymous 2018b). Over the past 30 years there has been a steady decline in the numbers of sheep in New Zealand (Figure 1.1) and a shift in the relative proportions of income that are generated from meat and wool (Anonymous 2013; Stafford 2017), with the majority of sheep farm income currently generated from the sale of sheep meat (Table 1.1). The average New Zealand sheep and beef farm is 634 hectares (Anonymous 2016b) with an average gross income of NZD $457,500 per year (Anonymous 2016b). Within this, there is variation in farm topography and flock size, which is important as it can influence farm management structure and contact with individual ewes within the flock (Stafford 2013).

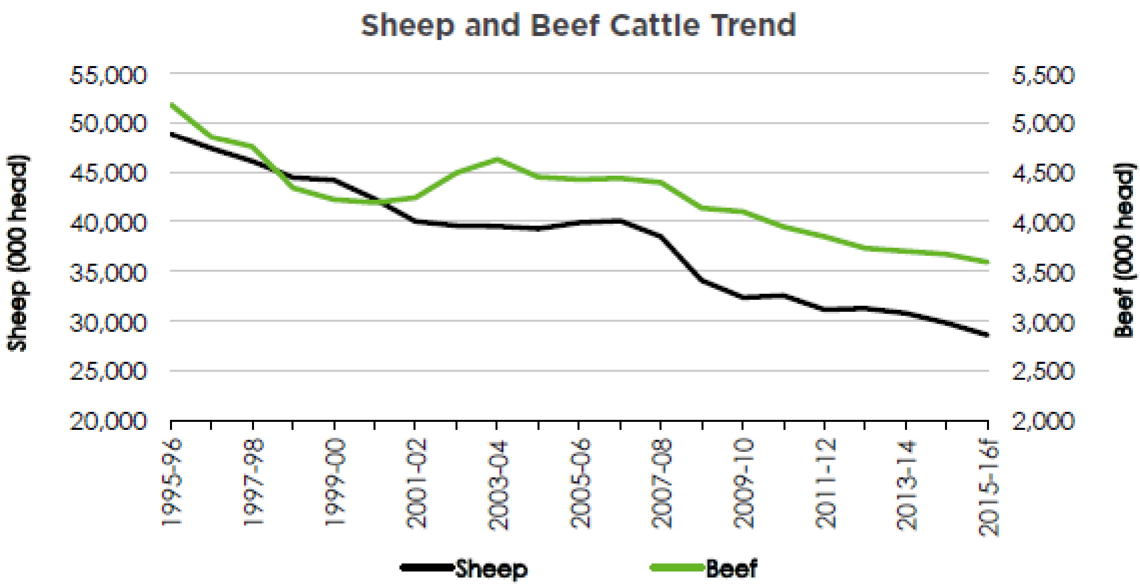
Considerable research has been undertaken to examine means of improving on-farm productivity, much of which has focused on increasing ewe reproductive performance and lamb growth rates. However, there is a lack of recent research on wastage in commercial ewe flocks in New Zealand, while the scant data that is available is at the flock level rather than the individual level. In this thesis, ewe wastage is the combination of both on-farm mortality and premature culling. Premature culling is where a ewe is culled prior to the potential end of her productive lifespan; either to slaughter, direct sale, or via slaughter on-farm. Increased ewe wastage results in a reduction in farm productivity and ability to generate profit (Farrell *et al.* 2019). Using a bio-economic model, Farrell *et al.* (2019) reported that for a New Zealand North Island Hill Country sheep farm with 21% of the flock lost annually due to wastage, a reduction in wastage to 5% could increase cash profit by 33%.

To maintain flock numbers, replacement rates for commercial flocks are typically in the range of 20 - 35% (MacKay *et al.* 2012; Farrell *et al.* 2019). This represents an inherent overhead cost, including fewer sale lambs, increased management and feed costs of virtually unproductive replacements (little income from wool or lambs), and potentially reduced selection pressure. Some farms may opt to purchase additional replacements, which can have biosecurity risks associated. In addition, the reproductive performance of ewes increases as they age (Edwards and Juengel 2017), so having a higher proportion of younger ewes reduces the overall productivity of a commercial flock (Farrell *et al.* 2019).

On-farm mortality has a direct cost in that the cull value of the ewe is not obtained, and may have an additional cost if the ewe dies during the pregnancy or lambing period as there is the loss of her potential lamb(s). It is also important to consider the welfare implications of having increased on-farm mortality rates (Munoz *et al.* 2018), and the perception that this creates of the New Zealand sheep industry (Stafford 2013).

This review summarises the existing literature relating to wastage in breeding ewes, while also incorporating the relevant measures of ewe health and productivity.

**Figure 1.1 Decline in numbers of sheep and beef cattle in New Zealand from 1995-96 to 2015-16**




Source: Anonymous (2015)

**Table 1.1 Revenue sources for commercial New Zealand Sheep and Beef farms (as a percentage of total revenue)**

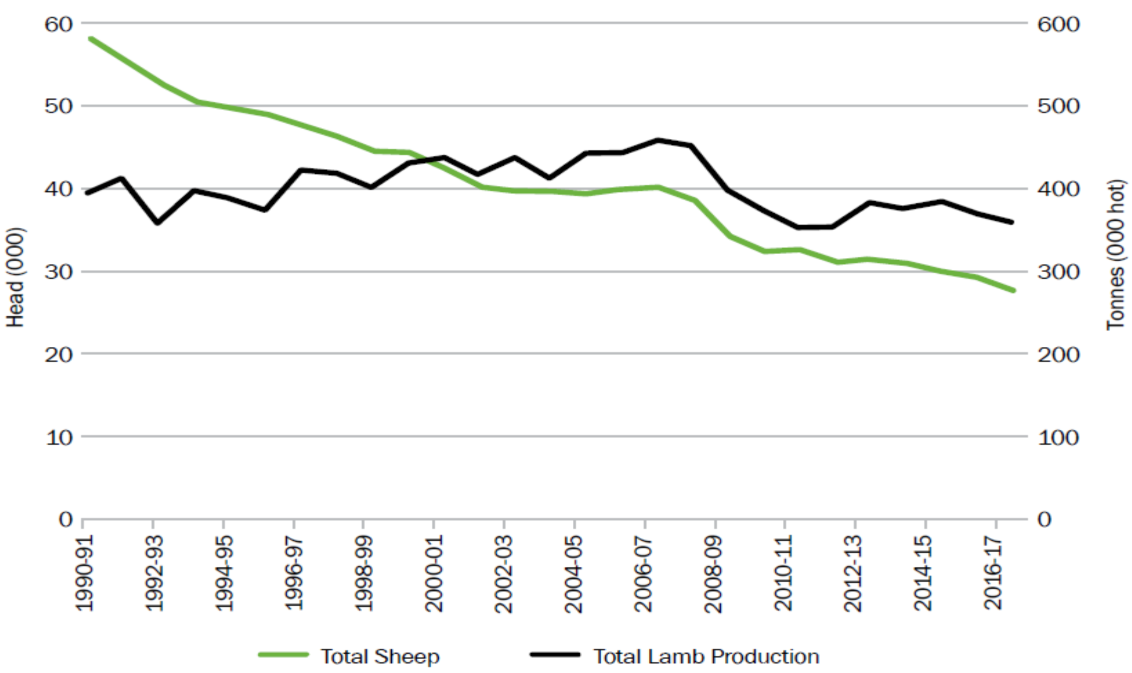
| | 2006-07 | 2015-16 | 2016-17 |
|---|---|---|---|
| **Wool** | 13% | 12% | 8% |
| **Sheep** | 44% | 40% | 43% |
| **Cattle** | 26% | 27% | 28% |
| **Dairy Grazing** | 2% | 6% | 6% |
| **Deer + Velvet** | 1% | 1% | 1% |
| **Cash Crop** | 9% | 10% | 11% |
| **Other** | 4% | 4% | 4% |

Source: Adapted from Anonymous (2014a; 2016b; 2018a, b)

## Sheep Farming in New Zealand

There have been a number of changes in the New Zealand sheep farming industry in the last fifty years due to the intensification of the pastoral based system (MacKay *et al.* 2012). Traditionally Romney were the predominant breed, however a recent survey by Corner-Thomas *et al.* (2013) identified 26 individual maternal breeds (Romney, Perendale and Coopworth the most common) and a further 12 terminal breeds (Texel, Suffolk and Poll Dorset the most common), while 40% of the flocks surveyed consisted of "composite" (mixed) breeds. Sheep numbers have declined (Figure 1.2); however, total lamb production has remained similar (Figure 1.2) due to increased reproductive performance of breeding ewes. This is seen as a 23% increase in average lambing percentage from 1987 – 2013 (Morris and Hickson 2016), and increased lamb growth rates, with average carcass weights of lambs increasing from 14kg to 18kg (Morris and Hickson 2016). These changes to the New Zealand sheep farming industry mean results generated from studies conducted on commercial farms prior to the late 1980's, related to ewe wastage should be interpreted with these changes in mind.

**Figure 1.2 Trends in New Zealand breeding ewe numbers and weight of lamb carcass production from 1990-91 to 2016-17**




Source: Anonymous (2018b)

In New Zealand, ewes are typically kept and managed as flock animals rather than as individuals (Stafford 2013), with few farmers utilising individual animal identification (Corner-Thomas *et al.* 2016). This presents a particular challenge when investigating longevity and wastage traits as ewe numbers are typically based on flock totals at key times of the year (i.e. pregnancy diagnosis and shearing being examples) and, in some instances, an annual stock reconciliation. The exception to this may be stud/recorded ewe flocks, which tend to have good individual monitoring, as this is essential to their breeding success. The recent introduction of electronic identification (EID) tags for use in sheep has provided farmers with a relatively straightforward means of tracking individual ewes within a flock, if they choose to utilise it. This new EID technology provides farmers with the opportunity to monitor productivity and wastage of ewes within a flock at an individual-level.

## Drivers of Productivity on New Zealand Commercial Sheep Farms

The majority of income for New Zealand commercial crossbred sheep flocks is from the sale of lambs, rather than sale of wool (Anonymous 2015, 2018a, b). Therefore, farmers currently aim to maximise the total weight of lambs available for sale (which is a combination of both the number and weight of the individual lambs) per ewe presented for breeding, which increases the efficiency of production.

To increase the total weight of lamb available for sale, focus is typically on increasing the number of lambs available for sale (through increasing ewe reproductive performance and improved lamb survival) and improving the growth of the lambs (resulting in increased weaning weights). It is important to consider lamb production on a per ewe basis (total weight of lamb available for sale per ewe presented for breeding), while also considering mature ewe maintenance requirements (Conington *et al.* 2001; Byrne *et al.* 2012). However, due to extensive flock management, and therefore a lack of ability to match dams to offspring; few New Zealand commercial farmers are likely to be able to match lambs to their respective dams. Therefore proxy's such as number of lambs scanned at pregnancy diagnosis and udder palpation to identify ewes that are actively lactating (wet) or not actively lactating (dry) are used to inform farmer decision making regarding ewe removal from the flock based on lamb production (Garrick 1998; Amer *et al.* 2009).

Reduced productive longevity and increased ewe wastage reduces both farm productivity and ability to generate profit (Farrell *et al.* 2019), due to a reduced number of lambs available for sale and subsequent lower income from lamb sales (Farrell *et al.* 2019). Individual replacement ewes that enter a commercial flock need to remain within the flock, and be productive, for a sufficient period to be economically efficient (Conington *et al.* 2001; Douhard *et al.* 2016). However, there is a lack of published data regarding how long an individual ewe has to remain in a flock for maximal efficiency. Available data tends to focus on improving efficiencies at the flock level rather than the individual level (Bohan *et al.* 2018; Farrell *et al.* 2019), for example considering flock age structure, stocking rate and total lamb production. The lack of performance recording on an individual ewe basis (Conington *et al.* 2001; Stafford 2013) and complexities of sheep farming systems likely contribute to this lack of efficiency data.

## Ewe Wastage

### Ewe mortality

#### *Annual ewe mortality*

Ewe mortality appears to be a topic of frequent discussion in the sheep industry, both within New Zealand and internationally. It is therefore surprising that there is very little data published in existing literature. At the beginning of this wastage study, after commencing literature searches, it became apparent there was scant data directly relating to the topic of wastage. Therefore, as part of the present study, a number of veterinarians, animal scientists and rural professionals (both New Zealand and international) were individually contacted to assess availability of additional data. All agreed that although surprising, very little data has been collected, recorded, analysed and published regarding on-farm ewe mortality. They agreed ewe longevity and wastage was an area requiring further investigation. In addition, articles were published in relevant publications (for example Rural News and Society of Sheep and Beef Cattle Veterinarians Newsletter) appealing for sources of data that were unpublished. While this created interest in the present ewe wastage project, unfortunately, it did not result in additional data becoming available. The following section focuses primarily on published data, with a summary of mortality rates provided in Table 1.2. It is important to note the majority of the wastage data reported in the following review have been extracted from studies that were primarily investigating topics other than wastage but have also reported data relevant to wastage, or have mentioned wastage but have not reported actual wastage rates.

Pyke (1974), in the King Country (New Zealand), reported on causes of death on one farm over a nine-year period; finding significant losses due to facial eczema (particularly before control measures were introduced) and "accidents", many of which the author suggested were likely a result of ewes being forced into swamps during times of feed shortage. Annual mortality ranged from 4.9% to 27.0%. Pyke (1974) also reported causes of mortality as seen in veterinary practice; with most commonly diagnosed causes being parasitism, salmonellosis, pneumonia and ketosis (age of ewe was not defined). However, caution is required when interpreting these results as farmers may only contact their veterinarians when there appear to be significant or ongoing issues or which they are unable to diagnose themselves. Davis (1979) conducted a sheep mortality study on nine commercial farms in the Hawke's Bay (New Zealand) to establish an annual ewe mortality rate and cause of death via necropsy results. The average mortality rate was 4.9%, with the main causes of death being ketosis (pregnancy toxaemia), lambing difficulty (dystocia) and pneumonia.

A 2007 Master's thesis (Ghazali 2007), reported annual mortality rates of between 7.0% – 10.8% over a six-year period on one North Island (New Zealand) farm. A recent longitudinal study by Anderson and Heuer (2016) reported on farm annual mortality rates in New Zealand commercial ewes from 17 farms ranging from 2.8% – 15.7%, with a mean flock mortality of 7.3%. The study also reported causes of ewe mortality as observed and reported by the enrolled farmers. Those most commonly reported were 'dog-tucker' (slaughtered on-farm), poor body condition score (BCS), lambing difficulties and found dead (Anderson and Heuer 2016).

In Australia, Turner *et al.* (1958) examined death rates in a flock of approximately 1000 Merino ewes over a number of years (1950 – 1958). Death rates of ewes aged 1.5 to 7.5 years were fairly uniform at 1.5% - 2.6% per annum, but rose quickly once they were older than 7.5 years to 7.3%. In a drought year (1957-58), the older ewes experienced a greater challenge, with a shortage of feed, and had higher death rates (26%). Also in Australia, annual mortality data was reported for 12 Merino flocks (mixed-sex, >6-months-old) during a 3-year-period (2002 – 2004), with necropsies conducted on a sample of dead sheep from each flock (Bush *et al.* 2006a, b). Bush *et al.* 2006a reported annual mortality rates ranging from 2.7% – 19.1%, with mean mortality rates of 7.8%, 10.5% and 9.4% in 2002, 2003 and 2004 respectively. The study also reported causes of mortality in a sample of necropsied dead sheep (dead sheep were collected from each farm during 1-week-periods four times per year). The most commonly reported causes of death were Ovine Johne's Disease, malnutrition, periparturient deaths of ewes and parasites (Bush *et al.* 2006b). However, it is important to note this study selected farms by purposive sampling, targeting farms with farmer estimates of Ovine Johne's disease of 5% or greater per annum, which may have biased results. In addition, this study included mixed-sex flocks, so results may differ from ewe-only flocks. Following farmer participation in the Australian Lifetime Ewe Management program, Trompf *et al.* (2011) reported changes in both farmer awareness of ewe mortality, and actual reported on-farm mortality. Prior to participation in the program 42% of farmers reported quantifying ewe mortality rates, however after the program this rose to 81% of participant farmers. In addition, reported on-farm annual mortality rates decreased from 4.9% to 2.8%, however it is important to note these were farmer reported rates, and it was not discussed how these were established. More recently in Australia, Kelly *et al.* (2014) reported mortality rates in Merino ewes on six farms of between 6% - 22% over a two-year period, however cause of death was not reported. Dever *et al.* (2017) reported annual ewe mortality rates of 6.3% to 6.7% across five Australian farms; however, again, cause of death was not reported.

In the UK annual ewe mortality rates of 3% - 10% have been reported (Scott 2005; Lovatt and Strugnell 2013). In Ireland, Keady (2014) reported on-farm annual mortality rates ranging from 3.6% - 6.8%, with an average of 4.7%; however cause of death was not reported. While modelling profitability of grass based sheep production systems (focused in Ireland), Bohan *et al.* (2018) assumed a 'likely' annual ewe mortality rate of 5.5% for mature ewes and 6.5% for ewe lambs (minimum 3%, maximum 8%). In Northern Ireland, Annett *et al.* (2011) reported ewe mortality (including missing, presumed dead) rather than culling was the main reason for ewes being removed from the Scottish Blackface Hill Sheep flocks with 33.5% of ewes exiting the flock due to mortality by the end of the 5-year-study-period, however cause of death was not reported. In Scotland, Wishart *et al.* (2016) reported a mortality rate of 7% in Scottish Blackface ewes over a two-year period, although, again, cause of death was not reported. Mekkawy *et al.* (2009) reported on-farm annual mortality rates by age of ewe, with rates ranging from 1.3% - 4.6%. Reported causes of death included 'pregnancy associated' (0% - 8.3% of deaths), 'lambing associated' (20% - 55.6% of deaths), 'disease' (20% - 55.2% of deaths) and unknown (9.5% - 44.4% of deaths), while a number of ewes were classified as missing, presumed dead (0% - 20% of deaths) (Mekkawy *et al.* 2009). The highest mortality rates were seen in younger ewes, with mortality rates reducing with age (Mekkawy *et al.* 2009).

In free-ranging ewe flocks in Norway, mortality rates of 9.1% over three summer grazing seasons (total over the three summers) were reported (Warren and Mysterud 1995). However, the predominant cause of mortality was predation, mainly from bears, an issue not faced in New Zealand.

The above review of annual mortality literature highlights the lack of published data regarding rates, causes and risk factors for on-farm ewe mortality. Available data has been extracted from studies with differing methodologies, allowing for limited comparisons between them. However, reported annual mortality rates range from 2.8% - 27.0% in New Zealand, 2.8% - 26.0% in Australia, and 3.0% - 10.0% for flocks in the UK and Ireland (Table 1.2). Commonly reported causes of ewe mortality include conditions associated with pregnancy or parturition (for example dystocia and ketosis), poor body condition score (BCS) or disease (Bush *et al.* 2006b; Mekkawy *et al.* 2009; Anderson and Heuer 2016). Additionally, there appears to be a seasonal distribution to ewe mortality, with mortality tending to increase during the lambing period, as will be discussed in the subsequent section.

**Table 1.2 Summary of reported annual ewe mortality rates, including source of data, country of origin, mortality rate range and average mortality rate**

| Reference | Country | Annual mortality rate (range) | Annual mortality rate (average) |
|---|---:|---:|---:|
| Pyke (1974) | New Zealand | 4.9% - 27.0% | 10.0% |
| Davis (1979) | New Zealand | NR | 4.9% |
| Ghazali (2007) | New Zealand | 7.0% - 10.8% | 8.7% |
| Anderson and Heuer (2016) | New Zealand | 2.8% - 15.7% | 7.3% |
| Turner *et al.* (1958) | Australia | 1.5% - 26.0% | NR |
| Bush *et al.* (2006a, b) | Australia | 2.7% - 19.1% | 9.2% |
| Trompf *et al.* (2011) | Australia | NR | 4.9%*<br>2.8%* |
| Kelly *et al.* (2014) | Australia | 6.0% - 22.0%# | NR |
| Dever *et al* (2017) | Australia | 6.3% - 6.7% | 6.5% |
| Scott (2005) | UK | 4.0% - 10.0% | NR |
| Lovatt and Strugnell (2013) | UK | 3.0% - 8.0% | NR |
| Keady (2014) | Ireland | 3.6% - 6.8% | 4.7% |
| Bohan *et al* (2018) | Ireland | 3.0% - 8.0%^ | 5.5% (Mature ewes)^<br>6.5% (ewe lambs)^ |
| Wishart *et al*. (2016) | Scotland | NR | 7%# |
| Mekkawy *et al.* (2009) | Scotland | 1.3% - 4.6% | 2.9% |

NR = Not reported, or data not available to allow calculation
*Note, these are farmer reported tallies and it was not discussed how these were established
#Note, this was over a 2-year period
^Note, these are assumed mortality rates for use in modelling profitability

*Ewe mortality during the lambing period*

Tarbotton and Webby (1999) studied pre-weaning lamb survival in the King Country and Taupo regions (New Zealand), via survey (30 farms) and on-farm investigations (8 farms), identifying at least 21% of the lamb losses observed were attributable to ewe mortality. The percentage of ewe mortality in the study varied between farms ranging from 2.5% - 7.5% over the lambing period; however, the causes of the ewe deaths were not reported. Ghazali (2007) reported ewe mortality increased markedly over the lambing and lactation period in each of the six study years. Interestingly, there was also an increase in incidence in mortality over the summer months observed in the younger (two-tooth; 18-months of age at breeding) ewes in two of the five years (Ghazali 2007). In 2006, Ghazali (2007) also conducted a study that aimed to determine incidence of ewe mortality from pregnancy diagnosis to weaning, and to determine causes of mortality over the lambing period in a cohort of 531 randomly selected mixed-age ewes. Necropsies were conducted on any ewe found dead during a 21-day period in late-pregnancy/early-lambing. During the 21-day necropsy period ewes were observed daily, with 16 ewes identified as dead (3.0%; 16/531), while the most commonly reported causes of death were dystocia, vaginal prolapse, unknown, cast and mastitis (Ghazali 2007). In addition, a further 35 ewes went missing during the period from pregnancy diagnosis to weaning (6.6%; 35/531). If it is assumed these missing ewes died, 51 ewes exited due to mortality in the study period (9.6%; 51/531).

Unpublished data (Pers. Comm. Heuer) from a 2014 investigation into ewe mortality in a New Zealand commercial flock reported mortality from pregnancy diagnosis to docking (where lambs are 3-6 weeks of age) of 9.8%, with mortality rates increasing in the older ewes within the flock (approximately 15% compared with 9%). In that investigation the main reported causes of death were metabolic, dystocia (lambing difficulties), vaginal prolapse, mastitis, cast and unknown. It was also noted that the ewes that died tended to be in poor BCS around lambing and lactation, however this was not investigated or analysed further. Unpublished data (Pers. Comm. Ridler) from a 2016 investigation into lamb mortality in lambs born to ewe lambs, reported a 5.1% ewe lamb mortality rate from immediately prior to lambing to docking, with reported causes of mortality being dystocia (44%) and vaginal prolapse (16%), while the rest were unknown (40%).

While discussing management of ovine obstetrical problems in the UK, Scott (2005), reported increased ewe mortality rates during the lambing period, however, actual rates were not reported. In Australia, Dever *et al.* (2017) reported an increased incidence of ewe mortality over the lambing period (pre-lambing to docking); however again, actual mortality rates were not reported. Also in Australia, Allworth *et al.* (2017) reported estimated ewe mortality rates in a number of flocks from pregnancy scanning to docking, with an average reported rate of 3.5% (range 0 - 13.7%). However, these rates were calculated based on farmer reported ewe tallies, rather than specifically recorded mortality data, so may represent an over- or under-estimate of actual mortality rates in this time-period. As part of a longitudinal assessment of welfare in extensively managed ewes in Australia, Munoz *et al.* (2018) reported a mortality rate from mid-pregnancy to weaning of 5%.

From the above mortality data, it is apparent there are difficulties in collecting accurate measures of ewe mortality on-farm, and identifying dead ewes, with a number of ewes classified as missing (Ghazali *et al.* 2007; Mekkawy *et al.* 2009; Annett *et al.* 2011). Commercial flock sizes, extensive management, paddock terrain and topography, and frequency of observation likely contribute to difficulties with collecting data on every ewe death on a commercial sheep farm. Due to this, ewes that go missing on-farm are presumed to have died and contribute to ewe mortality rates.

#### Ewe Culling

There is surprisingly little research directly examining culling strategies in New Zealand commercial sheep flocks. However, it is likely commercial farmers select ewes to cull based on either known poor performance (for example non-pregnant (dry) at pregnancy diagnosis), predicted poor performance (for example ewes whose lambs are predicted to have poor survival or poor growth to weaning) or poor ewe health (for example poor teeth).

Premature ewe culling in relation to a breeding flock can be defined as a ewe that is culled prior to the potential end of her productive lifespan (i.e. before she is culled for age). Ewes are generally culled for age in New Zealand at six to seven years of age (Farrell *et al.* 2019); however, some farms may choose to keep older ewes for longer, or may purchase ‘culled for age’ ewes from other farms. It is surprising that although it is commonplace to cull ewes for age, there is little objective data available to support this common practice or its economic consequences (McGregor 2011; Wishart *et al.* 2016).

Ewes can be culled via either slaughter on-farm, slaughter at the slaughterhouse, sale at a sale yard, or in some instances as a direct sale to another farmer. The slaughterhouse or sale options provide a direct monetary value, while on-farm culling is often utilised directly as a source of dog food (Anderson and Heuer 2016).

**Wastage associated with poor reproductive performance**

*Ewe reproductive performance and productivity*

Considerable improvements have been made in ewe reproductive performance in New Zealand commercial ewe flocks in the past 30 years, resulting in increased numbers of lambs born (per ewe) and increased carcass weights of lambs (Morris and Hickson 2016). This has been driven by a combination of genetic selection to improve reproductive performance (for example traits for ewe prolificacy, lamb survival and lamb growth) (Byrne *et al.* 2012; Lee *et al.* 2015; Douhard *et al.* 2016), and by improved awareness and implementation of on-farm management strategies and tools to optimise ewe reproductive performance (Kenyon 2008; Brown *et al.* 2015; Kenyon *et al.* 2014b).

The seasonal nature of breeding activity in ewes means failure to conceive results in the loss of a year's productivity. Subsequent losses of potential lambs from pregnancy diagnosis to weaning also result in reduced productivity. Failure of a ewe to successfully rear a lamb(s) to weaning reduces both the total weight of lamb available for sale and overall flock efficiency (MacKay *et al.* 2012).

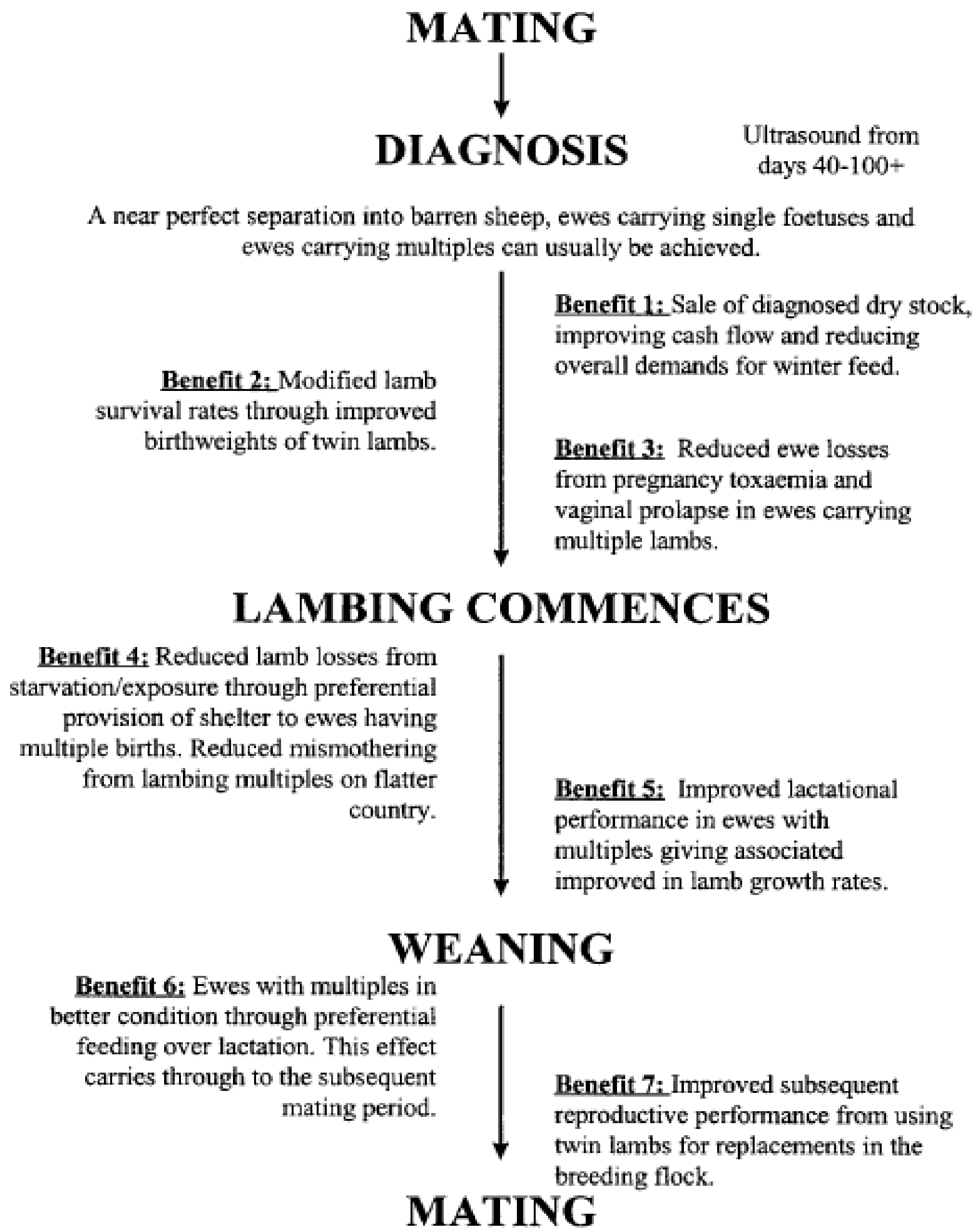
*Culling based on poor reproductive performance*

If non-pregnant (dry) ewes are identified, they can be culled, saving feed for those that are pregnant while enabling farmers to receive monetary value for these dry ewes (Figure 1.3) (Blair 1986; Garrick 1998). Corner-Thomas *et al.* (2014) reported that approximately 70% of New Zealand farmers utilised ultrasound pregnancy diagnosis as a farm management tool. The potential benefits of ultrasound pregnancy diagnosis are demonstrated in Figure 1.3. Garrick (1998) reported 7% of ewes presented for breeding in New Zealand were barren (dry) at pregnancy diagnosis, while Farrell *et al.* (2019) suggested poor ewe reproductive performance was the main driver of culling for New Zealand flocks. Similarly, in Northern Ireland, Annett *et al.* (2011) reported the primary reason for culling was infertility. On commercial New Zealand farms, ewes are also culled for failure to rear a lamb to docking having previously been identified as pregnant (Amer *et al.* 2009; Lee *et al.* 2015). However, the extent and numbers of ewes that are prematurely culled due to failure to rear a lamb is currently unknown.

*Relationship between ewe reproductive performance and ewe mortality*

As discussed previously, ewe mortality rates have been reported to increase markedly over the lambing period, both in New Zealand and overseas. However, when considering the commonly reported causes of ewe mortality this is not surprising. Commonly reported causes of ewe death in New Zealand include metabolic disease (particularly ketosis), vaginal prolapse, dystocia and cast (Pyke 1974; Davis 1979; Ghazali 2007; Jackson *et al.* 2014; Anderson and Heuer 2016), conditions that are typically observed around lambing.

**Figure 1.3 An overall view of the productive benefits of ultrasound pregnancy diagnosis**




Source: Garrick (1998)

## Wastage associated with poor udder health

### *Ewe udder health and productivity*

Lambs born on commercial farms are dependent on the ewe's milk supply for survival and growth in early life, and milk remains an important source of digestible energy and protein up until weaning (Hayman *et al.* 1955; Glover 1972; Clark 1980). Hayman *et al.* (1955) reported lower survival, lower growth rates (average daily gain) and lower weaning weights in lambs born to ewes with defective udders. It is well established that perinatal and neonatal loss is a significant issue for sheep farmers (Stafford 2013; Dwyer *et al.* 2016; Allworth *et al.* 2017) and that ewes with defective udders contribute to this loss (Hayman *et al.* 1955; Watson and Buswell 1984; Arsenault *et al.* 2008). In addition, the quantity and quality of milk produced by the ewe directly influences lamb growth (Hayman *et al.* 1955; Clark 1980). Lambs whose dams have poor udder health, low milk yield, poor colostrum quality or quantity have reduced growth rates (Watson and Buswell 1984; Arsenault *et al.* 2008; Huntley *et al.* 2012; Grant *et al.* 2016).

### *Culling based on ewe udder health*

Poor udder heath and mastitis in non-dairy breed ewes results in a number of economic costs for the farmer including: costs associated with premature culling of affected ewes, reduced income from loss of lambs, poor lamb growth rates, and treatment of affected ewes (Conington *et al.* 2008; Grant *et al.* 2016; McLaren *et al.* 2018). The available data suggests between 2% - 6% of New Zealand commercial breeding ewes have defective udders at weaning (Clark 1980; West *et al.* 2009; Peterson *et al.* 2017). However, there is scant data available regarding udder health and its relationship to culling on New Zealand sheep farms. Recent survey results from Corner-Thomas *et al.* (2016) indicate greater than 85% of commercial New Zealand farmers examine ewes' udders, presumably to assist in culling decisions, although there is currently no standardised scoring method available for use in non-dairy breed ewes. This lack of standardised scoring has resulted in a number of different definitions of poor udder health in available literature, with terms such as 'udder defect', 'mammary disease' and 'abnormal udder' used (Clark 1980; Quinlivan 1972; Peterson *et al.* 2017).

International studies recognise both udder defects and mastitis as important causes of wastage of ewes due to increased risk of premature culling. In the UK, Watson and Buswell (1984) concluded the most significant economic impacts of mastitis (both clinical and subclinical cases) were those related to premature culling of ewes and the effect of reduced milk yields on lamb survival and growth. More recently, Agriculture & Horticulture Development Board (AHDB) Beef and Lamb UK (Anonymous 2016c) reported similar conclusions, ranking mastitis as one of the most important diseases affecting ewes, with a flock level incidence of 0% - 6.6% per annum. Also in the UK, Grant *et al*. (2016) estimated approximately 8% of the national flock were culled because of mastitis each year. Madel (1981) conducted an abattoir survey of mammary glands from cull ewes, reporting udder abnormalities were an important reason for culling ewes. A similar result was reported from Northern Ireland with Annett *et al.* (2011) finding the primary reason for culling was infertility (40%), but that this was followed by udder abnormalities (22.7%). In Ireland, Keady (2014) reported an average of 4.7% of ewes were culled each year due to mastitis (range: 1.6% - 6.0%).

Mastitis is an important mammary disease of ewes in New Zealand, with a reported incidence of between 0.6% - 7.7% (Quinlivan 1968; Clark 1980; Peterson *et al.* 2017), with variations between age of ewe, farm, timing (the majority of cases occurring at lambing and post-weaning) and between years. Quinlivan (1972) suggested that a higher incidence of mastitis (6% - 10%) may be present in high producing flocks, although it is important to note that a high performing flock in the 1970's may now be considered an 'average' flock with changes in on-farm productivity. Mastitis is also an important mammary disease in overseas sheep production systems (Arsenault *et al.* 2008 (Canada); Gelasakis *et al.* 2015 (Review: includes data from Brazil, Canada, Europe, Turkey, UK, USA); Grant *et al.* 2016 (UK); McLaren *et al.* 2018 (UK)).

A number of bacteria including *Staphylococcus aureus, Mannheimia haemolytica, Escherichia coli* and mixed infections have been identified as involved in ovine mastitis in New Zealand commercial ewes (Quinlivan 1968; Quinlivan 1972; Clark 1980; Peterson *et al.* 2017), with *S. aureus* reported to be of particular importance at lambing (Quinlivan 1972). *S. aureus* has been associated with acute cases of mastitis, a high mortality rate and in the majority of cases, permanent udder damage (Quinlivan 1972; Clark 1980). In addition, as occurs in cows, a carrier state can exist (Quinlivan 1972; Bergonier *et al.* 2003), which may be particularly relevant in flocks with a high incidence of mastitis and high rates of culling due to poor udder health. As in New Zealand, several bacterial agents have been associated with subclinical or clinical mastitis in ewes overseas. In non-dairy breed sheep (meat production) systems, most reported cases of clinical mastitis are associated with *M. haemolytica* or *S. aureus* (Bergonier and

Berthelot 2003; Arsenault *et al.* 2008; Gelasakis *et al.* 2015). Current recommendations for treatment of ewes with clinical mastitis tend to be based on either clinical reports or extrapolated from cattle or goat studies (Bergonier and Berthelot 2003; Bergonier *et al.* 2003; Attili *et al.* 2016). However, it appears that bacteriological cure in ewes is difficult to achieve (Gelasakis *et al.* 2015); indicating it may be best to cull these ewes prior to the next breeding season.

Udder morphology scoring is utilised in dairy ewes as a selection tool to improve both ewe udder health and associated milk quality, and machine milkability (Casu *et al.* 2006, 2010). Dairy ewes can be observed daily during milking, allowing udder health and morphology data to be recorded for individual ewes. This is in contrast with non-dairy breed ewes where udder observations are typically infrequent and may be limited to weaning or prior to breeding to help inform culling decisions (Grant *et al.* 2016; Peterson *et al.* 2017). There appears to be a lack of data regarding application and relevance of udder morphology scores in non-dairy breed ewes, although recently there appears to be greater interest in development and application of an udder health and morphology scoring system in non-dairy ewes. For example, in the UK, increasing research focus has been directed at udder health in non-dairy breed ewes that extends to intramammary masses (palpable udder abnormalities) (Grant *et al.* 2016), on-farm measures of udder health (Cooper *et al.* 2016), udder morphology traits (Huntly *et al.* 2012), and phenotypic selection of ewes based on udder conformation (McLaren *et al.* 2018).

Grant *et al.* (2016) conducted 7,021 udder-scoring examinations in 10 non-dairy sheep flocks during a 2-year longitudinal study. Intramammary masses (IMM) were reported in 4.7% of ewes during pregnancy and 10.9% of ewes during lactation, while lambs born to ewes with IMM during lactation had lower daily growth rates (10g/day) (Grant *et al.* 2016). The presence of an IMM at one time-point was associated with an increased risk of subsequent IMM although IMM were not consistently present (Grant *et al.* 2016). Based on a survey of 329 sheep farms Cooper *et al.* (2016) reported associations between poor udder conformation, increasing mean number of lambs reared and lambing indoors, and increased risk of clinical mastitis. However, it is important to note poor udder conformation was not defined in the survey therefore it was unclear what farmers considered poor conformation, and farmers collected and reported the data used in analyses. Huntley *et al.* (2012) conducted a study involving 67 non-dairy ewes from one farm from lambing until lambs were 8-10 weeks old. Milk samples were collected for somatic cell counting (SCC) and the ewes had morphological udder scores measured at one time point (two weeks after lambing) based on a method used in dairy ewes described by Casu *et al.* (2006) (Huntley *et al.* 2012). They reported an association between poor udder conformation and high SCC (>400,000 cells/ml), and between high SCC and lamb weight (reduced weight with increased SCC) (Huntley *et al.* 2012).

Combined, these findings suggest it is worthwhile further investigating development of an udder and teat scoring system that is appropriate for use in non-dairy breed ewes, and which can be practically incorporated into a farm management system. At present, there is no standardised udder and teat scoring method that New Zealand sheep farmers can use, so ewes may be culled unnecessarily or conversely, kept when they are unsuitable for lamb rearing. Ideally, farmers would select ewes to cull (or retain) based on the predicted performance of their offspring, culling those whose lambs are predicted to have poor survival or poor growth to weaning. If such an udder and teat scoring system could be developed related to lamb survival and growth, it would enable farmers to identify ewes that are unsuitable for retention in the flock, or alternatively, require selective treatment (if appropriate).

*Relationship between ewe udder health and ewe mortality*

In New Zealand, recorded deaths from mastitis vary; Davis (1979) reported 2.3% of the deaths in his survey were attributable to mastitis, while Clark (1972) found total deaths from mastitis averaged 0.20% - 0.26% in the flocks surveyed. In Canada, Arsenault *et al.* (2008) reported a mortality rate of 12.8% in ewes with clinical mastitis, while the occurrence of clinical mastitis was associated with an increase in ewe mortality during lactation (OR 4.4, 95% CI: 1.1-17.8). In the UK Cooper *et al.* (2016) reported an average mortality rate of 3.1% in ewes that had mastitis. However, it is important to note that overseas lambing systems may vary compared to those in New Zealand (indoor *vs.* outdoor lambing) so care is required if extrapolating overseas results.

**Wastage associated with poor teeth health**

*Ewe teeth health and productivity*

Teeth wear in commercial ewes is important because of the potentially negative effect on production parameters (McGregor 2011). Excessive teeth wear and loss has been associated with decreased feed intake, particularly when pasture supply was limited (Coop and Abrahamson 1973). Teeth wear and loss has been associated with ewe liveweight and body condition score, with ewes with poor teeth having reduced liveweight and reduced body condition score (Coop and Abrahamson 1973; Sykes *et al.* 1974; Dove and Milne 1991). A reduction in lamb production has been reported for ewes that have poor teeth (Sykes *et al.* 1974; Dove and Milne 1991). However, it has been suggested that this may only be evident (or may be more pronounced) when ewes with poor teeth are placed under nutritional stress during late pregnancy and/or lactation (Barnicoat 1957; Sykes *et al.* 1974; Dove and Milne 1991). It is important to note, as it is very difficult to examine molar teeth in live ewes, the impact of poor molar teeth health on ewe productivity is largely unknown.

*Culling based on poor incisor teeth*

Ewes on commercial sheep farms are often culled due to incisor teeth problems (Coop and Abrahamson 1973; West *et al.* 2009; Ridler and West 2010; McGregor 2011). A recent survey in New Zealand by Corner-Thomas *et al.* (2013) reported 88% of both commercial and stud farmers examined their ewe’s teeth, with this being one of the most common management tools utilised by farmers. Presumably, farmers are using this information to help inform their culling decisions, culling those ewes that are identified as having poor teeth, but exact use is unknown. Mouthing ewes involves individually checking the incisor teeth, which can be time-consuming and difficult. The process of checking teeth and the decision to cull or retain cull ewes is subjective with variation likely between farms (Coop and Abrahamson 1973).

Orr *et al.* (1986) found 65% of farmers surveyed in the South Island of New Zealand culled ewes because of teeth problems. More recently in New Zealand, Ridler and West (2010) reported poor teeth as a common reason for farmers to cull ewes. In Northern Ireland, Annett *et al.* (2011) reported 19% of ewes culled were due to poor teeth condition. A similar result was reported in Ireland, with Keady (2014) reporting between 0% - 36.5% of ewes were annually culled due to poor teeth, with rates increasing as the ewes increased in age (from 2 – 6 years). Results of the ‘Longwool’ project (UK) (Anonymous 2016d) also reported an increasing proportion of ewes were culled for poor teeth with increasing age. Also in the UK, Mekkawy *et al.* (2009) reported ewes were mainly culled due to having unsound mouths (poor teeth), and as with other studies, the proportion culled due to poor mouths increased with increasing age. Additionally, ewes that are prematurely culled due to poor teeth are likely to fetch a lower sale price (West *et al.* 2009; McGregor 2011).

*Relationship between ewe teeth health and ewe mortality*

There is scant published data available examining the relationship between ewe teeth health and ewe mortality. However, given that poor teeth health has been associated with reduced liveweight, reduced body condition score, and poor productivity (Coop and Abrahamson 1973; Sykes *et al.* 1974; Dove and Milne 1991), it is possible these ewes are likely to be prematurely culled before they die on-farm. Ewes with poor teeth are more likely to have reduced feed intake (Coop and Abrahamson 1973), and a subsequent reduction in body condition score (Coop and Abrahamson 1973; Sykes *et al.* 1974; Dove and Milne 1991), and as such are potentially more likely to succumb to other diseases resulting in mortality.

### Wastage associated with body condition score

#### *Ewe body condition score (BCS) and productivity*

Body condition scoring of sheep is a quick, inexpensive and easily learned tool that was developed in the 1960's (Jefferies 1961; Russel *et al.* 1969). Body condition score (BCS) has inherent advantages over measuring liveweight alone, as it is not influenced by the size, shape, breed or physiological state of the ewe, or by gut fill (Jefferies 1961; Russel 1984; Kenyon *et al.* 2014b), which can be of particular relevance during periods of prolonged yarding and handling. Body condition score has also been shown to be closely linked to liveweight; allowing liveweight targets to be calculated from condition score targets (Kenyon *et al.* 2014b).

The technique for BCS has been well-described (Russel *et al.* 1969; Russel 1984; Kenyon *et al.* 2014b) allowing for the establishment of a standard measure across flocks/breeds. Body condition score is used to assess the amount of subcutaneous fat and soft tissue by palpation of the lumbar region of the backbone spinous and transverse processes (Russel 1984; Kenyon *et al.* 2014b), thus providing the assessor with a measure of the condition of the ewe, using a 1-5 scale (1=thin, 5=obese; see Figure 1.4). BCS is commonly measured to the nearest half score (Russel 1984; Kenyon *et al.* 2014b). BCS provides the assessor with an estimate of the proportion of fat in the live animal (Russel *et al.* 1969). The 'hands-on' palpation technique is required, as variation in wool cover means BCS cannot be accurately assessed by eye (Kenyon *et al.* 2014b).

In Australia, Jones *et al.* (2011) reported that although the vast majority of producers (96%) indicated they monitored the condition of their sheep, only 7% actually used the hands on technique described for body condition scoring. Also in Australia Trompf *et al.* (2011) reported increases in farmer use of BCS following participation in the Lifetime Ewe Management program (4% increasing to 94%), however these were farmer reported rates and it was unclear the method used, the frequency of BCS or the proportion of the flock that were BCS. In New Zealand, Corner-Thomas *et al.* (2016) found 60% of farmers had utilised BCS as a management tool at least once over a three-year period, an increase from 43% in 2012. However, from that study it was unclear whether the 'hands on' method was used, or if farmers estimated BCS by eye. Combined, these results indicate many farmers fail to understand the potential benefits of BCS and how BCS can be utilised within their flocks.

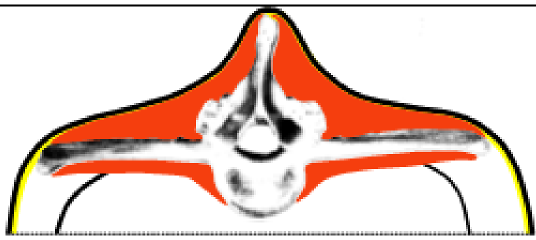
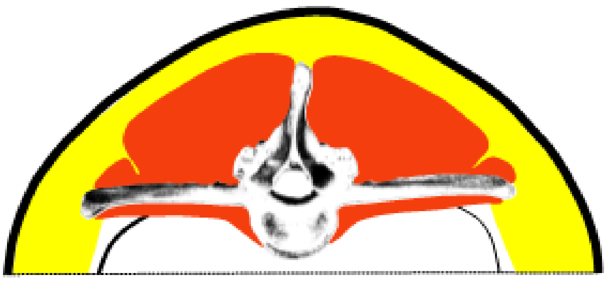
There are a number of reviews or papers examining the relationship between ewe BCS and performance; thus the relationship between BCS and various reproductive traits are well documented (see review by Kenyon *et al.* 2014b). There is a generally positive relationship between BCS and ewe reproductive traits. However, it is important to note, the relationship between ewe BCS and reproductive performance is not linear, as there is a BCS above which reproductive performance does not improve (Kenyon *et al.* 2014b). Higher ovulation rates and conception rates have been reported in ewes of greater BCS (Gunn and Doney 1979; Gunn *et al.* 1991; Kleemann and Walker 2005; Sejian *et al.* 2010). Studies have reported either no effect, or a positive effect, of ewe BCS on lamb survival to weaning (Kleemann and Walker 2005; Oldham *et al.* 2011; Kenyon *et al.* 2014b). As with lamb survival to weaning, studies have reported either no effect or a positive effect, of ewe BCS on lamb growth to weaning or lamb weaning weights (Kenyon *et al.* 2011a; Kenyon *et al.* 2012; Thompson *et al.* 2011). In addition, greater liveweight gain to weaning has been reported in lambs (single and twin born) born to ewes with a high pre-lambing BCS that then lose BCS prior to weaning, or in ewes that have a lower pre-lambing BCS but then gain BCS prior to weaning (Mathias-Davis *et al.* 2013). Therefore, farmers would ideally manage their ewes to achieve a high BCS prior to lambing, however, if they haven't managed to achieve that and there are poorer BCS ewes in the flock, the offspring of these ewes may benefit from their dams being drafted-off and preferentially fed.

The optimum BCS for a ewe from a production perspective is suggested to be 2.5-3.5 at breeding, 2.5-3.0 at lambing, with a minimum of 2.0 at weaning (Russel 1984; Kenyon *et al.* 2014b). At low BCS, performance is limited, while at very high BCS the return may not outweigh the inputs. Kenyon *et al.* (2014b) suggested farmers focus on achieving a minimum BCS rather than a flock average, which allows a proportion of the flock to be below the ideal.

However, a potential problem with the minimum BCS approach is that with flock-managed animals, when fed for a minimum BCS some ewes end up above the minimum target. Therefore, the ideal would be to reduce the BCS variation within a flock through targeted feeding management.

**Figure 1.4 A description of body condition score assessment in ewes (1-5 scale)**

**Sheep body condition scoring technique including illustrations of the vertebra and ribs showing the approximate muscle and fat distribution** (Adapted from Kenyon et al 2014)

| Grade | Description | Illustration |
|---|---|---|
| Score 1 | The spinous processes are prominent and sharp. The transverse processes are also sharp, with fingers passing easily under the end of this process. The eye muscle areas are shallow with little to no fat cover. |  |
| Score 2 | The spinous processes are smooth but still prominent. The individual processes can still be felt but only as fine corrugations. The transverse processes are smooth and rounded. However it is still possible to pass the fingers under the ends of the processes with some pressure. The eye muscle areas is of moderate depth, but has sparse fat cover. |  |
| Score 3 | The spinous processes are smooth and rounded, and individual bones can be only be felt with some pressure applied. The transverse processes are also smooth and are well covered. Firm pressure is required to feel over the ends. Eye muscle area is full and covered by a moderate degree of fat. |  |
| Score 4 | With pressure applied the spinous processes can just be detected. While the ends of the transverse processes cannot. Eye muscle areas are full with a thick covering of fat. |  |
| Score 5 | Even with firm pressure applied the spinous processes cannot be detected. Due to a high level of fat adjacent to the spinous process, a depression directly above where the spinous processes would normally be felt may be present. It is not possible to detect the transverse processes. The eye muscle areas are very full with very thick fat cover. It is possible to have significant deposits of fat cover over the rump and tail. |  |

*Culling based on poor body condition score (BCS)*

Poor body condition appears to be a cause of premature culling of commercial ewes. In Northern Ireland Annett *et al.* (2011) reported that it was common policy for farmers to cull their poor BCS ewes, with 4% of the total ewes culled because of poor BCS. In Ireland, Keady (2014) reported between 0% - 5.4% of ewes were annually culled because of poor body condition, with the proportion increasing as ewes aged (from 2 – 6 years). Similar relationships were reported in the UK by Anonymous (2016d). In New Zealand, the relationship between BCS and premature culling in commercially farmed ewes is not well documented. Further investigation into this relationship is required.

*Relationship between ewe body condition score (BCS) and ewe mortality*

Anderson and Heuer (2016) discussed farmer reported causes of ewe wastage, reporting 28.4% of ewes that were found dead on-farm were recorded as BCS 1.0, and was reported as likely causing the death of the ewe. In a non-published report, Anonymous (2014b) compared the performance of New Zealand commercial "tail end" ewes, which were defined as BCS 2.0 or less at breeding, with that of higher BCS ewes. They reported a higher mortality of tail end ewes (17% versus 10%), although no statistical analysis was performed. Similar results were reported in another non-published report (Anonymous 2017), which compared the effect of BCS at lambing, on mortality rates during the lambing period in Australian ewes. Ewes of BCS 1.5 had a greater mortality rate of 11%, compared with rates of 2% - 5% for ewes BCS 2.0 – 4.0. In Merino ewes in Australia, Kelly *et al.* (2014) examined mortality rates, reporting the risk of mortality increased seven-fold with each unit decrease in BCS. Annett *et al.* (2011) studied longevity and lifetime performance in Scottish blackface ewes and their crosses in hill sheep flocks in Ireland, reporting a reduced survival probability for ewes in poor BCS (BCS<2.0). At present, the relationship between BCS and mortality in commercially farmed ewes is not well documented, with further investigation into this required.

**Wastage associated with liveweight**

*Ewe liveweight and productivity*

Liveweight is affected by frame size and body condition score. It is therefore possible to have a large framed ewe that is heavy but with a poor BCS, or a small framed ewe that is relatively light but has a good BCS. Liveweight and condition score are often studied separately, although it has been shown they are closely linked (Kenyon *et al.* 2004a; Kenyon *et al.* 2014b), and therefore should likely be considered in conjunction. In an Australian survey, Jones *et al.* (2011) reported only 17% of respondent farmers "usually" weigh ewes. In New Zealand, Corner-Thomas *et al.* (2016) reported 50% of respondent farmers weighed ewes, an increase from 36% in the 2012; however, this survey did not provide information on the frequency or the proportion of the flock that was weighed.

The relationship between pre-breeding and breeding liveweight and fertility and fecundity in ewes has been well described. There is a positive linear relationship between both pre-breeding and breeding liveweight and ewe reproductive performance (Coop 1962; Allison and Kelly 1978; Kenyon *et al.* 2004a). However, there is a limit to this liveweight reproduction relationship in ewes, with the effects of increasing liveweight being reduced at very high liveweights (Rutherford *et al.* 2003; Kenyon *et al.* 2004a). The liveweight of a ewe also influences other aspects of productive performance, such as lamb birth weights, lamb survival and lamb growth rates (Brown *et al.* 2015). Studies have demonstrated under-nutrition in pregnancy and/or reduced ewe liveweight can negatively affect lamb birth-weight (Kelly 1992; Kenyon 2008; Oldham *et al.* 2011; Schreurs *et al.* 2012). Light lamb birth-weight is in itself associated with an increased risk of lamb mortality (Kenyon 2008; West *et al.* 2009; Oldham *et al.* 2011). In addition, Kelly (1992) and Oldham *et al.* (2011) reported mortality rates of lambs to be highly correlated with liveweight of ewes in pregnancy; with increases in ewe liveweight associated with reduced lamb mortality.

For each ewe there will be an optimum liveweight at which she is most productive and the greatest returns are seen (Brown *et al.* 2015). Kenyon *et al.* (2004a) suggested that farmers focus on achieving a minimum liveweight. A minimum liveweight is more useful than an average, as an average means a proportion of the flock are below the ideal liveweight.

*Culling based on poor liveweight*

There is a lack of data examining the relationship between culling and ewe liveweight, both in New Zealand and internationally. Further investigation into this relationship is required.

*Relationship between ewe liveweight and ewe mortality*

Coop (1962) examined ewe mortality and its potential relationship to liveweight, finding that mortality was independent of the liveweight of the ewe, except at very low weights (<40kg).

However, there is a lack of recent studies examining the relationship between ewe liveweight and mortality in New Zealand, therefore further investigation into this relationship is required.

### Wastage associated with ewe lamb breeding

*Ewe lamb breeding and productivity*

If managed appropriately ewe lamb breeding (bred at 7-9 months of age) can be utilised in the New Zealand pastoral based production system to increase the number of lambs available for sale each year (and therefore farm income), while concurrently increasing the ewe lamb's lifetime productivity (Kenyon *et al.* 2004b; Kenyon *et al.* 2008; Kenyon *et al*. 2011b; Corner *et al.* 2013a; Catley 2017). However currently less than 40% of ewe lambs are bred each year (Kenyon *et al*. 2014a; Edwards and Juengel 2017), indicating the majority of farmers perceive there are significant disadvantages or it is not worthwhile to breed their ewe lambs. Kenyon *et al.* (2014a) summarised the potential limitations, which can be grouped into two broad categories: management (increased feed demand, greater liveweight targets at younger ages, increased workload, reduced flexibility, poor management can affect future liveweight and productivity) and physiological factors (variable reproductive performance, poorer survival of lambs, lighter lambs and higher mortality rates).

If farmers choose to utilise ewe lamb breeding it is important the ewe lambs are appropriately managed (Kenyon *et al.* 2014a). Ewe lambs need to be well grown prior to breeding, and in New Zealand for Romney-type sheep a minimum liveweight of 40kg (preferably 65% of mature liveweight) and a BCS of 3.0 is recommended (Corner *et al.* 2013b; Kenyon *et al.* 2014a). Corner *et al.* (2013b) reported the reproductive performance of ewe lambs increased with increasing pre-breeding liveweight up to 55kg, after which there was no reported reproductive advantage. Ewe lambs should then be fed well through-out pregnancy (Morris *et al.* 2005; Corner *et al.* 2013a) in lactation and post-weaning (Corner *et al.* 2013a; Kenyon *et al.* 2008; Kenyon *et al.* 2014a), as they are still growing themselves.

A number of studies, including Baker *et al.* (1981), McMillan and McDonald (1983) and Kenyon *et al.* (2008), have reported that ewes that are bred as ewe lambs are lighter at subsequent two-tooth (18-months of age at breeding) breeding. However, they found the reduced liveweight had only a small effect on the two-tooth reproductive performance.

*Culling based on ewe lamb breeding performance*

Kenyon *et al.* (2011b) studied the effect of breeding Romney ewe lambs on lifetime performance, concluding that ewe lamb breeding resulted in greater lifetime reproductive performance without negatively affecting the longevity of the ewe. A similar result was reported by Baker *et al.* (1981). However, it is important to note this may vary depending on overall ewe lamb reproductive performance combined with an individual farm's culling policies. For example, ovulation and conception rates have been reported to be lower in ewe lambs than mature ewes (Kenyon *et al.* 2014a). In addition, lower survival rates have been reported for lambs born to ewe lambs compared to those born to mature ewes (Corner *et al*. 2013a; Kenyon *et al.* 2014a). Farmers may elect to cull bred ewe lambs that fail to rear a lamb, resulting in increased likelihood of wastage at a young age in ewe lambs that are presented for breeding. However, the relationship between ewe lamb breeding and subsequent risk of culling has not been investigated in large commercial flocks and therefore further investigation is required.

*Relationship between ewe lamb breeding and ewe mortality*

There is a lack of data examining the relationship between ewe lamb breeding and mortality, both in New Zealand and internationally. Further investigation into this relationship is required. However, given that ewe mortality is reported to increase over the lambing period (Ghazali 2007; Scott 2005; Dever *et al.* 2017), it is likely pregnant ewe lambs may have a greater risk of mortality when compared to non-bred (and therefore non-pregnant) ewe lambs. In addition, the effect of ewe lamb breeding on subsequent risk of mortality in later years is unknown, with further investigation required.

# Chapter 2

# General Materials and Methods

# Introduction

There are two main experimental components to this thesis. The first, ewe wastage and associated measures of productivity (Chapters 3, 4 and 5), and the second, ewe udder health and its association with lamb survival and growth to weaning (Chapters 6 and 7). Each of these two experimental components used different animals and methodology, with general materials and methods for each described below. This chapter aims to provide general methodology and context for the following experimental chapters, with detailed materials and methods that are specific to each chapter described within each respective chapter.

# Chapters 3, 4 and 5

### Farms and Animals

The ewe wastage study commenced in March 2011, with data collection concluding in December 2017. In total, 13,142 replacement ewe lambs were enrolled from three different commercial flocks (Farm A, Farm B and Farm C). Farms were recruited as they were large commercial North Island flocks with large numbers of replacement ewes, and were willing to commit to participating in a longitudinal study. Enrolment of study ewes was undertaken when ewes were approximately 5-6 months of age, with each enrolled ewe lamb tagged with an electronic identification tag (EID; Alflex, Palmerston North, New Zealand) at this time. For each of the commercial farms, all replacement ewe lambs present within the flock, for that respective year, were enrolled. All ewes that participated in the study were managed as part of the wider commercial flocks.

Farm A was located in the Waikato region (3,219 ha), with a flock of semi-stabilised composite ewes consisting of Coopworth and East Friesian genotypes. Two cohorts of ewe lambs from Farm A were enrolled: 2010-born (n=3,717) and 2011-born (n=4,609). Farm B was located in the Wairarapa region (2,952 ha), and included Romney ewes that were 2011-born (n=3,998). Farm C was also located in the Wairarapa region (476 ha), and included Romney ewes that were 2014-born (n=818).

### General management

Throughout the study period, the flock managers/owners did not change their routine (normal) management of their flock, and continued to manage the cohorts as part of the larger commercial flock.

*Reproductive management*

On Farm A and Farm C, all enrolled ewe lambs were joined with rams regardless of pre-breeding liveweight (7-8 months old at breeding). On Farm B, only selected ewe lambs (approximately 38kg and above) were joined with rams (n=2,222; 55.6%). In subsequent years, all ewes present on each farm were presented for breeding.

Each year, during mid-pregnancy, pregnancy diagnosis (PD) was undertaken by transabdominal ultrasound scanning by an experienced operator. At PD ewes were identified as either non-pregnant (no fetus), single (one fetus) or multiple bearing (two or more fetuses). Prior to lambing each year, ewes were set-stocked. Set stocking involved allocating ewes into paddocks at a rate of approximately 6-12 ewes per hectare. During the lambing period, ewes on Farm A were observed every 2-3 days, while on Farm B and C they were observed daily. If seen, any obvious problems such as dystocia, vaginal prolapse or cast ewes were resolved, however their incidence was not recorded, and no attempt was made to revive weak lambs or to mother-on or artificially rear orphaned lambs, as per normal practice on these farms. Live and dead lambs were not counted during the lambing period. Three to six weeks after parturition, the ewes and their offspring were gathered into handling facilities for tail removal and castration of the male offspring (docking). At this time, the flock manager palpated the udder of each ewe and an assessment was made as to whether she was actively lactating (wet) or not (dry). Lambs were separated from their dams (weaning) when lambs were approximately 14-16 weeks old.

*Grazing management*

As these ewes were part of commercial flocks, they were grazed under typical New Zealand extensive pastoral conditions, on permanent pasture consisting of predominantly ryegrass and white clover. Ewes were rotationally grazed throughout the year, with the exception that they were set stocked each year prior to lambing. Grazing decisions were solely made by the farm managers to mimic commercial conditions. Each year, on Farm B and Farm C, set stocking occurred one to four weeks prior to the planned start of lambing. However, on Farm A set stocking time varied between years; ewes were set stocked one to four weeks prior to the planned start of lambing in 2011, 2012 and 2015, however in 2013, 2014 and 2017 ewes were set stocked immediately following PD. As these were commercial flocks, no pasture measurements were taken at any stage.

### Data collection

Researchers visited each of the farms at four key management times each year: prior to breeding (pre-mating), at PD, at set stocking (where set stocking occurred within four weeks of lambing) and at weaning.

*Weight and Body Condition Score (BCS)*

At each visit all ewes were weighed (to the nearest 0.5 kg) and body condition score (BCS) was assessed by the study researchers. Body condition scoring was undertaken by assessing the soft tissues over the lumbar region, using a 1-5 scale (where 1=thin; 5=obese), assessed to the nearest 0.5 of a BCS (Jefferies 1961; Kenyon *et al.* 2014).

*Cull data*

On each farm, ewes were culled at the flock managers' discretion as per routine farm policy. At the time of culling, each ewe had her EID tag number, date of culling and reason for culling recorded by the flock manager.

All study flocks culled ewes for age after Year 6 weaning (remaining ewes were 6-years-old at lambing in Year 6).

*Mortality data*

On all farms, any ewe that was found dead on-farm had their EID tag number and the interval in which they were found recorded by the flock manager. However, data was not collected on every death due to the extensive nature of these farms and the frequency of observation. Cause of death was not determined for any ewe. If a ewe was absent from the last visit and not recorded as present at any of the subsequent visits then it was presumed dead and classified as dead/missing. Missing ewes were presumed to have died in the interval between the last visit they were recorded as present and the visit immediately subsequent.

## Chapters 6 and 7

### Farms and Animals

The udder study ewes (n=1,009) were mixed-age, mature Romney ewes that were born in 2013 or 2014 and were part of a commercial sheep flock located in the Wairarapa region. Ewes were individually identified using both an electronic identification tag (EID; Allflex, Palmerston North, New Zealand) and a visual identification tag (VID; Allflex, Palmerston North, New

Zealand). All ewes enrolled in the study flock had lambed previously. Nutritional management was as per a commercial farm, with grazing decisions made solely by the farm manager.

### Data Collection

*Udder scoring and lamb productivity data*

In 2017, ewes had a range of udder and teat scores measured at four key management times: pre-mating, pre-lambing, docking and weaning. The udder and teats of each ewe were scored using both visual assessment and hands-on palpation techniques, with ewes in both standing and sitting positions (see further detail in Chapters 6 & 7).

During the lambing period each newborn lamb was matched to its' dam and lamb birthweight, birth rank and sex were recorded. Lamb mortalities were recorded throughout the lactation period. All live lambs were weighed again at weaning.

*Weight and Body Condition Score (BCS)*

All ewes were weighed (to the nearest 0.1kg) and body condition score (BCS) was assessed prior to breeding, at PD and at set stocking (prior to lambing).

# Chapter 3

# Investigating ewe wastage in New Zealand commercial flocks

## Abstract

AIMS: Firstly, to establish and describe the extent, timing and cause of ewe wastage in commercial New Zealand ewe flocks. Secondly, to investigate the association between reproductive outcomes as a ewe lamb and risk of wastage. Finally, to investigate if pre-mating body condition score (BCS) could be used as a predictor of ewe wastage in that production year. Ewe wastage was defined as a combination of premature culling and on-farm mortality (dead/missing ewes).

METHODS: The study used data collected from 13,142 individually identified commercial ewes from four cohorts on three farms during the period 2011 – 2017, as the ewes aged from replacement ewe lambs to 6-year-old ewes. Each year, data collection visits occurred at four key management times. Ewes were weighed and BCS recorded at each visit. On each farm, ewes were culled at the flock managers' discretion as per routine farm policy and date and reason for culling recorded. Any ewe that was found dead on farm had their tag number and interval in which they were found recorded. Each ewe was assigned an outcome and corresponding exit interval. To account for competing risks (premature culling and mortality) using interval censored data, the data were analysed using semiparametric competing risks regression under interval censoring using the R package "intccr".

RESULTS: Of the 13,142 enrolled ewes, 50.4% (n=6,629) exited their respective flocks due to premature culling, 40.0% (n=5,253) due to on-farm dead/missing, 5.1% (n=676) were culled due to age and 4.4% (n=584) were right censored, giving a total of 90.4% (n=11,882) that exited due to wastage. Annual mortality rates ranged from 3.5% - 20.8% in Years 1 – 5 and 7.0% - 40.2% in Year 6. In Year 1, wastage for each cohort ranged from 7.6% - 45.4% of ewe lambs enrolled. Ewes that were presented for breeding as a ewe lamb but dry at PD as a ewe lamb had 28.1% greater odds of wastage due to premature culling compared to ewes that were not presented for breeding as a ewe lamb (OR=1.281; p=0.032). There was no difference in risk of wastage due to premature culling of those that were bred as a ewe lamb and dry at docking (p=0.471) or those that were bred as a ewe lamb and wet at docking (p=0.818), compared to those that were not presented for breeding as a ewe lamb. There was no association between reproductive outcomes as a ewe lamb and risk of wastage due to dead/missing (p>0.2 for all groups). In all years, pre-mating BCS could be used as a predictor of ewe wastage with odds of wastage lower with increasing ewe BCS.

CONCLUSIONS: To the authors' knowledge, this is the first study that reports both lifetime wastage and detailed annual wastage in commercial New Zealand ewe flocks. Wastage as a ewe lamb represents an area in which improvements can be made to reduce overall wastage. To reduce ewe lamb wastage, farmers need to consider on-farm mortality rates, management practices to improve ewe lamb reproductive performance, and evaluation of their culling policies. In addition, further investigation into causes of, and risk factors associated with, ewe mortality in New Zealand flocks is required. Ewes with greater pre-mating BCS had lower odds of wastage due to both premature culling and mortality, therefore farmers should focus on improving pre-mating BCS. To achieve this, farmers could assess BCS of their ewes at weaning, enabling poor BCS ewes to be identified, drafted off and managed to gain BCS before breeding.

## Introduction

Productive longevity is the ability of a ewe to survive and be productive until she is culled for age. In New Zealand commercial flocks the age at which ewes are culled due to age varies between farms, but is typically around six to seven years of age (Farrell *et al.* 2019). Ewe wastage is defined as a combination of both on-farm mortality and premature culling. Premature culling is where a ewe is culled prior to the potential end of her productive lifespan; either to slaughter, direct sale, or via slaughter on-farm.

Increased ewe wastage results in a reduction in farm productivity and subsequent ability to generate profit (Farrell *et al.* 2019). However, there is a lack of research on actual wastage in commercial ewe flocks in New Zealand (Farrell *et al.* 2019). To maintain consistent breeding ewe flock numbers replacement ewe lambs are required, with numbers of replacements needed equalling the combined annual total of ewes that are culled for age and ewes that are lost to wastage. Therefore, flocks that have higher wastage rates require an increased proportion of replacement ewe lambs. Rearing additional replacement ewe lambs to a productive age (or purchasing additional replacements) incurs a number of costs (Turner *et al.* 1958; McHugh 2012), including fewer sale lambs, increased management and feed costs, reduced selection pressure and potential biosecurity risks. In addition, the reproductive performance of ewes increases as they age (Edwards and Juengel 2017), so having an unnecessarily high proportion of younger ewes in a flock, due to increased wastage rates, reduces overall flock productivity due to a lower average flock age (Farrell *et al.* 2019). Combined, this indicates that it is important for replacement ewe lambs to remain in a flock, and be productive, for a sufficient period to be economically efficient (Conington *et al.* 2001; Douhard *et al.* 2016).

It is important to note variability and potential inaccuracy in recording wastage rates in extensively managed flocks, such as those in New Zealand. This is due to variation in farm topography and flock size, which in turn influences farm management structure, human contact with individual ewes within the flock and perceived likelihood of wastage (Trompf *et al.* 2011; Kelly *et al.* 2014, Doughty *et al.* 2019). In addition, in extensive production systems, ewes are typically managed as a flock, with management decisions based on flock needs rather than individual animal needs *per se*. This presents a particular challenge when investigating wastage in New Zealand commercial flocks as ewe numbers are typically based on flock totals at key times of the year (for example pregnancy diagnosis and shearing) and, in some instances an annual stock reconciliation, rather than individual ewe data. The recent introduction of electronic identification (EID) tags for use in sheep has provided farmers with a relatively straightforward means of tracking individual ewes within a flock, if they choose to utilise it, although to date use rates in New Zealand are relatively low (Corner-Thomas *et al.* 2016). However, if used this technology provides an opportunity to more accurately monitor ewe wastage at an individual-level.

In New Zealand, reported annual ewe mortality rates range from 2.8% - 27.0% (Pyke 1974; Davis 1979; Ghazali 2007; Anderson and Heuer 2016). Ghazali (2007) reported an increase in incidence in ewe mortality in a New Zealand commercial flock over the lambing period. Ewe mortality has additional costs when compared to premature culling, as cull sale-value is not obtained and there are likely increased welfare costs associated with on-farm mortality (Munoz *et al.* 2018; Stafford 2013). To the authors' knowledge there are no published reports directly examining premature culling policies in New Zealand commercial sheep flocks. However, it is likely commercial farmers select ewes to cull based on either known poor performance (for example not pregnant (dry) at pregnancy diagnosis), predicted poor performance (for example ewes whose lambs are predicted to have poor survival or poor growth to weaning) or poor ewe health. For commercial farmers, it would be optimal if they were able to identify ewes that are likely to be poor performing or at greater risk of wastage, prior to breeding. This would enable management interventions to be put in place to improve ewe performance and reduce risk of wastage.

There is a common concern among New Zealand commercial farmers that ewe lamb breeding may result in increased risk of ewe wastage (Kenyon *et al.* 2014a). However, there is limited published data evaluating this (Kenyon *et al.* 2014a), therefore further investigation is needed. Poor ewe body condition score (BCS) appears to be associated with ewe wastage (Annett *et al.* 2011; Anderson and Heuer 2016) both in New Zealand and overseas. Poor BCS is reported as a common reason for premature culling of ewes in Ireland and the UK (Annett *et al.* 2011; Keady 2014; Anonymous 2016d); however, the relationship between BCS and premature culling in New Zealand commercially farmed ewes is not well documented. In addition, poor BCS has been reported as a cause of ewe mortality (Anderson and Heuer 2016), while others have reported higher mortality rates in poor BCS ewes (Anonymous 2014b; Kelly *et al.* 2014; Anonymous 2017). At present, the relationship between BCS and ewe wastage is not well documented, with further investigation required.

The present study had three aims: firstly, to establish and describe the extent, timing and general cause of ewe wastage (premature culling or mortality) in commercial New Zealand ewe flocks. Secondly, to investigate the association between reproductive outcomes as a ewe lamb and risk of wastage. It was hypothesised that ewes that were bred as a ewe lamb would have greater risk of wastage. The final aim was to investigate if pre-mating BCS could be used as a predictor of ewe wastage in that production year. It was hypothesised that ewes that had poorer body condition scores would have a greater risk of wastage.

## Materials and Methods

### Farm and animals

The present study utilised data collected from 13,142 commercial ewes during the period 2011 – 2017, as the ewes aged from replacement ewe lambs (7-8 months) to 6-year-old ewes (Farms A and B) or to 3-year-old ewes (Farm C) (Chapter 2). As outlined in Chapter 2, all ewes that participated in the study were managed as part of three larger commercial flocks on pastoral based sheep and beef farms (Farm A, Farm B and Farm C). Throughout the study period, the flock managers did not change their routine (normal) management of their flock, and continued to manage the cohorts' as part of the larger commercial flock. Enrolment occurred when study ewes were approximately 7-8 months of age: with each enrolled ewe lamb tagged with an electronic identification tag (EID; Alflex, Palmerston North, New Zealand) at this time. For each of the farms, all replacement ewe lambs present within the flock, for that respective year, were enrolled.

Farm A was located in the Waikato region, with a flock of semi-stabilised composite ewes consisting of Coopworth and East Friesian genotypes. Two cohorts of ewe lambs from Farm A were enrolled: 2010-born (n=3,717) and 2011-born (n=4,609). Farm B was located in the Wairarapa region, and included Romney ewes that were 2011-born (n=3,998). Farm C was also located in the Wairarapa region, and included Romney ewes that were 2014-born (n=818). General management, reproductive management and grazing management were as previously outlined in Chapter 2.

On Farm A and Farm C, all enrolled ewe lambs were joined with rams regardless of pre-breeding liveweight (7-8 months old at breeding). On Farm B, only selected ewe lambs (approximately 38kg and above) were joined with rams. In subsequent years, all ewes present on each farm were presented for breeding. Farms A and B routinely culled ewes for age following 6-year-old weaning; hence, any remaining ewes were censored at this time. For the Farm C cohort, all remaining ewes were sold in Year 3, and were therefore censored at this time.

### Data collection

During each year, farm visits occurred at four key management times: prior to breeding (pre-mating (PM)), at pregnancy diagnosis (PD), at set stocking (where set stocking occurred within four weeks of lambing; pre-lambing) and at weaning (W). A summary of the timing of each of the data collection visits, with reference to calendar date, management visit and time (in days) since enrolment (where Day 0 = day of enrolment), is presented in Table 3.1. To enable standardisation and subsequent comparison between cohorts, a mean 'days since enrolment' was assigned to each data collection visit (Table 3.1). This was calculated using the mean of Farm A 2010- and 2011-born and Farm B cohorts, but excluding Farm C, as they were enrolled at a later management time than the other cohorts (enrolment for the Farm C cohort occurred in the PM-PD interval, rather than immediately prior to breeding as in other cohorts (Table 3.1)).

*Weight and Body Condition Score (BCS)*

At each visit all study ewes were weighed (to the nearest 0.5 kg) and body condition score (BCS) was assessed. Body condition scoring was undertaken by assessing the soft tissues over the lumbar region, using a 1-5 scale (where 1=thin; 5=obese), assessed to the nearest 0.5 of a BCS (Jefferies 1961; Kenyon *et al.* 2014).

*Cull data*

On each farm, ewes were culled at the flock managers' discretion as per routine farm policy. At the time of culling, each ewe had her EID tag number and date of culling recorded.

*Mortality data*

On all farms, any ewe that was found dead on-farm had their EID tag number and the interval in which they were found recorded, with the EID tags collected at the subsequent visit. However, data was not collected on every death due to the extensive nature of these farms and the frequency of observation. Cause of death was not determined for any ewe.

**Table 3.1 Summary of timing of each of the data collection visits, for each cohort of ewes in a ewe wastage study. With reference to: year-of-age (years 1-6), management visit within each year (pre-mating, pregnancy diagnosis (PD), set-stocking and weaning), calendar date (date), time in days since enrolment (DSE; where Day 0 = day of enrolment) and mean days since enrolment (Mean DSE)**

| | | **Year 1 (ewe lamb; 1-year-old at lambing)** | | | | **Year 2 (two-tooth; 2-years-old at lambing)** | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | **Pre-mating** | **PD** | **Set-stocking** | **Weaning** | **Pre-mating** | **PD** | **Set-stocking** | **Weaning** |
| **Farm A 2010-born** | Date | 11.4.11 | 14.7.11 | 10.8.11 | 20.12.11 | 8.3.12 | 13.6.12 | 16.7.12 | 13.12.12 |
| | DSE | 0 | 94 | 121 | 253 | 332 | 429 | 462 | 612 |
| **Farm A 2011-born** | Date | 11.4.12 | 23.7.12 | 21.8.12 | 6.12.12 | 12.3.13 | 18.6.13 | - | 19.12.13 |
| | DSE | 0 | 103 | 132 | 239 | 335 | 433 | - | 617 |
| **Farm B** | Date | 1.4.12 | 2.8.12 | 12.9.12 | 9.1.13 | 9.3.13 | 25.6.13 | 20.8.13 | 6.12.13 |
| | DSE | 0 | 123 | 164 | 283 | 352 | 450 | 506 | 614 |
| **Farm C** | Date | n.a. | 27.7.15 | 15.9.15 | 15.1.16 | 23.3.16 | 30.6.16 | 22.8.16 | 12.12.16 |
| | DSE | n.a. | 27 | 77 | 199 | 267 | 366 | 419 | 531 |
| | **Mean DSE*** | | 107 | 139 | 258 | 340 | 437 | 484 | 615 |

n.a. Not applicable, as enrolment had not occurred either at, or prior, to this visit
- Data not collected for this visit, as set-stocking occurred >4 weeks prior to lambing
*based on data from both cohorts from Farm A and from Farm B

**Table 3.1 Summary of timing of each of the data collection visits, for each cohort of ewes in a ewe wastage study. With reference to: year-of-age (years 1-6), management visit within each year (pre-mating, pregnancy diagnosis (PD), set-stocking and weaning), calendar date (date), time in days since enrolment (DSE; where Day 0 = day of enrolment) and mean days since enrolment (Mean DSE)**

| | | Year 3 (four-tooth; 3-years-old at lambing) | | | | Year 4 (six-tooth; 4-years-old at lambing) | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | **Pre-mating** | **PD** | **Set-stocking** | **Weaning** | **Pre-mating** | **PD** | **Set-stocking** | **Weaning** |
| **Farm A 2010-born** | Date | 13.3.13 | 17.6.13 | - | 18.12.13 | 11.3.14 | 18.6.14 | - | 15.12.14 |
| | DSE | 701 | 798 | - | 982 | 1,065 | 1,164 | - | 1,344 |
| **Farm A 2011-born** | Date | 11.3.14 | 18.6.14 | - | 15.12.14 | 11.3.15 | 9.6.15 | 20.7.15 | 7.12.15 |
| | DSE | 699 | 798 | - | 978 | 1,064 | 1,154 | 1,195 | 1,335 |
| **Farm B** | Date | 3.3.14 | 17.6.14 | 4.8.14 | 28.11.14 | 23.3.15 | 18.6.15 | 5.8.15 | 26.11.15 |
| | DSE | 701 | 807 | 855 | 955 | 1,086 | 1,173 | 1,221 | 1,334 |
| **Farm C#** | Date | 17.3.17 | 20.6.17 | | | | | | |
| | DSE | 626 | 721 | | | | | | |
| | **Mean DSE*** | 700 | 801 | 855 | 972 | 1,072 | 1,164 | 1,208 | 1,338 |

- Data not collected for this visit, as set-stocking occurred >4 weeks prior to lambing
#All ewes remaining in the Farm C cohort at Year 3 PD were sold to another farmer at that time point and were therefore right censored to reflect this
*based on data from both cohorts from Farm A and from Farm B

**Table 3.1 Summary of timing of each of the data collection visits, for each cohort of ewes in a ewe wastage study. With reference to: year-of-age (years 1-6), management visit within each year (pre-mating, pregnancy diagnosis (PD), set-stocking and weaning), calendar date (date), time in days since enrolment (DSE; where Day 0 = day of enrolment) and mean days since enrolment (Mean DSE)**

| | | Year 5 (mixed-age; 5-years-old at lambing) | | | | Year 6 (mixed-age; 6-years-old at lambing) | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | **Pre-mating** | **PD** | **Set-stocking** | **Weaning** | **Pre-mating** | **PD** | **Set-stocking** | **Weaning** |
| **Farm A 2010-born** | Date | 11.3.15 | 9.6.15 | 20.7.15 | 7.12.15 | 2.3.16 | 6.6.16 | - | 13.12.16 |
| | DSE | 1,430 | 1,520 | 1,561 | 1,701 | 1,787 | 1,883 | - | 2,073 |
| **Farm A 2011-born** | Date | 2.3.16 | 6.6.16 | - | 13.12.16 | 28.2.17 | 8.6.17 | - | 23.12.17 |
| | DSE | 1,421 | 1,517 | - | 1,707 | 1,784 | 1,884 | - | 2,081 |
| **Farm B** | Date | 25.2.16 | 16.6.16 | 1.8.16 | 25.11.16 | 15.2.17 | 16.6.17 | 4.8.17 | 28.11.17 |
| | DSE | 1,425 | 1,537 | 1,583 | 1,699 | 1,781 | 1,902 | 1951 | 2,067 |
| **Farm C#** | Date | * | * | * | * | * | * | * | * |
| | DSE | * | * | * | * | * | * | * | * |
| | **Mean DSE*** | 1,426 | 1,525 | 1,572 | 1,702 | 1,784 | 1,890 | 1,951 | 2,074 |

- Data not collected for this visit, as set-stocking occurred >4 weeks prior to lambing
#All ewes remaining in the Farm C cohort at Year 3 PD were sold to another farmer at that time point and were therefore right censored to reflect this.
*based on data from both cohorts from Farm A and from Farm B

## Statistical analysis

All statistical analyses were conducted using either SAS (SAS Institute Inc., Cary, USA, Version 9.4) or R (R, Version 3.6.0 for Windows, 64-bit).

### *Lifetime wastage and related descriptive statistics*

As this was a ewe lifetime study, each ewe was assigned an outcome. By the end of the study, all enrolled ewes had exited their respective flocks, were classified as either 1=prematurely culled, 2=dead/missing, or 3=censored, and either the exact date or interval in which they exited the flock was known. In this study, ewe wastage was defined as a combination of classifications 1 and 2 i.e. premature culling and dead/missing. Dead/missing ewes were considered a proxy for on-farm mortality.

#### *Assignment of 'exit-age' and outcome for each study ewe*

The assigned 'exit age' reflects the time the ewe remained in the flock following enrolment. If a ewe was recorded as prematurely culled then the date of culling was known, allowing assignment of an 'exit age' for that ewe. However, to allow for comparison between flocks, this date was adjusted to correspond to the mean 'days since enrolment' used across all flocks (Table 3.1). If the ewe was absent from the last visit, and was not recorded as present at any of the subsequent measurement visits, then it was classified as dead/missing in the interval between the 'last recorded date' (i.e. the visit the ewe was last recorded as present) and the visit immediately subsequent. This enabled assignment of a 'minimum exit age' (last recorded date) and a 'maximum exit age' (visit immediately subsequent) for each of these ewes; therefore providing the interval in which they exited the flock. To allow for comparison between flocks, the interval used the 'mean days since enrolment' used across all flocks (Table 3.1). As all study flocks culled ewes for age after the Year 6 weaning visit, any ewes present in the flock at this time were right-censored to reflect culling for age, rather than wastage. All ewes remaining in the Farm C cohort at Year 3 PD were sold to another farmer at that time point, and were therefore right-censored at that time to reflect this. Set-stocking data was not collected for Farm A cohorts in some years (Table 3.1) so to allow for this inconsistency the intervals used in reporting and analyses of wastage data were pre-mating to pregnancy diagnosis (PM-PD), pregnancy diagnosis to weaning (PD-W) and weaning to pre-mating (W-PM); as these were comparable across all study cohorts.

*Competing risks models*

To account for competing risks using interval-censored data, the data were analysed using semiparametric competing risks regression under interval censoring using the R package “intccr”, using the methodology described by Park *et al.* (2019). In the present analyses the two competing events (outcomes) were wastage due to premature culling (c = 1), and wastage due to dead/missing (c = 2) with remaining ewes censored (c = 0).

Firstly, for each of the models (outlined below), a 10% random sample of the relevant dataset was selected, and four preliminary models were applied to the data. Each of these preliminary models returned only the estimated regression coefficients without calculating the bootstrap variance-covariance matrix for the estimated regression coefficients. The preliminary models were subdistribution hazards models for both outcomes (c = 1, c = 2), proportional odds for both outcomes (c = 1, c = 2), subdistribution hazards for the first outcome (c = 1) and proportional odds for the second outcome (c = 2), and proportional odds for the first outcome (c = 1) and subdistribution hazards for the second outcome (c = 2). The model with the best fit was selected based on each model’s log likelihood. The final models used the entire dataset and 50 bootstrap samples to compute the variance-covariance matrix. Odds-ratios and corresponding p-values are calculated from the final models. In addition, for the models examining the associations between pre-mating BCS and risk of ewe wastage the mean cumulative incidence for each outcome (premature culling and dead/missing) were predicted for ewes from each cohort (Farm A 2010- and 2011-born, Farm B) on the basis of BCS (BCS 2.0 *vs.* BCS 3.5).

*Association between reproductive outcomes as a ewe lamb and risk of wastage to Year 6 weaning on Farm B*

This model included only ewes from the Farm B cohort, as they were the only cohort that had both ewe lambs that were presented for breeding and ewe lambs that were not presented for breeding, and were the only cohort that did not cull any ewes based on reproductive outcomes as a ewe lamb (i.e. all dry at PD and dry at docking ewe lambs were retained in the flock). For a ewe to be included in the model, their reproductive outcome as a ewe lamb had to be known and they had to be present in the flock at Year 2 pre-mating (the start point of the model). Ewes were classified into four categories based on ewe lamb reproductive outcome: 1 = not presented for breeding as a ewe lamb, 2 = presented for breeding as a ewe lamb and dry at PD, 3 = bred as a ewe lamb and dry at docking, and 4 = bred as a ewe lamb and wet at docking. For this model, the predictor variable was ewe lamb reproductive outcome. The final chosen model was proportional odds for both outcomes.

*Associations between pre-mating body condition score (BCS) and risk of ewe wastage in that production year*

For a ewe to be included in the model, they had to be present in the study cohort at the start of that year (pre-mating), and have had a BCS recorded at the pre-mating time point. Each production year (pre-mating to the following pre-mating) was analysed separately, with a production year defined as pre-mating to the subsequent pre-mating (i.e. pre-mating Year 1 to pre-mating Year 2). For each model, the predictor variable was pre-mating BCS, while each model also included additional covariates of cohort (Farm A 2010-born and 2011-born, Farm B, and Farm C). The final chosen model for each year was proportional odds for both outcomes.

## Results

### Lifetime survival and Descriptive statistics

Of the 13,142 ewes enrolled in the study, 50.4% (n=6,629) exited their respective flocks due to premature culling, 40.0% (n=5,253) due to on-farm dead/missing, while only 5.1% (n=676) were culled due to age (i.e. made it to the end of Year 6) and 4.4% (n=584) were right censored (i.e. they were lost to the study), giving a total of 90.4% (n=11,882) that exited due to wastage (Table 3.2).

**Table 3.2 Number and percentage (%) of ewes that were enrolled in the study and subsequently classified as dead/missing, culled or culled for age, following exit of all ewes from each cohort*, for each enrolled cohort, and as an overall across cohorts. Where n represents total enrolled ewes for each cohort, and overall across cohorts**

| | Farm A 2010-born | Farm A 2011-born | Farm B | Farm C* | Overall* |
|---|---|---|---|---|---|
| Total enrolled (n) | 3,717 | 4,609 | 3,998 | 818 | 13,142 |
| Dead/Missing | 1,494 | 1,515 | 2,172 | 72 | 5,253 |
| % of n | 40.2% | 32.9% | 54.3% | 8.8% | 40.0% |
| Prematurely culled | 2,190 | 3,006 | 1,271 | 162 | 6,629 |
| % of n | 58.9% | 65.2% | 31.8% | 19.8% | 50.4% |
| Culled for age | 33 | 88 | 555 | - | 676 |
| % of n | 0.9% | 1.9% | 13.9% | - | 5.1% |

*Note, for Flock C, any ewes remaining at Year 3 PD (n=584) were sold and were therefore right censored at this time

*Lifetime wastage*

Ewe wastage from enrolment to Year 6 weaning, where all remaining ewes were culled for age, is shown in Figure 3.1. Actual recorded numbers of ewes that exited each cohort during each interval and production year are shown in Appendix 1, which displays wastage of the ewes over their lifetime. In Year 1, wastage for each cohort ranged from 7.6% - 45.4% of ewe lambs enrolled (Figure 3.2). The Farm B cohort had the lowest wastage as ewe lambs (7.6%), but did not cull any ewe lambs for poor reproductive performance (non-pregnant, or those that were identified as pregnant but subsequently failed to rear their lamb(s) (dry at docking)). In contrast, both Farm A 2010-born and Farm C culled non-pregnant ewe lambs, while only Farm A 2011-born culled non-pregnant ewe lambs as well as those that were dry at docking.  For both Farm A cohorts, wastage was highest when ewes were younger and older, while for the Farm B cohort, the general trend was for wastage to increase as ewes aged (Figure 3.2). For the Farm C cohort, wastage was greater as ewe lambs, compared to two-tooths, however wastage could not be evaluated beyond this as all remaining ewes were censored in Year 3 (Figure 3.2).

**Figure 3.1 Interval censored ewe wastage (premature culling and on-farm mortality) from enrolment (Time = 0) to Year 6 weaning (Time = 2,074), stratified by cohort**

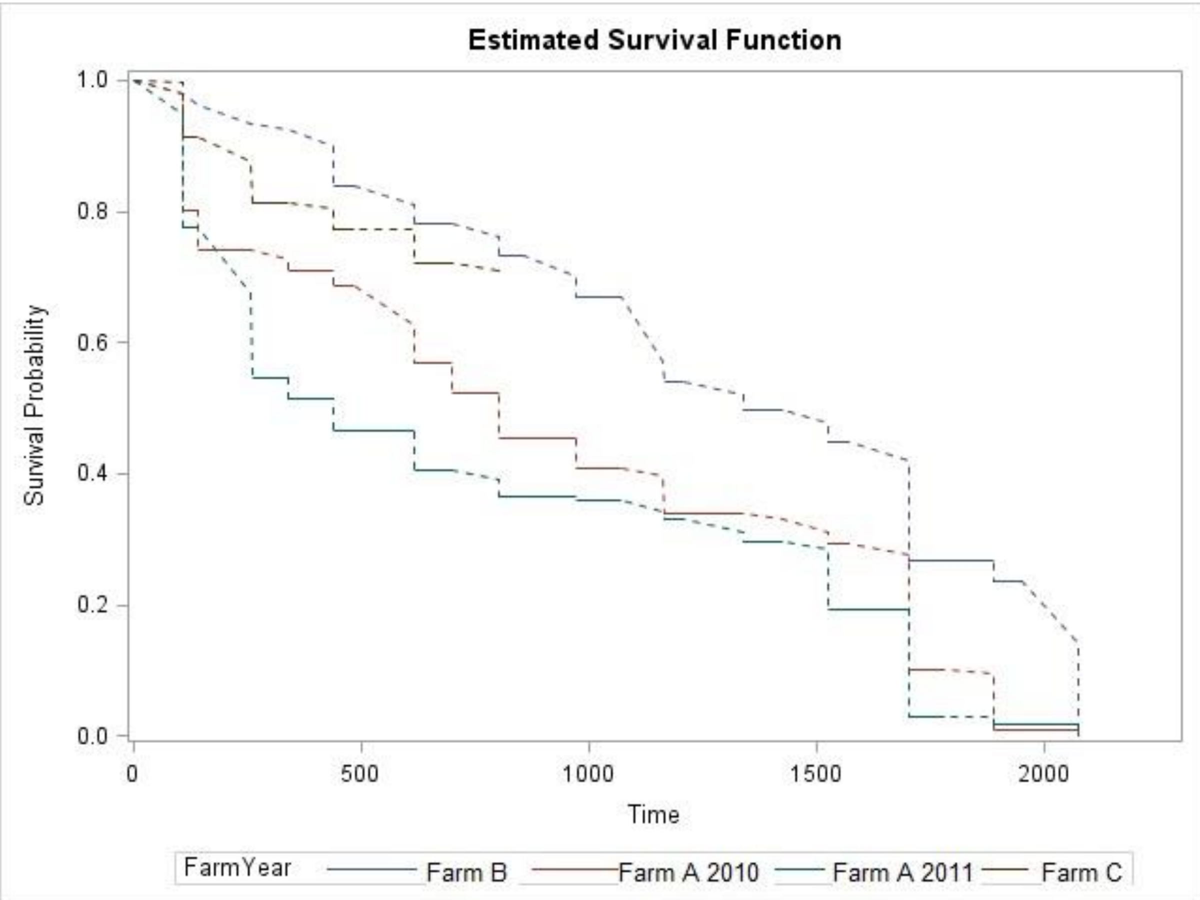
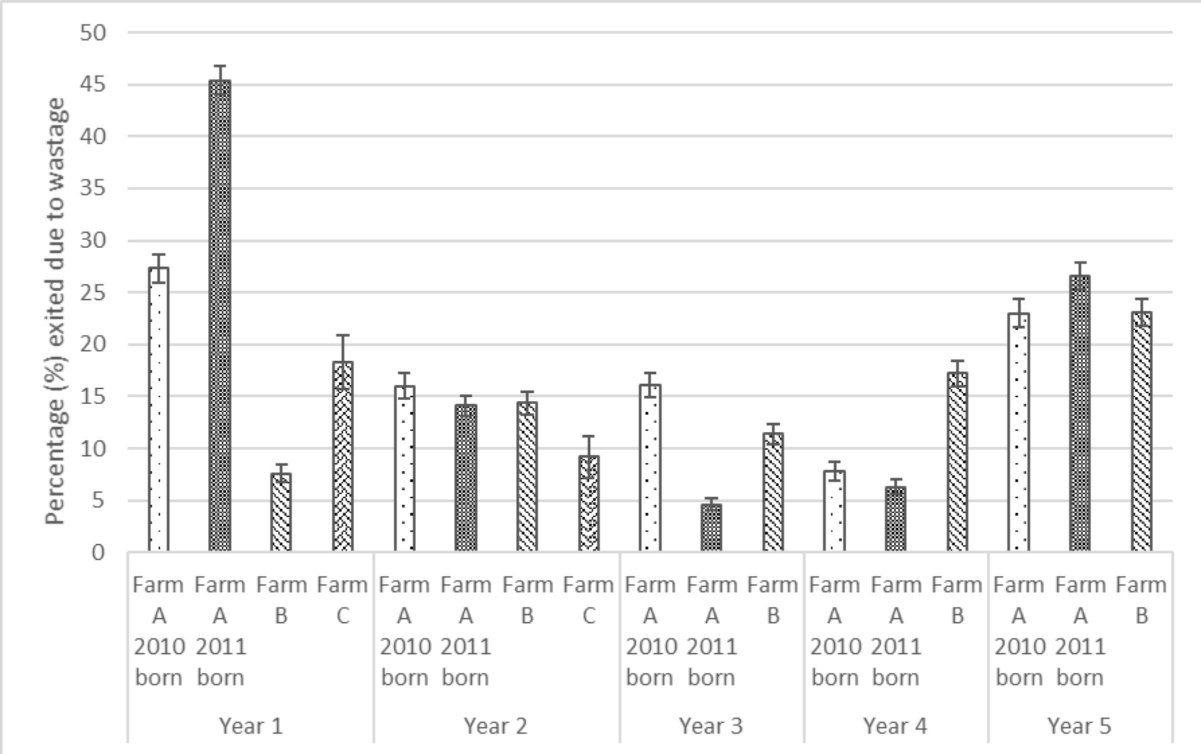


**Figure 3.2 Percentage (and 95%CI) of total enrolled ewes that exited the study cohort due to wastage (premature culling and dead/missing) during each year of the study, for each study cohort**




*Lifetime wastage due to premature culling*

For both Farm A cohorts, wastage due to premature culling was greatest when ewes were younger and older (Figure 3.3). However, for the Farm B cohort, wastage due to premature culling was highest when ewes were 5-years-old (Year 5) (Figure 3.3). An overall summary of recorded reasons for premature culling can be seen in Table 3.3, with 48.8% (n=3,231) of the prematurely culled ewes culled due to poor reproductive performance (either dry at PD or dry at docking). Of those 3,231 ewes culled for poor reproductive performance, 32.5% (n=1,051) were culled as they were identified as dry at docking, the remainder being due to dry at PD (Table 3.3).

**Figure 3.3 Percentage (and 95%CI) of total enrolled ewes that were prematurely culled during each year of the study, for each study cohort**

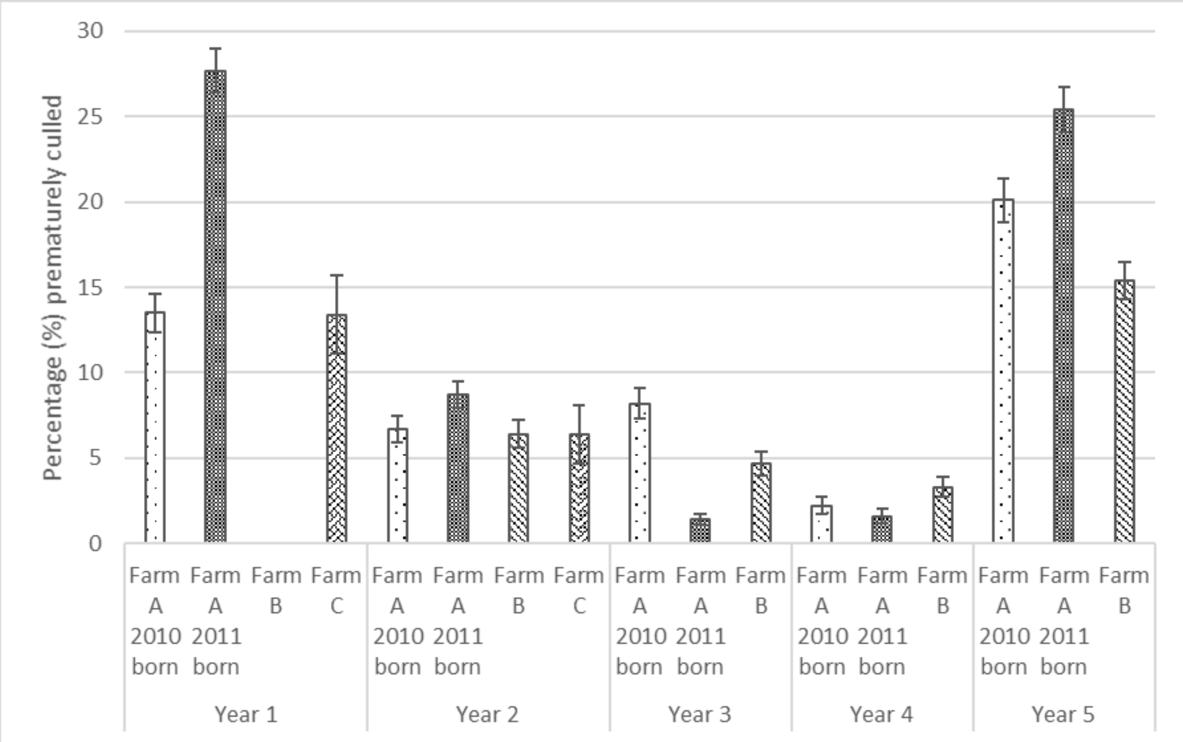



**Table 3.3 Of the ewes that were prematurely culled from their respective cohorts, for each cohort the number (and % of those that were prematurely culled within that cohort) that were recorded as culled for each reason, and the total across all study cohorts**

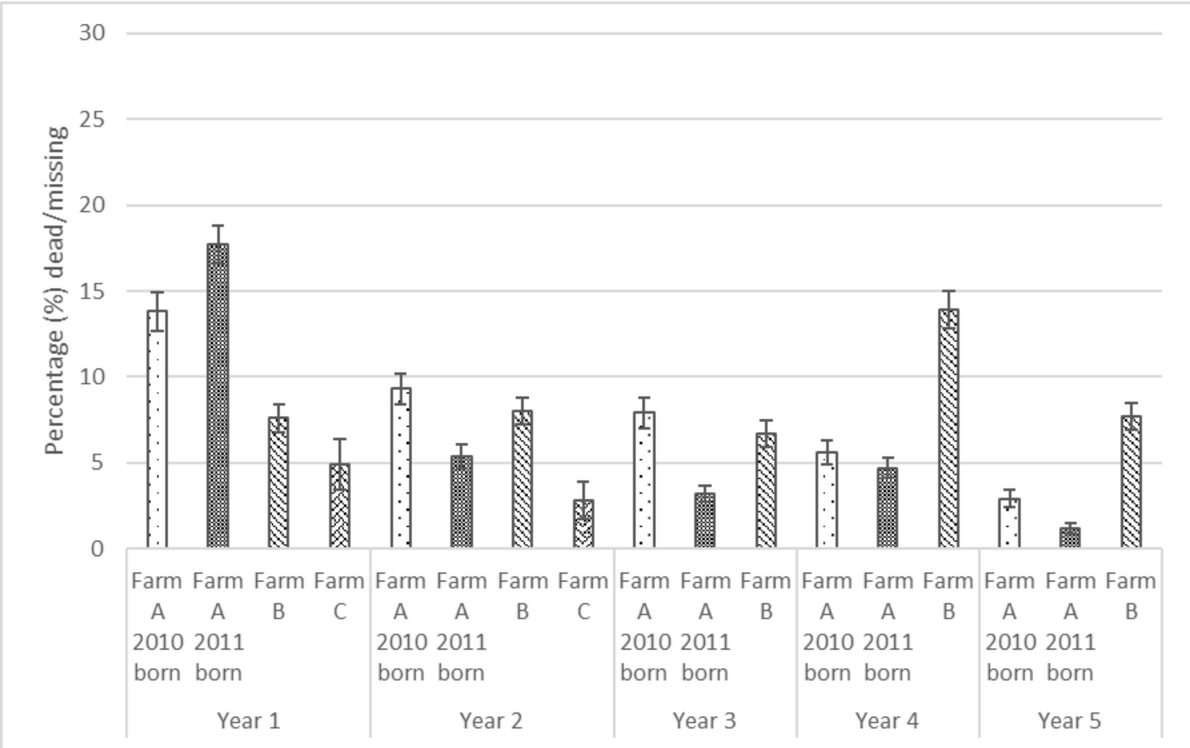
| | Dry at PD | Dry at docking | Other* | Unknown | Total |
|---|---|---|---|---|---|
| Farm A 2010-born | 671 (30.6%) | 210 (9.6%) | 995 (45.4%) | 314 (14.3%) | 2,190 |
| Farm A 2011-born | 918 (30.5%) | 661 (22.0%) | 1,369 (45.4%) | 58 (1.9%) | 3,006 |
| Farm B | 500 (39.3%) | 151 (11.9%) | 567 (44.6%) | 53 (4.2%) | 1,271 |
| Farm C# | 91 (56.2%) | 29 (17.9%) | 42 (25.9%) | 0 (0.0%) | 162 |
| Total | 2,180 (32.9%) | 1,051 (15.9%) | 2,973 (44.8%) | 425 (6.4%) | 6,629 |

*Other includes ewes that were recorded as having been prematurely culled for poor teeth, poor feet, poor body condition score (BCS) or poor udder health
#Note, these ewes were only included in the study to Year 3 pregnancy diagnosis

*Lifetime wastage due to dead/missing*

Ewe wastage due to dead/missing was greatest as ewe lambs for both Farm A cohorts (2010-born, 13.8%; 2011-born, 17.7%), while for the Farm B cohorts it was consistent across years (range 6.7% - 10.8%), with the exception of 4-year-old ewes (Year 4) when it increased to 13.9% (Figure 3.4). For the Farm C cohort, wastage due to dead/missing was 4.9% as ewe lambs, and 2.8% as two-tooths (Year 2) (Figure 3.4); however, rates could not be evaluated beyond this as remaining ewes were censored in Year 3.

**Figure 3.4 Percentage (and 95%CI) of total enrolled ewes that exited due to dead/missing during each year of the study, for each study cohort**




*Ewe wastage on an annual basis*

Annual wastage rates ranged from 7.6% - 90% (Figure 3.5), with annual wastage greatest when ewes were older for the three cohorts that had ewes that remained (Figure 3.5). Actual recorded numbers of ewes that exited each cohort during each interval and production year are shown in Appendix 2, which displays ewe wastage on an annual basis (i.e. wastage of ewes that remained in the flock at the start of each interval and production year). Annual wastage due to culling was greatest in Year 5 for all cohorts, however Farm A 2011-born also had markedly increased wastage due to culling in Year 1 (Figure 3.6).

*Annual wastage due to dead/missing*

Annual mortality rates ranged from 3.5% - 20.8% in Years 1 - 5, with variation between cohorts and years (Figure 3.7). For example, the Farm A 2010-born cohort had annual mortality rates of 12.8% - 13.9% from Years 1 – 4, with mortality decreasing to 8.7% in Year 5 (Figure 3.7). In contrast, mortality rates for the Farm B cohort were greatest in the older ewes (Years 4 – 5) (Figure 3.7). In Year 6, annual mortality rates were 7.0% for the Farm A 2010-born cohort and 24.8% and 40.2% for the Farm A 2011-born and Farm B cohorts respectively (Appendix 2). In each year, for all cohorts, mortality rates were greatest during the pregnancy diagnosis to weaning (PD-W) interval (Appendix 2). Specifically for the PD-W interval, mortality ranged from 6.9% - 10.5% for Farm A 2010-born, 4.0% - 11.1% for Farm A 2011-born, 4.5% - 8.0% for Farm B, and 0.5% - 4.0% for Farm C (Figure 3.8).

**Figure 3.5 Of the ewes that remained in the cohort at the start of each production year (pre-mating (PM)), the percentage (and 95%CI) of ewes that exited each production year due to wastage (premature culling or dead/missing), for each study cohort**

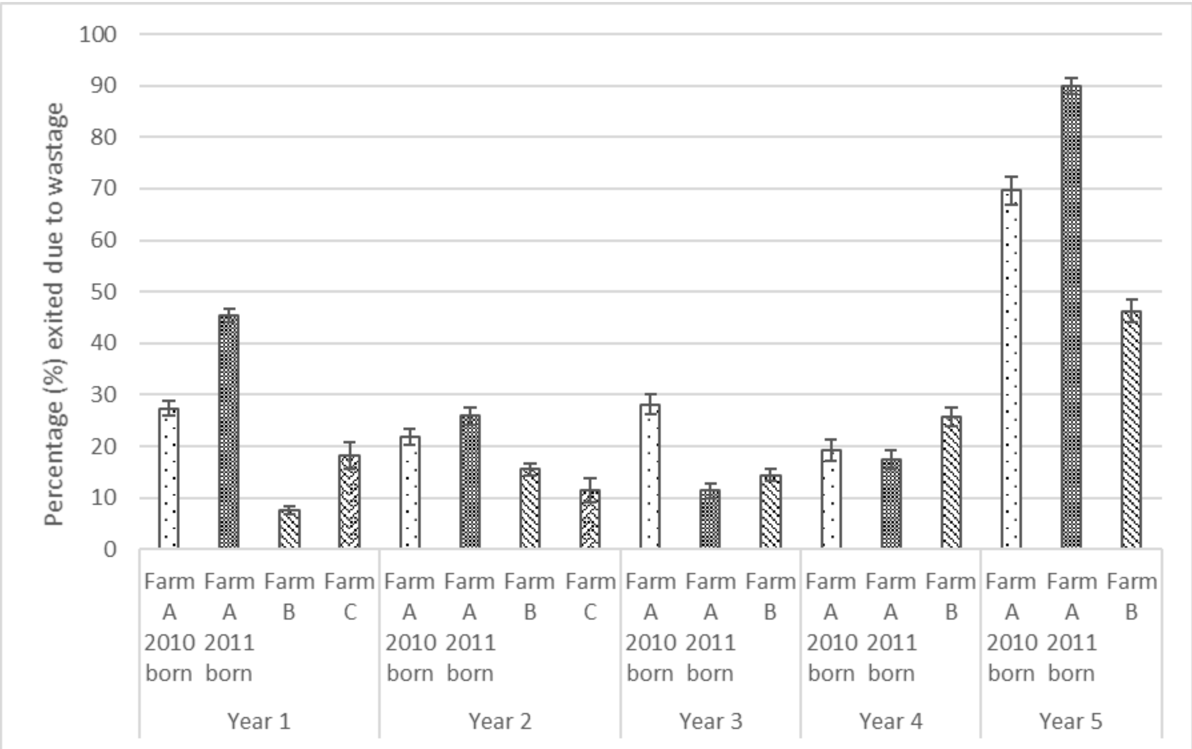


**Figure 3.6 Of the ewes that remained in the cohort at the start of each production year (pre-mating (PM)), the percentage (and 95%CI) of ewes that were prematurely culled in each production year, for each study cohort**

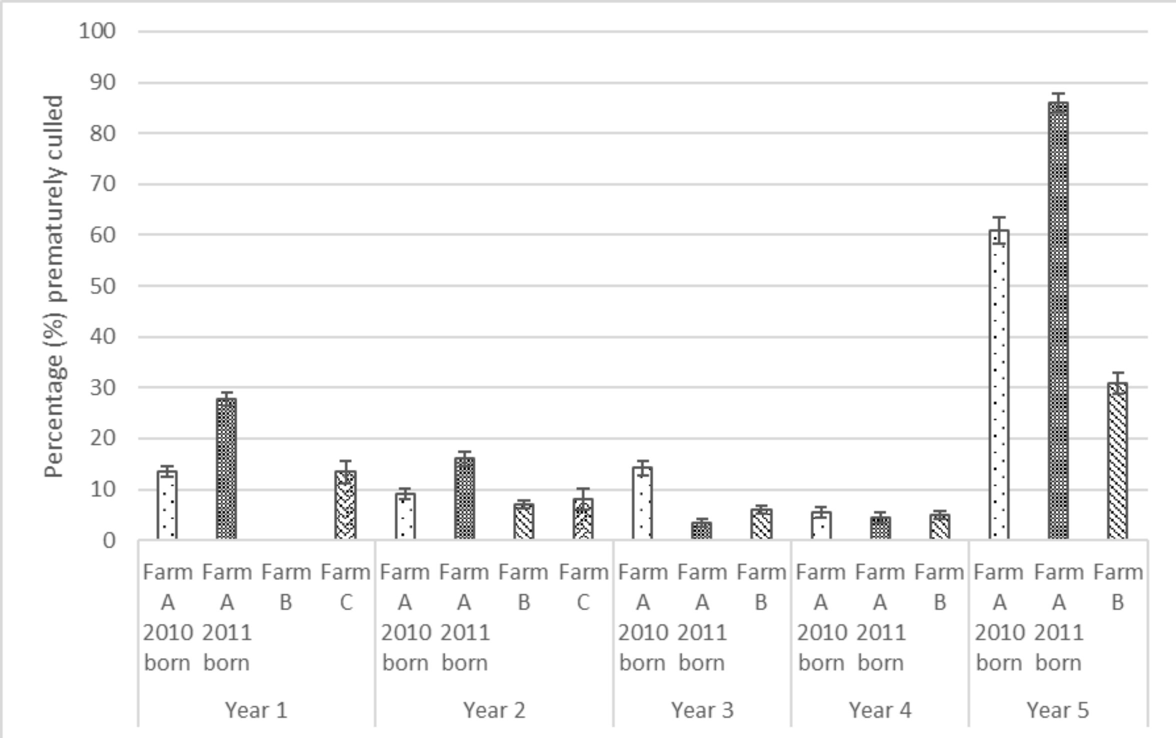



**Figure 3.7 Of the ewes that remained in the cohort at the start of each production year (pre-mating (PM)), the percentage (and 95%CI) of ewes that exited each production year due to dead/missing (i.e. annual mortality rate), for each study cohort**

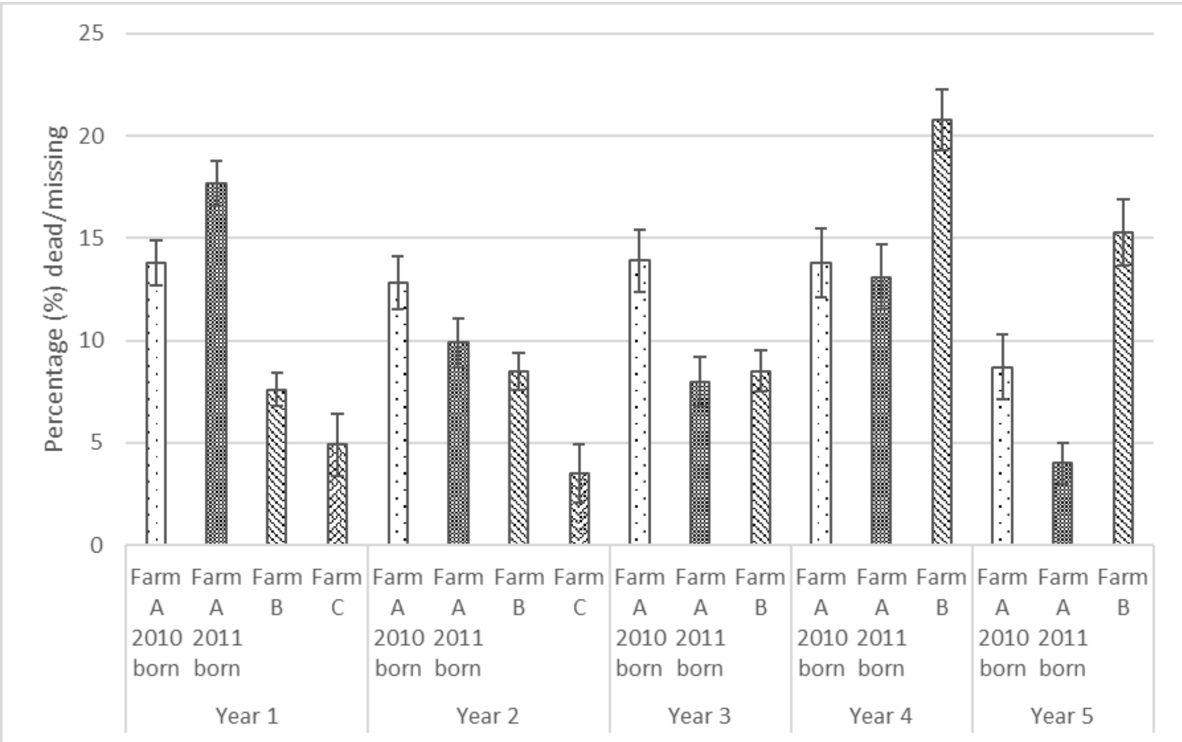
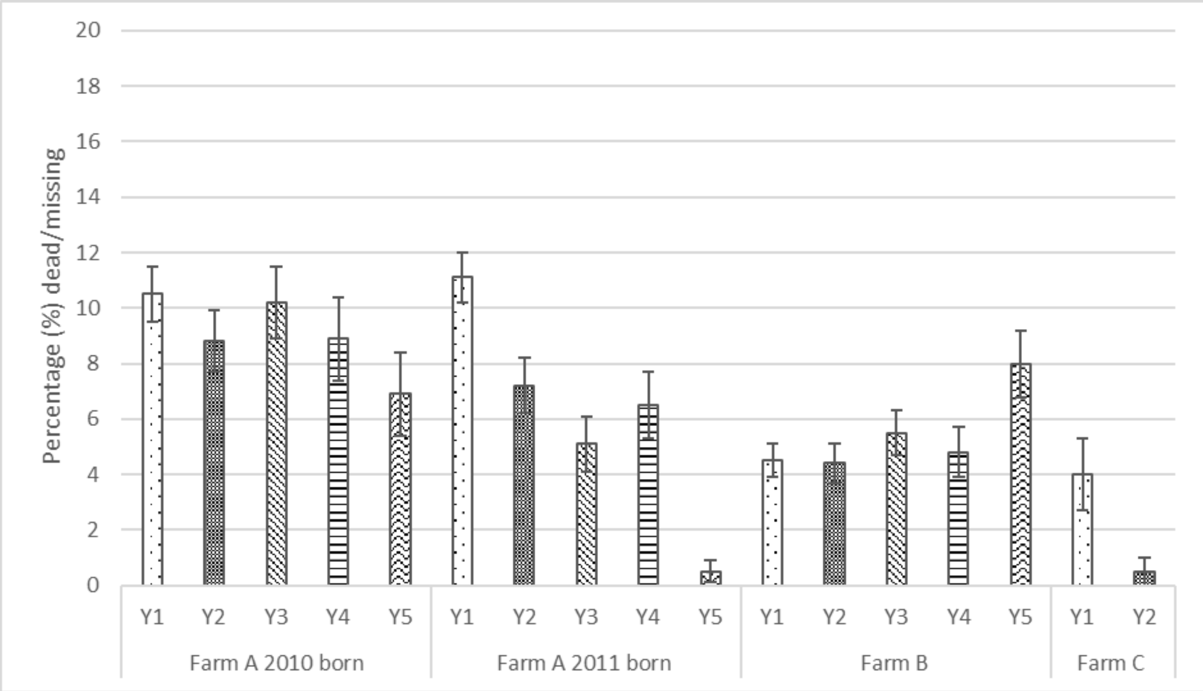


**Figure 3.8 Of the ewes that remained in the cohort at pregnancy diagnosis (PD) each year, the percentage (and 95%CI) of ewes that exited due to dead/missing during the period from pregnancy diagnosis to weaning (PD-W), for each study cohort**




### Association between reproductive outcomes as a ewe lamb and risk of wastage from Year 2 pre-mating to Year 6 weaning on Farm B only

Ewes that were presented for breeding as a ewe lamb but subsequently dry at PD as a ewe lamb had 28.1% greater odds of wastage due to premature culling compared to ewes that were not bred as a ewe lamb (OR=1.281 (95%CI 1.166-1.397); p=0.032). There was no difference in risk of wastage due to premature culling of those that were bred as a ewe lamb but dry at docking as a ewe lamb (p=0.471) or those that were bred as a ewe lamb but wet at docking as a ewe lamb (p=0.818) compared to those that were not presented for breeding as a ewe lamb. There was no association between reproductive outcomes as a ewe lamb and subsequent risk of wastage due to dead/missing (p>0.2 for all groups).

### Associations between pre-mating body condition score (BCS) and risk of ewe wastage in the following production year (pre-mating to subsequent pre-mating)

The number (and percentage) of ewes in each of the pre-mating BCS categories (1.0 – 5.0), at each year's pre-mating visit, for each enrolled cohort, is available in Appendix 3.

In addition to the OR reported below, the mean cumulative incidence of wastage due to premature culling and wastage due to dead/missing were predicted for ewes from each cohort (Farm A 2010- and 2011-born, Farm B) on the basis of BCS (BCS 2.0 *vs.* BCS 3.5 (Table 3.4)).

**Table 3.4 For each year, the mean cumulative incidence of wastage due to premature culling and wastage due to dead/missing for ewes from three cohorts (Farm A 2010-born, Farm A 2011-born and Farm B) on the basis of body condition score (BCS) (BCS 2.0 *vs.* BCS 3.5)**

| | | Premature culling | | | | Dead/missing | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Cohort | p-value | BCS 2.0 estimate* | BCS 3.5 estimate# | Difference^ | p-value | BCS 2.0 estimate∞ | BCS 3.5 estimate§ | Differenceα |
| Year 1 | Farm A 2010-born | <0.0001 | 19.4% | 12.1% | 7.3% | 0.431 | 13.0% | 11.9% | 1.1% |
| | Farm A 2011-born | | 33.7% | 22.5% | 11.2% | | 19.0% | 17.5% | 1.5% |
| | Farm B | | 4.6% | 2.7% | 1.9% | | 10.3% | 9.4% | 0.9% |
| Year 2 | Farm A 2010-born | <0.0001 | 16.7% | 5.4% | 11.3% | 0.003 | 14.9% | 10.3% | 4.6% |
| | Farm A 2011-born | | 25.4% | 8.7% | 16.7% | | 11.1% | 7.6% | 3.5% |
| | Farm B | | 12.5% | 3.9% | 8.6% | | 9.6% | 6.5% | 3.1% |
| Year 3 | Farm A 2010-born | <0.0001 | 33.8% | 2.5% | 31.3% | 0.002 | 16.4% | 9.4% | 7.0% |
| | Farm A 2011-born | | 13.5% | 0.7% | 12.8% | | 10.4% | 5.8% | 4.6% |
| | Farm B | | 21.1% | 1.4% | 19.7% | | 10.1% | 5.6% | 4.5% |

*The mean cumulative incidence of wastage due to premature culling for ewes from each cohort that had a pre-mating BCS of 2.0
#The mean cumulative incidence of wastage due to premature culling for ewes from each cohort that had a pre-mating BCS of 3.5
^The mean difference between BCS 2.0 estimate and BCS 3.5 estimate for wastage due to premature culling
∞The mean cumulative incidence of wastage due to dead/missing for ewes from each cohort that had a pre-mating BCS of 2.0
§The mean cumulative incidence of wastage due to dead/missing for ewes from each cohort that had a pre-mating BCS of 3.5
αThe mean difference between BCS 2.0 estimate and BCS 3.5 estimate for wastage due to dead/missing

**Table 3.4 For each year, the mean cumulative incidence of wastage due to premature culling and wastage due to dead/missing for ewes from three cohorts (Farm A 2010-born, Farm A 2011-born and Farm B) on the basis of body condition score (BCS) (BCS 2.0 *vs.* BCS 3.5)**

| | | **Premature culling** | | | | **Dead/missing** | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Cohort | p-value | BCS 2.0 estimate* | BCS 3.5 estimate[#] | Difference^ | p-value | BCS 2.0 estimate[∞] | BCS 3.5 estimate[§] | Difference[α] |
| Year 4 | Farm A 2010-born | 0.045 | 8.2% | 3.7% | 4.5% | <0.0001 | 20.6% | 7.6% | 13.0% |
| | Farm A 2011-born | | 7.7% | 3.4% | 4.3% | | 18.8% | 6.8% | 12.0% |
| | Farm B | | 8.8% | 3.9% | 4.9% | | 17.8% | 6.4% | 11.4% |
| Year 5 | Farm A 2010-born | <0.0001 | 69.5% | 53.5% | 16.0% | 0.336 | 8.3% | 7.1% | 1.2% |
| | Farm A 2011-born | | 90.0% | 81.9% | 8.1% | | 3.7% | 3.1% | 0.6% |
| | Farm B | | 39.3% | 24.6% | 14.7% | | 16.5% | 14.2% | 2.3% |
| Year 6 | Farm A 2010-born | 0.522 | 81.6% | 85.2% | -3.6% | 0.007 | 1.1% | 0.5% | 0.6% |
| | Farm A 2011-born | | 8.0% | 10.1% | -2.1% | | 4.2% | 1.9% | 2.3% |
| | Farm B | | 6.7% | 8.5% | -1.8% | | 11.1% | 5.3% | 5.8% |

*The mean cumulative incidence of wastage due to premature culling for ewes from each cohort that had a pre-mating BCS of 2.0
[#]The mean cumulative incidence of wastage due to premature culling for ewes from each cohort that had a pre-mating BCS of 3.5
^The mean difference between BCS 2.0 estimate and BCS 3.5 estimate for wastage due to premature culling
[∞]The mean cumulative incidence of wastage due to dead/missing for ewes from each cohort that had a pre-mating BCS of 2.0
[§]The mean cumulative incidence of wastage due to dead/missing for ewes from each cohort that had a pre-mating BCS of 3.5
[α]The mean difference between BCS 2.0 estimate and BCS 3.5 estimate for wastage due to dead/missing

*Year 1 (ewe lamb; 1-year-old at lambing)*

As a ewe lamb, the odds of wastage due to premature culling were 31.2% lower (OR=0.688 (95%CI 0.620-0.757); p<0.0001) for each unit increase in pre-mating BCS. However, as a ewe lamb, there was no association between pre-mating BCS and risk of wastage due to dead/missing (p=0.431).

*Year 2 (two-tooth; 2-years-old at lambing)*

As a two-tooth, the odds of wastage due to premature culling were 57.0% lower (OR=0.430 (95%CI 0.307-0.552); p<0.0001) for each unit increase in pre-mating BCS, while the odds of wastage due to dead/missing were 24.4% lower (OR=0.756 (95%CI 0.663-0.849); p=0.003) for each unit increase in pre-mating BCS.

*Year 3 (four-tooth; 3-years-old at lambing)*

As a four-tooth, the odds of wastage due to premature culling were 86.2% lower (OR=0.138 (95%CI 0.122-0.397); p<0.0001) for each unit increase in pre-mating BCS, while the odds of wastage due to dead/missing were 34.8% lower (OR=0.652 (95%CI 0.512-0.792); p=0.002) for each unit increase in pre-mating BCS.

*Year 4 (six-tooth; 4-years-old at lambing)*

As a six-tooth, the odds of wastage due to premature culling were 43.4% lower (OR=0.566 (95%CI 0.282-0.850); p=0.045) for each unit increase in pre-mating BCS, while the odds of wastage due to dead/missing were 53.6% lower (OR=0.464 (95%CI 0.313-0.616); p<0.0001) for each unit increase in pre-mating BCS.

*Year 5 (mixed-age; 5-years-old at lambing)*

As a mixed-age ewe in Year 5, the odds of wastage due to premature culling were 36.7% lower (OR=0.633 (95%CI 0.545-0.722); p<0.0001) for each unit increase in pre-mating BCS. However there was no association between pre-mating BCS and risk of wastage due to dead/missing (p=0.336).

*Year 6 (mixed-age; 6-years-old at lambing)*

As a mixed-age ewe in Year 6, there was no association between pre-mating BCS and risk of wastage due to premature culling (p=0.522). However, as a mixed-age ewe in Year 6, the odds of wastage due to dead/missing were 41.8% lower (OR=0.582 (95%CI 0.383-0.781); p=0.007) for each unit increase in pre-mating BCS.

## Discussion

To the authors' knowledge, this is the first study that reports both lifetime wastage and detailed annual wastage on commercial flocks in New Zealand. Previous papers have detailed either mortality or culling (Pyke 1974; Davis 1979), but to our knowledge, they have not been considered together. Farrell *et al.* (2019) demonstrated an increase in sheep flock productivity and subsequent profitability when ewe wastage was reduced. However, Farrell *et al.* (2019) also highlighted the need for accurate estimates of ewe wastage to provide clarity for sheep producers around the productive and economic impact of reducing wastage. Although, before farmers can begin to reduce ewe wastage they need to understand the extent, timing, and cause of wastage in their commercial flocks and risk factors associated with increased wastage, as addressed in this study.

In the present study, the annual dead/missing rates, considered a proxy for mortality rates, ranged from 3.5% to 20.8% in Years 1 - 5. This is comparable to previously reported annual on-farm mortality rates of 2.8% - 27.0% in New Zealand (Pyke 1974; Davis 1979; Anderson and Heuer 2016), 2.8% - 22.0% in Australian extensive flocks (Trompf *et al.* 2011; Kelly *et al.* 2014; Dever *et al.* 2017), and 3.0% - 10.0% for flocks based in the UK and Ireland (Mekkawy *et al.* 2009; Lovatt and Strugnell 2013; Keady 2014). However, mortality rates in Year 6 were between 7.0% - 40.2%. Higher mortality rates in older ewes (26%) have been reported in Australia (Turner *et al.* 1958); however, the rates reported in six-year-old ewes in the present study are higher than those. It is possible that the cohort with the 40.2% mortality rate culled some ewes from the flock without recording this; however, that cannot be accurately known. In addition to costs associated with replacing these dead ewes, on-farm mortality has a direct cost in that the cull sale-value of the ewe is not obtained. There is also an additional cost if the ewe dies during the pregnancy or lambing period as there is the concurrent loss of her potential lamb(s). In the present study, mortality rates tended to be greatest during the PD-W interval, ranging from 0.5% - 11.1%. This is in agreement with previous reports of increased ewe mortality rates during the lambing period in both New Zealand and overseas (Tarbotton and Webby 1999; Scott 2005; Dever *et al.* 2017). It is also important to consider the welfare implications of having increased on-farm mortality rates (Stafford 2013; Munoz *et al.* 2018), with mortality used in a number of welfare assessments (Doughty *et al.* 2019). Further investigation into causes of, and risk factors associated with, ewe mortality in New Zealand commercial flocks is required.

As a ewe lamb in Year 1, wastage rates were 7.6%, 18.3%, 27.3% and 45.4% for the Farm B, Farm C and Farm A 2010-born and 2011-born cohorts respectively. Rearing these replacement ewe lambs to a productive age would have incurred a number of costs (Turner *et al.* 1958; McHugh 2012), but given these ewe lambs were lost to wastage prior to Year 2 breeding it is unlikely they would have been in the flock for a sufficient period to be economically efficient. In addition, in Year 1, wastage due to dead/missing accounted for 26.8% - 100.0% of ewe lamb wastage across cohorts, and premature culling was primarily due to poor reproductive performance (dry at PD or dry at docking). Hence, other than the cull sale-value for those that were prematurely culled, the farmer received no productive or economic benefit from these wasted ewe lambs.

To reduce ewe lamb wastage a number of areas need to be considered. Firstly, in this study, mortality rates as a ewe lamb ranged from 4.9% - 17.7% per annum while mortality in just the PD-W interval ranged from 4.0% - 11.1%. In an on-farm commercial study (Ridler, unpublished), the mortality rate of ewe lambs from set-stocking to docking was 5.1%, comparable although at the low end of the range of the rates reported in the present study. In that study, 44% of the ewe lamb mortalities were attributed to dystocia, 16% to vaginal prolapse, while 40% were unknown. Combined these results indicate further investigation into causes of ewe lamb mortality and risk factors associated with ewe lamb mortality in New Zealand commercial flocks are required.

Poor ewe lamb reproductive performance results in both reduced productivity as a ewe lamb and increased premature culling (as described for both Farm A and Farm C cohorts). For the Farm A 2011-born cohort in particular, culling decisions associated with poor ewe lamb reproductive performance resulted in a large number (27.7% enrolled ewe lambs) being culled from the cohort. Farmer culling decisions can have a significant impact on ewe lamb wastage rates, therefore, if farmers elect to breed their ewe lambs and cull based on poor ewe lamb reproductive performance they should address risk factors associated with poor reproductive performance. Management practices required to maximise the likelihood of a ewe lamb becoming pregnant are well-documented for Romney-type sheep (Kenyon *et al.* 2014a) and include a minimum liveweight of 40kg (ideally greater than 65% of mature liveweight) and a recommended BCS of 3.0 at breeding (Corner *et al.* 2013b; Kenyon *et al.* 2014a). This contrasts with management of ewes in the Farm A and Farm C cohorts in which there was no minimum mating weight applied, and with the Farm B cohort which used a minimum mating weight of approximately 38kg. Once ewe lambs are pregnant, it is then important that losses between PD and docking be minimised, to both improve flock and individual ewe productivity and to reduce risk of premature culling due to being dry at docking. Farmer and veterinary evidence suggests lamb losses between PD and docking continue to be an issue on commercial New Zealand farms (Kenyon *et al.* 2014a; Ridler *et al.* 2015, 2017), however there is scant published data regarding risk factors associated with ewe lambs being dry at docking. In Chapter 4, we identify that ewe lambs with heavier conceptus adjusted liveweight (CALW) at PD and set-stocking, ewe lambs with greater CALW gain between PD and set-stocking, and ewe lambs with greater BCS at PD and set-stocking, are less likely to be dry at docking.

Kenyon *et al.* (2014a) reported that commercial farmers are concerned ewe lamb breeding results in increased ewe wastage; however, there was limited published data evaluating this. In the present study, the association between ewe lamb reproductive outcomes and subsequent wastage were evaluated for the Farm B cohort, as they were the only cohort that had both ewe lambs that were presented for breeding and ewe lambs that were not presented for breeding, and which did not cull any ewe lambs for poor reproductive performance. Pregnancy itself as a ewe lamb did not have any association with subsequent risk of wastage due to either premature culling or mortality when compared to those that were not presented for breeding as ewe lambs. This supports the results of Kenyon *et al.* (2011b) and Baker *et al.* (1981) in which ewe lamb breeding resulted in greater lifetime reproductive performance without negatively affecting ewe longevity. However, it is important to note, this may vary depending on overall ewe lamb reproductive performance (i.e. no lifetime productive benefit if the ewe lamb is dry at PD or docking) combined with an individual farm’s culling policies. For example, the Farm A 2011-born cohort elected to cull ewe lambs that were dry at docking, resulting in 511 ewe lambs (16.4% of the cohort that remained at Year 1 weaning) being prematurely culled. Ewes from the Farm B cohort that were presented for breeding as ewe lambs but dry at PD as a ewe lamb had a greater odds of premature culling to Year 6 weaning compared with ewes that were not presented for breeding as ewe lambs. This suggests routine culling of ewe lambs that are dry at PD may be justified, as these ewes are more likely to be culled subsequently, however further investigation of causes is required. Further economic evaluation of culling on commercial farms based on ewe lamb reproductive outcome is required.

For commercial farmers, it would be optimal if they could identify ewes that are at greater risk of wastage prior to breeding. This would allow either selective culling of these ewes, enabling feed and resources to be directed at those ewes that are likely to be more productive (Klaassen *et al.* 2015) while obtaining cull sale-value, or would enable these ewes to be preferentially managed to reduce risk of wastage. The results of the present study support the hypothesis that ewes that had poorer pre-mating body condition scores would have a greater risk of wastage in that production year. There is a generally positive relationship between BCS and ewe reproductive traits and lamb survival (see review by Kenyon *et al.* 2014b). In the present study, ewes with greater pre-mating BCS had lower odds of wastage due to premature culling. It is likely these greater BCS ewes had greater reproductive performance (i.e. were less likely to be dry at PD or dry at docking), and were therefore less likely to be prematurely culled.

Greater BCS was associated with reduced risk of mortality in Years 2, 3, 4 and 6. This is in agreement with New Zealand results from Anderson and Heuer (2016) in which poor BCS was reported as a common cause of ewe mortality, and Anonymous (2014b) in which ewes that were BCS 2.0 or less at breeding had higher mortality rates than ewes with a BCS >2.0. These results are also consistent with overseas data in which mortality rates were increased in poorer BCS ewes (Annett *et al.* 2014 (Ireland); Kelly *et al.* 2014 (Australia); Anonymous 2017 (Australia)). It is possible that for some of these poor BCS ewes, the poor BCS is a proxy for other diseases; therefore, further investigation into the causes of poor BCS in New Zealand commercial ewes is required. Combined, the above suggests farmers should focus on improving pre-mating BCS as they will not only improve ewe reproductive performance but should also concurrently reduce ewe wastage. To achieve this, farmers could assess the BCS of their ewes at weaning, enabling poor BCS ewes to be identified, drafted off and managed to gain BCS before breeding.

The extensive management of the commercial flocks within the present study resulted in limited frequency of interactions with individual ewes within the study cohorts. In addition, there were only four on-farm data collection visits each year, resulting in the collection of interval-censored data. Unfortunately, the extensive management of the flocks and frequency of observation combined with paddock terrain meant data was not collected on every death, and cause of death was not established for any ewe. Therefore, for analysis, missing ewes were classified in the same category as dead ewes (dead/missing), as it was presumed that they were most likely dead, however this was not accurately known. The wastage study used data collected from only four cohorts of ewe, from three commercial farms. Further studies involving more flocks and farms are required to determine cause of on-farm mortalities, to investigate culling policies and their impacts on flock productivity and profitability, and to provide robust support for recommendations.

## Conclusions

The present study outlined wastage rates across four cohorts of ewe from three commercial farms as they aged from replacement ewe lambs to six-year-old ewes. Annual mortality rates ranged from 3.5% to 40.2%; further investigation into causes of, and risk factors associated with, ewe mortality in New Zealand flocks is required. As a ewe lamb, wastage rates ranged from 7.6% - 45.4%, which represents an area improvements can be made to reduce overall flock wastage. To reduce ewe lamb wastage, farmers should consider on-farm mortality rates, management practices to improve ewe lamb reproductive performance, and evaluation of culling policies. Ewes with greater pre-mating BCS had lower odds of wastage due to both premature culling and mortality, therefore farmers should focus on improving pre-mating BCS. To achieve this, farmers could assess BCS of their ewes at weaning, enabling poor BCS ewes to be identified, drafted off and managed to gain BCS before breeding.

## Further research

The present chapter highlights ewe lamb wastage and wastage due to poor reproductive performance (including dry at docking) as areas where improvements can be made to reduce overall flock wastage. Management practices required to maximise the likelihood of a ewe becoming pregnant are well documented, however, there are a lack of studies that have directly examined factors associated with ewes being dry at docking in New Zealand. Therefore, Chapters 4 and 5 investigate associations between liveweight and body condition score and previous reproductive outcomes and the risk of being dry at docking, and utilise data collected from the ewes in this Chapter.

# Chapter 4

# Associations between liveweight and body condition score and the ability of ewe lambs to successfully rear their offspring

**Publications:** This chapter is based on the following publication:

**Griffiths KJ, Ridler AL, Heuer C, Corner-Thomas RA, Kenyon PR.** The effect of liveweight and body condition score on the ability of ewe lambs to successfully rear their offspring. *Small Ruminant Research* 145, 130-135, 2016

## Abstract

AIM: To investigate associations between liveweight and body condition score (BCS) at breeding, pregnancy diagnosis (PD) and immediately prior to lambing (set-stocking) and the ability of ewe lambs to rear their offspring to docking, on commercial New Zealand farms.

METHODS: This study included 7,171 replacement ewe lambs from two commercial New Zealand sheep farms that were presented for breeding during their first breeding season (aged 7-8 months) and were subsequently identified as pregnant. Ewe lambs were weighed and BCS assessed at three management times: pre-breeding, at PD (during mid-pregnancy) and at set-stocking. Palpation and examination of the ewe lambs' udders at docking was used to classify each as either lactating or dry at docking.

RESULTS: There was no association between breeding weight and the risk of being dry at docking ($p=0.135$). There was an association between conceptus adjusted liveweight (CALW) at PD and at set-stocking, such that ewe lambs with heavier CALW were less likely to be dry ($p<0.0001$). There was also an association between weight change from PD to set-stocking and the risk of being dry ($p<0.0001$); such that the more ewe lambs gained in CALW the less likely there were to be dry. The above relationships were also observed with non-adjusted (actual) liveweights. There was an association between BCS at PD ($p=0.0013$) and BCS at set-stocking ($p=0.007$) and risk of being dry, such that ewe lambs that were of greater BCS were less likely to be dry.

CONCLUSIONS: The findings of the present study enable commercial farmers to identify ewe lambs within a flock that are at increased risk of failing to successfully rear a lamb(s) to docking. Farmers are then able to plan management prior to breeding, and throughout pregnancy, to ensure ewe lamb weight and BCS targets are monitored, met and achieved.

## Introduction

Currently in New Zealand, the sale of lamb in crossbred flocks is a greater contributor to sheep farm income than wool (Anonymous 2015). Ewe lamb breeding (7-9 months of age at breeding) is a means to further increase the number of lambs available for sale each year while concurrently increasing the ewe lamb's lifetime productivity (Kenyon *et al.* 2011b; Corner *et al.* 2013a). However, less than 40% of New Zealand farmers choose to breed their ewe lambs (Kenyon *et al.* 2014a) indicating that there must be limiting factors which are restricting the uptake of this management option.

Management practices required to maximise the likelihood of a ewe lamb becoming pregnant are well documented (see review Kenyon *et al.* 2014a). However, farmer and veterinary evidence suggest losses between pregnancy diagnosis and marking (docking), when lambs are approximately three to six weeks of age, continue to be an issue on commercial New Zealand farms (Kenyon *et al.* 2014a; Ridler *et al.* 2015). Lower survival rates of lambs born to ewe lambs compared with those born to mature ewes have been reported, although few studies have directly compared this (Corner *et al.* 2013a; Kenyon *et al.* 2014a). Corner *et al.* (2013a) reported lamb survival to weaning of 69-89% for offspring born to ewe lambs, compared with 83-96% with mature ewes.

The development of ultrasound pregnancy diagnosis in sheep has enabled farmers to identify and cull their non-pregnant ewe lambs, while palpation of udders at docking enables actively lactating (wet) ewe lambs and not actively lactating (dry) ewe lambs to be identified. Those that are identified as dry at docking are assumed to have lost their lambs(s) between pregnancy diagnosis and docking.

The aim of this study was to investigate associations between liveweight and body condition score (BCS) at breeding, pregnancy diagnosis and at set-stocking, and the ability of ewe lambs to rear their offspring to docking, on commercial New Zealand farms.

## Materials and Methods

### Farms and animals

The study included 7,171 replacement ewe lambs from two commercial New Zealand sheep farms (Farm A, 2010-born and 2011-born, and Farm B, 2011-born) that were presented for breeding during their first breeding season (at the age of 7-8 months) and were subsequently identified as pregnant. Farm A was located in the Waikato, New Zealand, and consisted of a semi-stabilised composite breed consisting of Coopworth and East Friesian genetics. Two cohorts of ewes from Farm A were included in this study: 2010-born (n=2,559) and 2011-born (n=3,078). Farm B was located in the Wairarapa, New Zealand, with Romney ewe lambs that were 2011-born (n=1,534).

### Animal management

All ewe lambs were grazed under commercial conditions on permanent ryegrass and white clover based pasture. At approximately five months of age all ewe lambs were individually identified using electronic identification tags (EID; Allflex, Palmerston North, New Zealand). Prior to breeding ewe lambs were vaccinated with a sensitiser dose of a killed Clostridial vaccine conferring protection against *Cl. perfringens* type D, *Cl. tetani, Cl. chauvoei, Cl. septicum* and *Cl. novyi* type B (Ultravac 5 in 1®, Zoetis New Zealand), a live attenuated vaccine against *Toxoplasma gondii* (Toxovax®, MSD Animal Health) and a sensitiser dose of a killed vaccine against *Campylobacter fetus fetus* and *Campylobacter jejuni* (Campyvax4®, MSD Animal Health). Four weeks later they received booster vaccinations with both the Clostridial and Campylobacter vaccine.

### Reproductive management

On Farm A, all ewe lambs were joined with rams regardless of premating live weight (range 27kg to 66.5kg; mean 42kg). On Farm B, only selected ewe lambs (approximately 38kg and above) were joined with rams. On both farms ewe lambs were exposed to vasectomised rams at a ratio of 1:200-1:300 for 17 days prior to the planned start of breeding. All ewe lambs were then joined with entire rams at a ratio of 1:75; Farm A 2010 born = 34 days, Farm A 2011-born = 34 days, Farm B = 26 days.

Pregnancy diagnosis (PD) was undertaken by trans-abdominal ultrasound scanning; Farm A 2010-born = 59 days, Farm A 2011-born = 68 days, Farm B = 80 days, after the end of the breeding period. At PD ewe lambs were defined as either non-pregnant (no fetus), single (one fetus) or multiple (two or more fetuses). Non-pregnant ewe lambs were removed from the study cohort on each farm. Single and multiple-bearing ewe lambs were allocated into separate management groups and managed such that the plane of nutrition for the multiple-bearing was greater than for the single-bearing ewe lambs. As these were commercial farms no pasture measurements were taken.

Five to 28 days before the planned start of lambing the ewe lambs on all farms were given a Clostridial booster vaccination and placed in lambing paddocks. Ewe lambs were placed into individual paddocks (set stocking) at a rate of approximately seven to twelve ewes per hectare. During lambing on Farm A, ewe lambs were observed from a distance every two to three days and on Farm B, they were observed from a distance daily. If observed, any obvious problems such as dystocia, vaginal prolapse or cast ewes were resolved but no attempt was made to revive weak lambs or to mother-on or artificially rear orphaned lambs. Live and dead lambs were not identified or counted during the lambing period.

#### Data collection

All ewe lambs were weighed (to nearest 0.5kg) and body condition scored (BCS) immediately prior to breeding, at pregnancy diagnosis (PD), and at set-stocking. Body condition score was undertaken by assessing the soft tissue over the lumbar region using a 1-5 scale (1=thin, 5=obese) with sheep assessed to the nearest 0.5 of a BCS (Jefferies 1961; Kenyon *et al.* 2014b). For consistency, the same operator assessed BCS for all sheep at all-time points on both farms.

Three to six weeks post-parturition ewe lambs and their offspring were gathered into handling facilities for ear marking, tail removal and castration of male offspring (docking). At this time the udder of each ewe lamb was palpated by the experienced flock manager and an assessment was made as to whether they were actively lactating (wet) or not (dry). Those that were deemed not to be actively lactating (dry) were assumed to have either had a mid to late-gestation pregnancy loss, abortion, or their offspring had died during the perinatal period. Those that were deemed to be still lactating were assumed to still have at least one live offspring.

#### Data analysis

A total of 7,171 ewe lambs which were identified as pregnant at PD and were subsequently deemed to be wet (n = 5,617) or dry (n =1,554) at docking were included in the analysis. All statistical analyses were conducted using SAS (SAS Institute Inc., Cary, NC, USA; Version 9.3).

*Calculation of conceptus adjusted liveweights*

In order to eliminate the potential influence of conceptus weight on ewe lamb liveweight during pregnancy, predicted conceptus adjusted liveweights (CALW) of the ewe lambs were used in the analyses. Ewe lamb CALW at PD and set-stocking were calculated by subtracting the estimated weight of the conceptus. The predicted weight of the conceptus was calculated using the GRAZPLAN model (Freer *et al.* 1997). This model requires data on stage of pregnancy and lamb birth weight. To estimate 'days pregnant' it was assumed all ewe lambs conceived nine days after the start of mating. Lamb birth weights were estimated using average birth weights from a number of New Zealand studies which included Romney or Composite ewe lambs (Schreurs *et al.* 2010), 4.46kg for single and 3.42kg for multiple born (assumed to be twin-born) lambs. It was assumed all pregnancies were 150 days in length.

Predicted conceptus weight = total birth weight x 1.43 x EXP (3.38 x (1-EXP (0.91 x (1 – days pregnant/150)))) (Freer et al. 1997).

Three logistic regression models were developed, one for liveweight at breeding and CALW at PD and set-stocking, one for changes in CALW from breeding to PD and from PD to set-stocking, and one for BCS at breeding, PD and set-stocking, as predictor variables of interest. All models used wet *vs.* dry as the output variable, the above mentioned predictor variables of interest and additional covariates of farm-year (Farm A 2010-born and 2011-born, Farm B). The models also included the number of foetuses at PD (single or multiple bearing).

Data are presented as back transformed logit means and their 95% confidence interval as calculated in SAS (SAS Institute Inc., Cary, NC, USA; Version 9.3). Inferences were based on scatter plots with Loess smoothing trend lines of predicted probabilities of interest stratified by farm-year. Significance was inferred when $p < 0.05$. Interaction between adjusted liveweight and farm-year or BCS and farm-year were not significant in any of the models. Model fit was evaluated by the Hosmer and Lemeshow goodness of fit test (Hosmer and Lemeshow 2000).

*Non-adjusted liveweights*

Models evaluating the effect of conceptus adjusted live weight were repeated using non-conceptus adjusted liveweights (i.e. the recorded total liveweight) and including number of foetuses at PD and farm-year as covariates to determine whether the same relationships held. Interactions between farm-year and variables of interest were tested in all models and included if significant. Significance was declared when $p < 0.05$ for the Wald-chi-square. Interaction between non-adjusted liveweight and farm-year was not significant in any of the models. Model fit was evaluated by the Hosmer and Lemeshow goodness of fit test (Hosmer and Lemeshow 2000).

# Results

## Ewe lamb pregnancy rank

At pregnancy diagnosis 3,721 (51.9%) ewe lambs were identified as single bearing, while 3,450 (48.1%) were identified as multiple bearing. Ewe lambs that were identified as multiple bearing at PD were less likely to be dry at docking than those that were identified as single bearing for Farm A 2010-born and Farm B cohorts, with the proportion of dry ewe lambs from all cohorts ranging from 9.3% to 36% (Table 4.1) over the study period. The relationships discussed below holds for ewe lambs identified as single and multiple bearing, therefore the data is presented as combined data.

**Table 4.1 Proportion of ewe lambs that were identified as wet or dry at docking, stratified based on cohort and pregnancy rank (Single = single bearing, Multiple* = multiple bearing)**

| Cohort | Pregnancy Rank | Number | Dry % (95% CI) | Wet % (95% CI) |
|---|---|---|---|---|
| Farm A 2010-born | Single | 1375 | 36.0 (33.5 - 38.5) | 64.0 (61.5 - 66.5) |
| | Multiple | 1184 | 25.2 (23.1 - 27.3) | 74.8 (72.7 - 76.9) |
| Farm A 2011-born | Single | 1423 | 17.2 (15.2 - 19.2) | 82.8 (80.8 - 84.8) |
| | Multiple | 1655 | 17.1 (15.3 - 18.9) | 82.9 (81.1 - 84.7) |
| Farm B | Single | 923 | 19.2 (16.7 - 21 -7) | 80.8 (78.3 - 83.3) |
| | Multiple | 611 | 9.3 (7.0 - 11.6) | 90.7 (88.4 - 93.0) |

*Note as udder palpation was used to determine if the ewe lamb was wet (actively lactating) or dry (not actively lactating); it cannot be known the if ewe lambs identified as multiple bearing at pregnancy diagnosis (PD) were rearing one or more of their litter, when diagnosed as wet.

## Associations between ewe lamb liveweight at breeding and CALW at PD and set-stocking and the risk of being dry at docking

Breeding weight had no association with the risk of a ewe lamb being dry on any farm or cohort ($p=0.135$). There was an association between CALW at PD and the risk of being dry at docking ($p<0.0001$); such that the ewe lambs with heavier CALW were less likely to be dry (Figure 4.1). There was also an association between CALW at set-stocking and the risk of being dry ($p<0.0001$); such that ewe lambs with heavier CALW were less likely to be dry (Figure 4.2).

**Figure 4.1 Association between conceptus adjusted liveweight at pregnancy diagnosis (PD) and the risk of being dry at docking, after being identified as pregnant**

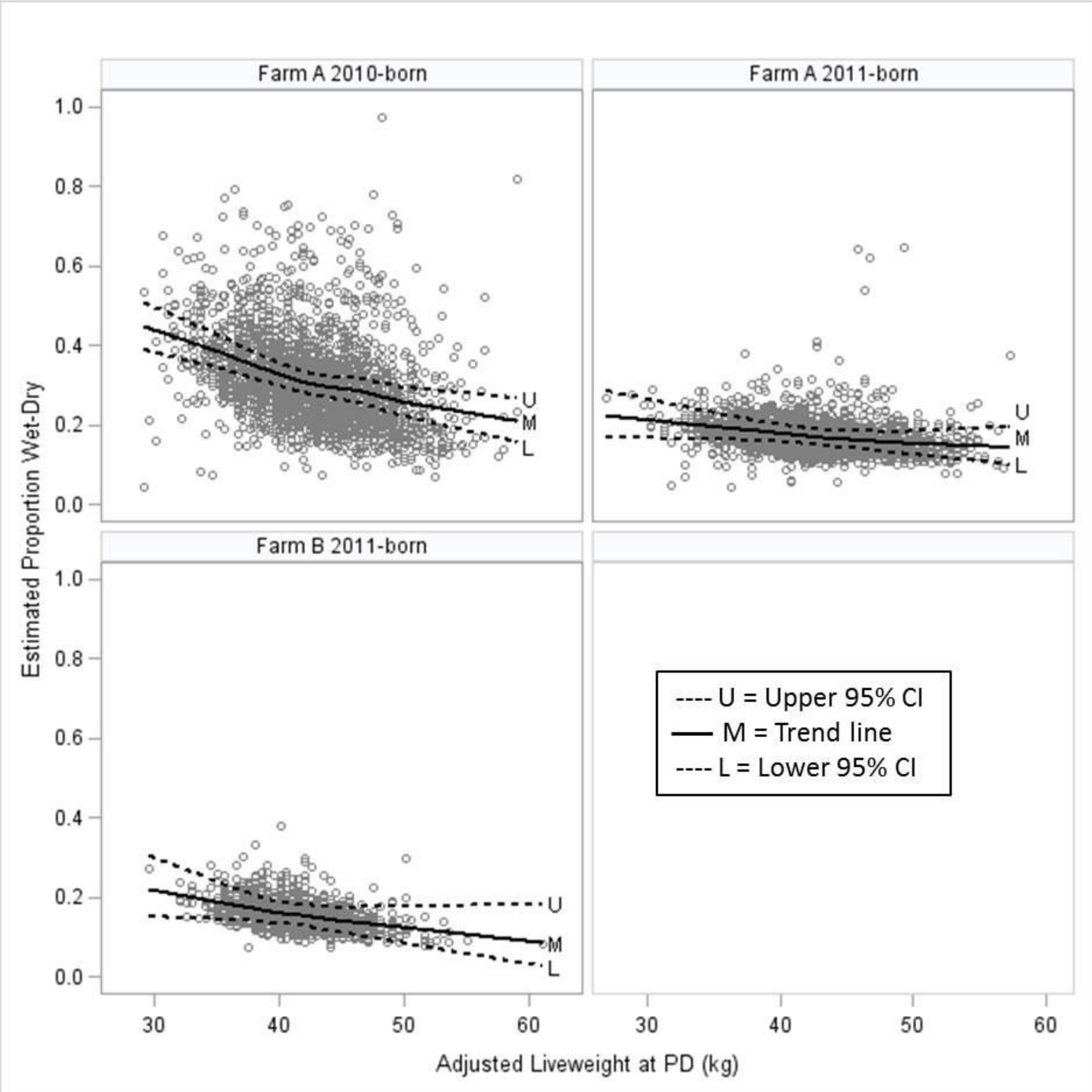
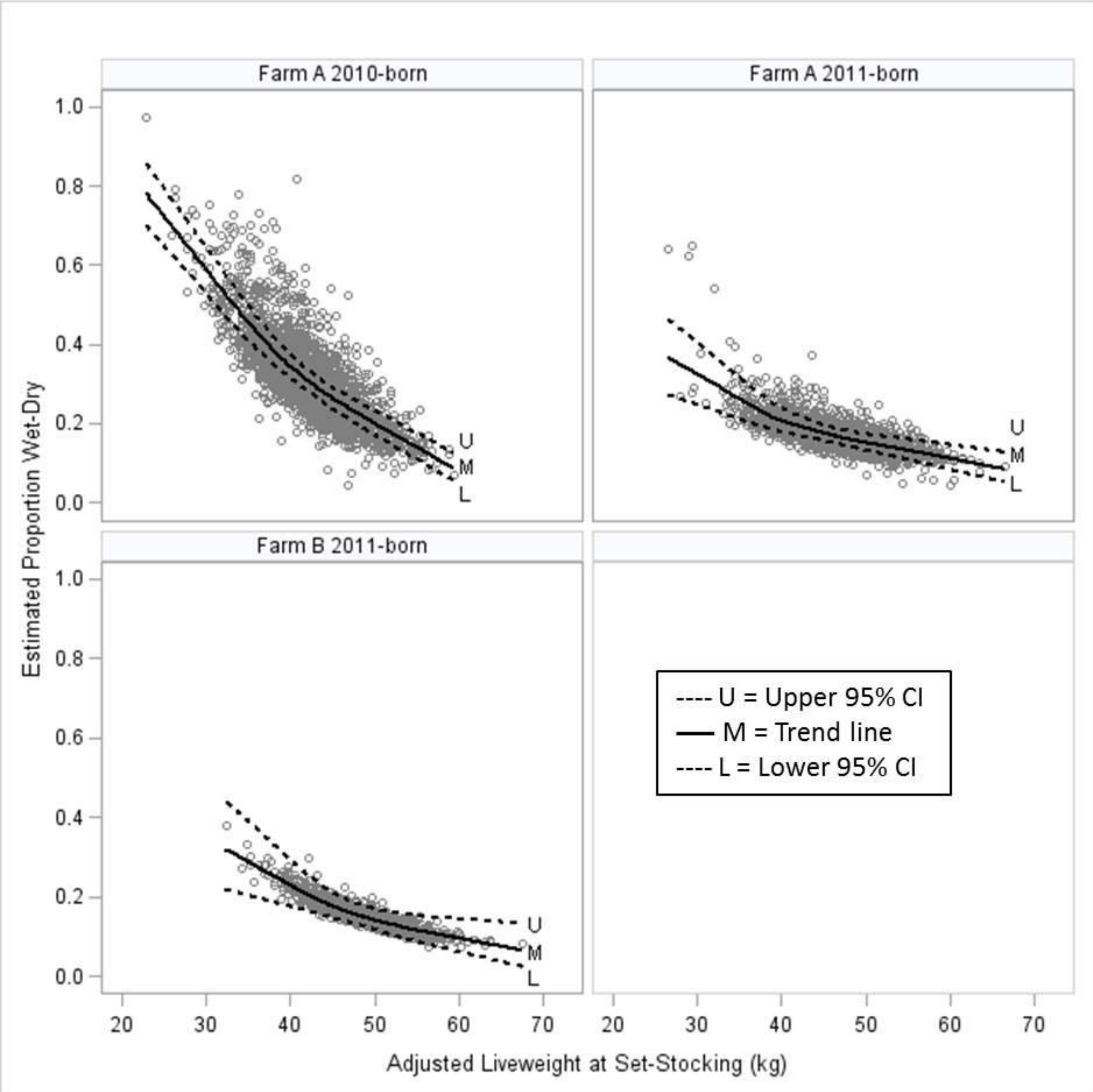


**Figure 4.2 Association between conceptus adjusted liveweight at set-stocking and the risk of being dry at docking, after being identified as pregnant**



### Associations between ewe lamb CALW changes and the risk of being dry at docking

There was an association between CALW change from breeding to PD and the risk of being dry ($p=0.0008$); such that the more ewe lambs gained in CALW between breeding and PD the less likely they were to be dry.

There was also an association between CALW changes from PD to set-stocking and the risk of being dry ($p<0.0001$); such that the more ewe lambs gained in CALW between PD and set-stocking the less likely they were to be dry (Figure 4.3).

### Analyses with non-CALW (actual liveweight)

The above relationships were observed using actual liveweights. There was an association between liveweight change from breeding to PD and the risk of being dry, such that the more liveweight ewe lambs gained the less likely they were to be dry ($p<0.0001$). There was an association between liveweight at PD and the risk of being dry ($p<0.0001$); such that ewe lambs with heavier liveweight at PD were less likely to be dry. There was also an association between liveweight at set-stocking and the risk of being dry ($p<0.0001$); such that ewe lambs with heavier liveweights at set-stocking were less likely to be dry.

There was also an association between total weight change between PD and set-stocking and the risk of being dry ($p<0.0001$); such that ewe lambs that gained greater liveweight between PD and set-stocking were less likely to be dry.

### Association between ewe lamb BCS and risk of being dry at docking

There was no association between BCS at breeding and risk of being dry at docking ($p=0.765$). However, there was an association between BCS at PD and the risk of being dry ($p=0.0013$); such that ewe lambs with greater BCS were less likely to be dry. There was also an association between BCS at set-stocking and risk of being dry ($p=0.0007$); such that ewe lambs with a greater BCS were less likely to be dry (Figure 4.4).

**Figure 4.3 Association between ewe lamb liveweight changes from pregnancy diagnosis (PD) to set-stocking and the risk of being dry at docking**

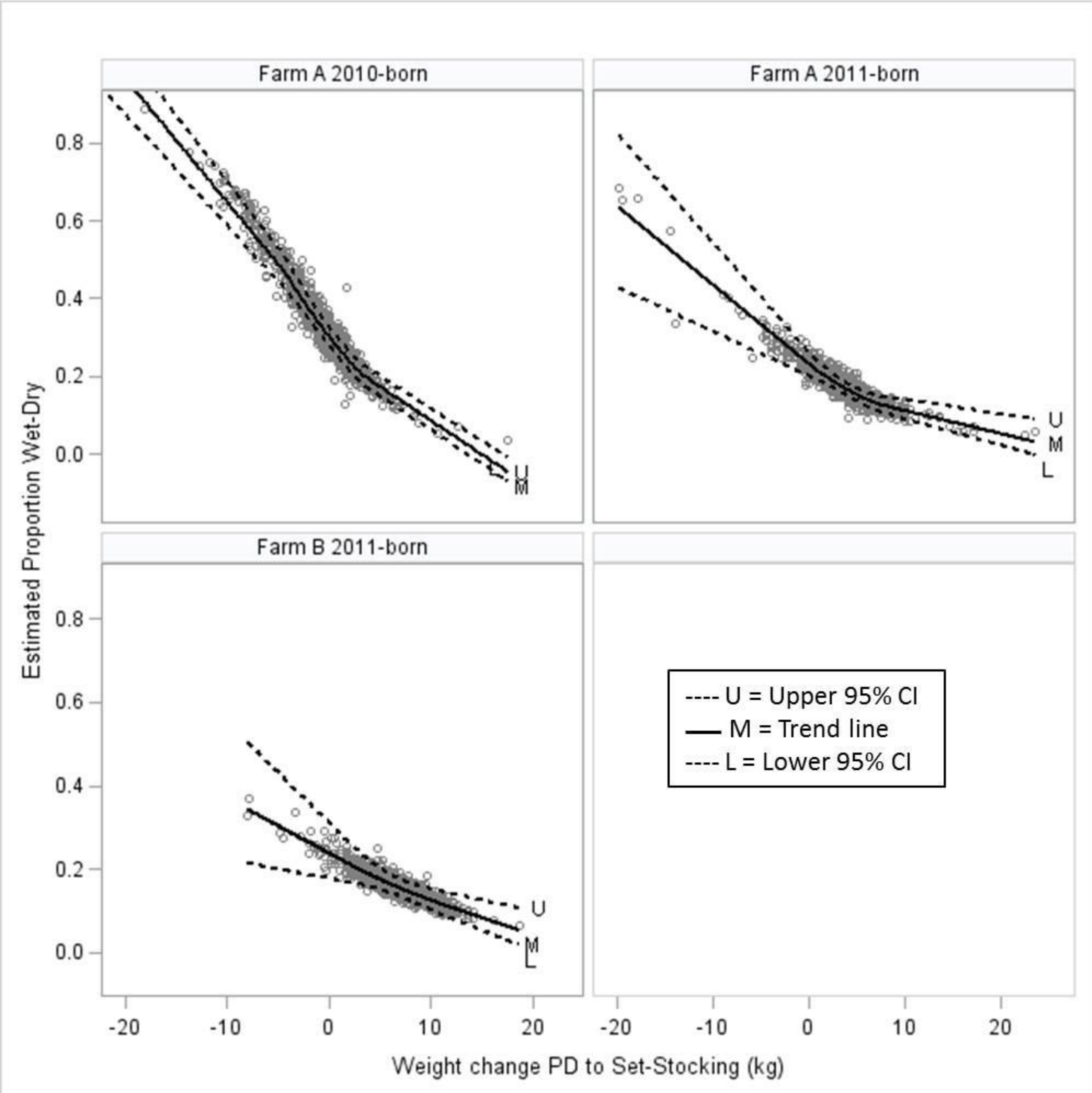
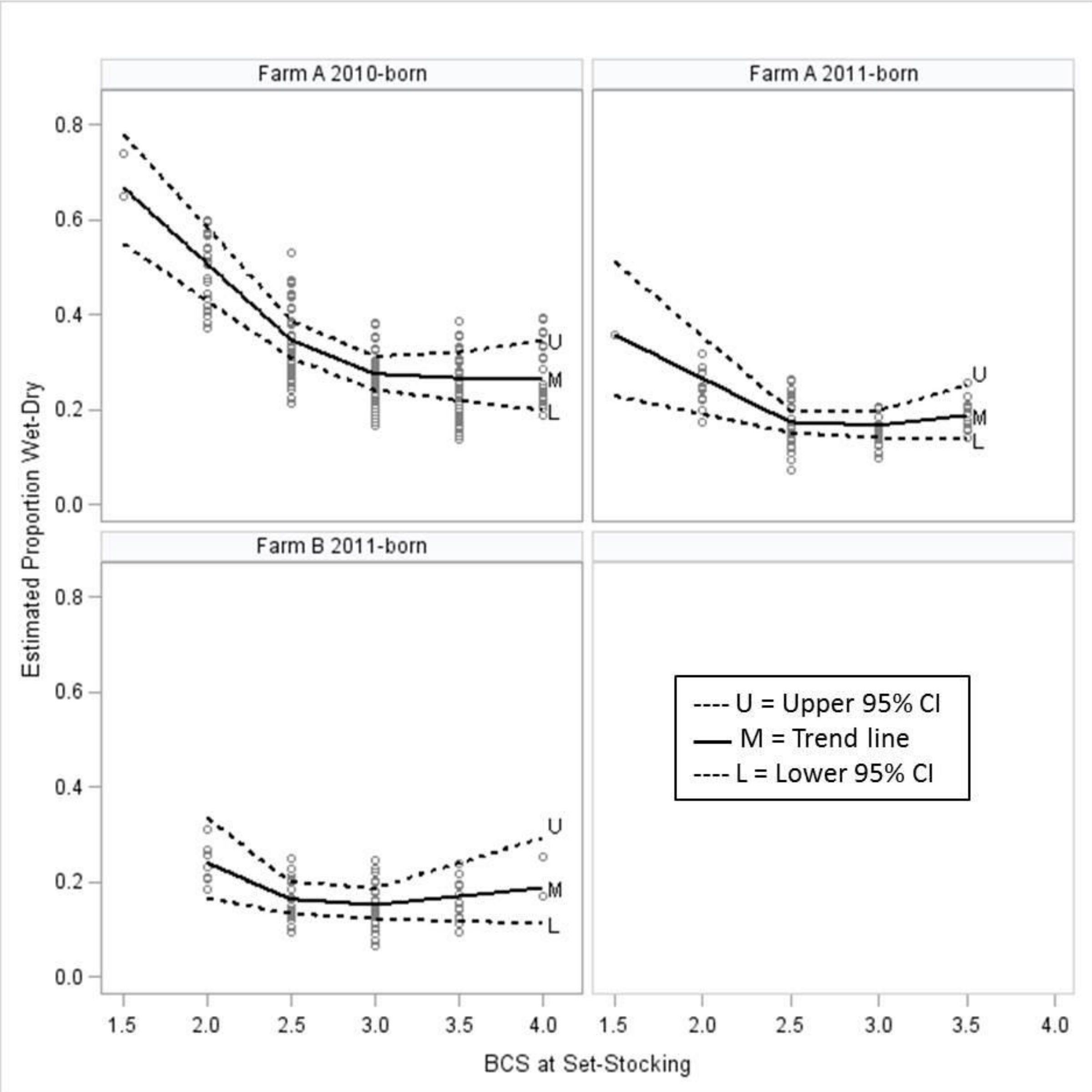


**Figure 4.4 Association between ewe lamb body condition score (BCS) at set-stocking and the risk of being dry at docking**



## Discussion

The proportion of dry ewe lambs varied by farm and year in this study. Potential causes of dry ewe lambs being identified at docking could include in-utero fetal loss, abortion, or perinatal lamb mortality. However, this study was not designed to determine the timing or the exact nature of the loss. Instead it was designed to examine the potential risk factors of liveweight, liveweight changes and body condition score on the risk of being dry at docking, after being diagnosed as pregnant in mid-pregnancy.

Although the magnitude of the risk of being dry varied between farms, the relationship between the risk of being dry and: CALW and actual liveweight at set-stocking, and CALW and actual liveweight change from pregnancy diagnosis to set-stocking were consistent across all cohorts in the study. It is recognised that the reproductive performance (both fertility and fecundity) of ewe lambs increases with increasing liveweight, with current recommendations that ewe lambs should be a minimum of 40kg at mating (Kenyon *et al.* 2014a). However, the importance of liveweight during the pregnancy period is less well defined. Although it has been stated that ewe lambs need to be well fed from breeding through to the weaning of their lamb(s) (Morris *et al.* 2005; Corner *et al.* 2013a), as they are also still growing themselves, thus avoiding negative impacts on future performance (Kenyon *et al.* 2014a). Ridler *et al.* (2017) reported that ewe lambs identified with fetal loss had lower (or no) liveweight gain in the 24-30 day period prior to identification of the loss, compared to ewe lambs which did not have fetal loss. In support of these previous findings, the present study identified an association between liveweight changes in pregnancy with risk of being dry at docking, further demonstrating the importance of ensuring ewe lambs continue to gain conceptus free liveweight throughout the pregnancy period.

In the present study, BCS at PD and set-stocking were associated with the risk of being dry at docking, with ewe lambs that were of low BCS more likely to be dry. BCS is used to assess the soft tissue cover over the lumbar region, predominantly fat, and is an indicator of energy reserves (Kenyon *et al.* 2014b). A general positive relationship between BCS and reproductive traits has been demonstrated in mature ewes (see review Kenyon *et al.* 2014b). However, the relationship between BCS and reproductive performance in ewe lambs is less well defined. Ewe lambs are still growing and therefore may be more likely to deposit muscle rather than lumbar body fat. The importance of BCS for lamb survival has been well documented in mature ewes (see review Hinch and Brien 2014), with a general positive relationship between ewe BCS and lamb survival. The results of the present study indicate farmers should aim to maintain ewe lambs at a BCS of 2.5 or greater to maximise the chance they will successfully rear a lamb to docking. This is in support of current recommendations for optimal BCS in ewe lambs previously described (Kenyon *et al.* 2014b).

Intensive lambing observations were not undertaken in this study therefore cause of loss is not known, nor was there a late-pregnancy ultrasound pregnancy scan conducted. However, results of previous studies allow for some speculation. In-utero fetal losses have been reported in ewe lambs in New Zealand (Kenyon *et al.* 2014a); however, the cause(s) of these fetal losses are not currently well understood. Results from Ridler *et al.* (2015) identified an association of fetal loss with low pre-mating liveweights and poor live weight gain between mating and pregnancy diagnosis. Ovine abortions in mature ewes in New Zealand are generally due to infectious agents, with the most significant being *Campylobacter fetus fetus* and *Toxoplasma gondii* (West 2002). Survey results from Kenyon *et al.* (2004b) suggest that ewe lambs that have been vaccinated for these infectious causes of abortion have higher lambing percentages, compared to ewe lambs which have not been vaccinated. In this study, the ewe lambs had been vaccinated against these. Further, abortions were not reported by the flock owners. Combined, this suggests abortion due to infectious disease was unlikely to be an important cause of dry ewe lambs in the present study.

The majority of perinatal lamb deaths in New Zealand are due to starvation, exposure and dystocia. Lamb losses of 19% to 43% have been reported for lambs born to ewe lambs (Kenyon *et al.* 2014a). McMillan (1983) reported dystocia was the major cause of perinatal lamb death in the offspring of ewe lambs, while Dalton *et al.* (1980) reported dystocia (particularly single born lambs) and starvation-exposure complex (particularly twin-born lambs) to be the most common causes of diagnosed perinatal lamb death in mature ewes. In Australia, a review by Hinch and Brien (2014), examining a number of different post-mortem studies, reported that dystocia, and the starvation complex, were attributed to between 3.0 – 53.6% and 4.0 – 82% lamb deaths respectively. In the current study light ewe lambs were less likely to rear a lamb to docking. This suggests dystocia may have been a contributing factor to the lamb losses in the present study; due to a potential mismatch in maternal pelvic size and lamb birthweight, as previously described by McSporran and Fielden (1979), with poorly fed and thus poorly grown ewe lambs having relatively smaller pelvic diameters (Kenyon *et al.* 2014a). Lamb death, due to starvation, has been reported in a number of studies (Hinch and Brien 2014), with poor ewe nutrition/condition contributing to these losses. Poor ewe condition/nutrition can contribute to both poor ewe behaviour and also poor or reduced colostrum production (Hinch and Brien 2014), thus increasing risk of lamb starvation. Snowder *et al.* (2001), using milk scores as a proxy for milk production, reported ewe lamb milk production was weakly positively correlated with bodyweight. It is possible that the lighter ewe lambs in this study had poor mothering ability, poorer colostrum and/or milk production, thus reducing the survival of their offspring.

## Conclusions

This study demonstrated clear relationships between ewe lamb liveweight, liveweight changes and body condition score during pregnancy on the risk of being dry at docking, after mid-pregnancy ultrasound pregnancy diagnosis. Ewe lambs that were heavier, of greater body condition, or gained greater liveweight during pregnancy were more likely to successfully rear a lamb to docking. Using this information commercial farmers can identify ewe lambs within a flock that are at risk of failing to successfully rear a lamb(s) to docking and may be able to plan management prior to breeding to ensure appropriate weight or BCS targets are monitored, met and achieved, or if problems are identified can implement management protocols targeting those ewe lambs which are most at risk.

# Chapter 5

# Associations between liveweight, body condition score and previous reproductive outcomes and the risk of ewes bred at 18-months of age being dry at docking

**Publications:** This chapter is based on the following publication:

**Griffiths KJ, Ridler AL, Heuer C, Corner-Thomas RA, Kenyon PR.** Associations between liveweight, body condition score and previous reproductive outcomes, and the risk of ewes bred at 18-months of age being dry at docking. *New Zealand Veterinary Journal* 66, 290-296, 2018

## Abstract

AIMS: Firstly, to investigate associations between liveweight and body condition score (BCS) of two-tooth ewes (18-months-old at breeding) at breeding, pregnancy diagnosis (PD) and pre-lambing and the risk of being dry at docking on commercial New Zealand sheep farms. Secondly, to investigate the association between previous reproductive outcomes as ewe lambs, and risk of being dry at docking as two-tooth ewes.

METHODS: Two-tooth ewes (n=9,006) were enrolled in four cohorts from three commercial sheep farms between 2010–14. Ewes were weighed and BCS assessed pre-breeding, at PD (mid-pregnancy) and pre-lambing. At PD, ewes were identified as either non-pregnant, or having single or multiple fetuses. Palpation and examination of udders at docking was used to classify each ewe as either lactating or dry at docking.

RESULTS: Overall, 437/8,025 (5.4%) of ewes that were diagnosed pregnant at PD were dry at docking. The risk of being dry at docking decreased with increasing pre-lambing conceptus adjusted liveweight (CALW) on all farms; for 2010-born ewes from Farm A the OR=0.87 (95% CI=0.81–0.92); ($p<0.001$); for Farm B the OR=0.88 (95% CI=0.83–0.92); ($p<0.001$) and for Farm C the OR=0.86 (95% CI=0.79–0.95); ($p=0.002$). The risk of being dry at docking also decreased with increasing CALW gain from PD to pre-lambing for all farms. For 2010-born ewes from Farm A the OR=0.89 (95% CI=0.84–0.94); ($p<0.001$); for Farm B the OR=0.85 (95% CI=0.81–0.89); ($p<0.001$) and for Farm C the OR=0.88 (95% CI=0.80–0.96); ($p=0.003$). There was no association between BCS at breeding, PD or pre-lambing and the risk of being dry at docking for 2010-born ewes from Farm A, Farm B or Farm C ($p>0.05$). For 2010-born ewes on Farm A, the risk of being dry at docking was greater for two-tooth ewes that were previously dry at docking as ewe lambs than those that were lactating at docking as ewe lambs (OR=1.7 (95% CI=1.1–2.8); $p=0.018$), but this difference was not observed for ewes on Farm B or Farm C ($p>0.5$).

CONCLUSIONS: There were negative associations between ewe CALW pre-lambing, and CALW gain between PD and pre-lambing, and risk of being dry at docking. For all cohorts, heavier ewes and those that gained CALW were less likely to be dry at docking than lighter ewes or those that lost CALW, however these relationships varied between cohorts.

## Introduction

Losses of lambs from pregnancy diagnosis until docking, when 3–6-week-old lambs are yarded for ear marking, tail removal and castration of males, remain an issue for commercial farmers both in New Zealand and internationally (Stafford 2013; Allworth *et al.* 2017). Failure of a ewe to successfully rear a lamb to weaning reduces both the total weight of lambs for sale, and overall flock efficiency (MacKay *et al.* 2012). Pregnancy diagnosis (PD) using ultrasonography enables farmers to identify and cull their non-pregnant ewes, and enables identification of multiple bearing ewes to facilitate preferential management during pregnancy, lambing and lactation (Garrick 1998; Allworth *et al.* 2017). A recent New Zealand survey indicated that 75% of farmers utilised ultrasonography for PD (Corner-Thomas *et al.* 2016). As discussed in Chapter 4, subsequent examination and palpation of udders at docking enables actively lactating and non-lactating (dry) ewes to be identified. Those that are identified as dry at docking are assumed to have lost their lamb(s) between pregnancy diagnosis and docking. However, few studies have directly examined factors associated with ewes being dry at docking in New Zealand.

In Chapter 4, an association between liveweight and liveweight change during pregnancy in ewe lambs and the risk of being dry at docking was reported, such that increasing liveweight of ewe lambs at PD and pre-lambing, and increasing liveweight gain between PD and pre-lambing were associated with decreasing risk of being dry at docking. In addition, increasing body condition score (BCS) of ewe lambs at PD and pre-lambing was associated with decreasing risk of being dry at docking (Chapter 4). To our knowledge, no comparable study has been undertaken in New Zealand with two-tooth ewes (18-months-old at breeding). However many studies have reported liveweight of ewes to be positively associated with lamb birth weights and lamb survival (Kelly 1992; Oldham *et al.* 2011; Schreurs *et al.* 2012), while ewe BCS has been reported to have either no association, or a positive association with lamb birth weight and lamb survival to weaning (reviewed by Kenyon *et al.* 2014b). Combined, these results would suggest a negative relationship between liveweight and BCS of two-tooth ewes and risk of being dry at docking would be expected. If found, such a relationship could enable farmers to set liveweight and BCS targets to assist in management of their ewes.

Studies examining the effect of ewe lamb breeding (bred at 7–8 months of age) on subsequent reproductive performance have reported a negative effect, no effect, or a positive effect, as reviewed by Kenyon *et al.* (2014b). It has been suggested that any potential effect on future reproductive performance would be dependent on the impact of ewe lamb breeding on subsequent liveweight (Kenyon *et al.* 2008; Kenyon *et al.* 2014a). For instance, if ewe lambs are not well grown and well fed during pregnancy and lactation, their liveweight at two-tooth ewe breeding may be compromised, resulting in reduced reproductive performance. However, there is currently a lack of information regarding the impact of this. Improved maternal behaviour score (MBS) is associated with improved lamb survival, and MBS improves with parity (Corner *et al.* 2013a). Therefore, it is possible that MBS would be greater in two-tooth ewe that have previously lambed as a ewe lamb. Further investigation into these relationships under commercial conditions would be of benefit.

The first aim of the present study was to investigate associations between liveweight and BCS of two-tooth ewes at breeding, PD and pre-lambing and risk of being dry at docking on commercial sheep farms. It was hypothesised that ewes that were heavier and of greater BCS would be less likely to be dry at docking. The second aim was to investigate the association between previous reproductive outcome as ewe lambs and risk of being dry at docking as two-tooth ewes. It was hypothesised that ewe lambs that were lactating at docking would be less likely to be dry at docking as two-tooth ewes than ewe lambs that were dry at docking.

## Materials and methods

### Farms and animals

The current study used data collected between 2012 and 2016 from 9,006 two-tooth ewes from three commercial sheep farms (Farm A, 2010-born and 2011-born, Farm B, 2011-born, and Farm C, 2014-born). Two cohorts of ewes from Farm A were included in this study; 2010-born (n=2,509) and 2011-born (n=2,341). One cohort of ewes were included from each of Farm B (n=3,500) and Farm C (n=656). As described in Chapter 4, all ewes from Farm A were presented for breeding as ewe lambs. On Farm B, only ewes that were approximately 38 kg or heavier had been presented for breeding as ewe lambs (n=2,001), while 1,499 were presented for breeding for the first time as two-tooth ewes. As with Farm A, all ewes on Farm C were bred previously as ewe lambs.

The general management of ewes on all farms has been described in Chapters 2-4. Ewe lambs that were dry at docking from the 2011-born cohort on Farm A were subsequently culled for failure to rear a lamb; however, ewe lambs that were dry at docking from the other cohorts were retained in their respective flocks for breeding as two-tooth ewes. The number of ewes enrolled in the present study and their prior reproductive outcomes as ewe lambs is shown for each cohort in Table 5.1.

**Table 5.1 Number of ewes born between 2010 and 2014 and enrolled from three farms, which were 18-months-old at breeding, and their prior reproductive outcomes as ewe lambs**

| | Farm A 2010-born | Farm A 2011-born | Farm B 2011-born | Farm C 2014-born |
|---|---|---|---|---|
| Enrolled | 2,509 | 2,341 | 3,500 | 656 |
| Not bred as ewe lamb | 0 | 0 | 1,499 | 0 |
| Bred as ewe lamb, not pregnant | NA | NA | 438 | NA |
| Pregnant as ewe lamb, dry at docking | 745 | NA | 239 | 34 |
| Pregnant as ewe lamb, lactating at docking | 1,639 | 2,325 | 1,299 | 580 |
| Reproductive outcome unknown | 125 | 16 | 25 | 42 |

NA=all ewes that met this criterion were culled as ewe lambs and so not enrolled in the current study

*Reproductive management*

On all farms, ewes were joined with entire rams at an approximate ratio of 1:100 for 34 days. During mid-pregnancy, approximately 60 days after ram removal, PD was undertaken using trans-abdominal ultrasonography by an experienced commercial operator. At PD, ewes were identified as either non-pregnant (no fetus), or having single or multiple (two or more) fetuses. Single and multiple-bearing ewes were then split into separate groups and managed so that pasture allowances were greater for the multiple than for single-bearing ewes. Non-pregnant ewes were excluded from the present study.

Five to fifteen days prior to the planned start of lambing, ewes from Farm A (2010-born), Farm B and Farm C were given an annual clostridial booster vaccination (Ultravac 5 in 1®, Zoetis New Zealand). In addition, at this time ewes were set-stocked as small groups of ewes in individual paddocks at a rate of approximately 7–10 ewes/ha. Ewes from Farm A (2011-born) were set-stocked immediately following PD. All ewes were managed as per normal commercial farm practice during the lambing period.

### Data collection

All ewes were weighed and BCS was assessed immediately prior to breeding, at PD, and pre-lambing. Due to Farm A 2011-born ewes being set-stocked immediately following PD there were no pre-lambing weights or BCS for this cohort.

On each farm, 3–6 weeks after lambing, ewes and their lambs were gathered into handling facilities for docking. At this time, the flock manager palpated the udder of each ewe and an assessment was made as to whether they were actively lactating or not.

All ewes present at breeding as two-tooth ewes were initially enrolled in the study. Ewes were removed from the study and subsequent analyses if they were non-pregnant at PD or had incomplete data.

*Calculation of conceptus adjusted liveweights*

As with Chapter 4, in order to eliminate the potential influence of conceptus weight on ewe liveweight during pregnancy, predicted conceptus adjusted liveweights (CALW) of the ewes were used in the analyses. For the present study, lamb birth weights were estimated to be 5.83 kg for single and 4.71 kg for multiple (assumed to be twin) lambs, using average birth weights from New Zealand studies which included Romney or Composite ewe lambs (Schreurs *et al.* 2012).

**Statistical analysis**

All statistical models were developed using SAS (Version 9.4; SAS Institute Inc., Cary, NC, USA). Multiple logistic regression models were developed for each of Farm A 2010-born, Farm A 2011-born, Farm B and Farm C separately, as there were variations between data collected for each. For each model, the output variable was risk of being dry at docking.

For models that examined associations with liveweight, the predictor variables were liveweight at breeding, CALW at PD, and CALW at pre-lambing (where available), and number of fetuses at PD (single or multiple). For models that examined associations with liveweight change, the predictor variables were CALW change from breeding to PD, and CALW change from PD to pre-lambing, and number of fetuses at PD (single or multiple). For models that examined associations with BCS, the predictor variables were BCS at breeding, PD and pre-lambing (where available), and number of fetuses at PD (single or multiple). Model fit was evaluated using the Hosmer and Lemeshow goodness of fit test (Hosmer and Lemeshow 2000). Data are presented as predicted geometric means and 95% CI.

The relationship between reproductive outcomes as a ewe lamb (bred or not bred; lactating or dry at docking) and risk of being dry at docking as a two-tooth ewe was assessed using $\chi 2$ analyses.

## Results

The number of ewes diagnosed as non-pregnant, or carrying single or multiple fetuses at PD for each cohort is shown in Table 5.2. The number of ewes with incomplete data was 246 and 177 for 2010 and 2011-born ewes on Farm A, respectively, 173 on Farm B, and 7 on Farm C. The total number of ewes included in analyses was 2,190 and 2,114 for 2010 and 2011-born ewes on Farm A, respectively, 3,096 on Farm B and 625 for Farm C.

**Table 5.2 Number (%) of ewes born between 2010 and 2014 and enrolled from three farms, which were 18-months-old at breeding, and subsequently identified as non-pregnant, single or multiple bearing at pregnancy diagnosis**

| | Farm A 2010-born | Farm A 2011-born | Farm B 2011-born | Farm C 2014-born |
|---|---|---|---|---|
| Enrolled | 2,509 | 2,341 | 3,500 | 656 |
| Non-pregnant | 73 (2.9%) | 50 (2.1%) | 231 (6.6%) | 24 (3.7%) |
| Single bearing | 594 (23.7%) | 702 (30.0%) | 1,954 (55.8%) | 189 (28.8%) |
| Multiple bearing | 1,842 (73.4%) | 1,589 (67.9%) | 1,315 (37.6%) | 443 (67.5%) |

The proportion of ewes that were identified as dry or lactating at docking on each farm is presented in Table 5.3. Ewes that were identified as multiple bearing at PD were less likely to be dry at docking than those that were identified as single bearing for 2010 and 2011-born ewes on Farm A, and for Farm B ($p<0.001$). Models examining associations with the risk of ewes being dry at docking included number of fetuses at PD, so the following results are for all ewes diagnosed pregnant with single or multiple fetuses.

**Table 5.3 Proportion of ewes born between 2010 and 2014 from three farms, which were 18-months-old at breeding, that were identified as lactating or dry at docking and were previously diagnosed as being pregnant with single or multiple fetuses**

| | Farm A 2010-born | | Farm A 2011-born | | Farm B 2011-born | | Farm C 2014-born | |
|---|---|---|---|---|---|---|---|---|
| | **Single** | **Multiple** | **Single** | **Multiple** | **Single** | **Multiple** | **Single** | **Multiple** |
| Proportion lactating | 492/533 | 1616/1657 | 592/657 | 1400/1457 | 1690/1855 | 1205/1241 | 173/186 | 420/439 |
| Percentage (95% CI) | 92.3 (90.0–94.6) | 97.5 (96.7–98.3) | 90.1 (87.8–92.4) | 96.1 (95.1–97.1) | 91.1 (89.8–92.4) | 97.1 (96.2–98.0) | 93.0 (89.3–96.7) | 95.7 (93.8–97.6) |
| Proportion dry | 41/533 | 41/1657 | 65/657 | 57/1457 | 165/1855 | 36/1241 | 13/186 | 19/439 |
| Percentage (95% CI) | 7.7 (5.4–10.0) | 2.5 (1.7–3.3) | 9.9 (7.6–12.2) | 3.9 (2.9–4.9) | 8.9 (7.6–10.2) | 2.9 (2.0–3.8) | 7.0 (3.3–10.7) | 4.3 (2.4–6.2) |

### Association between liveweight at breeding and CALW at PD and pre-lambing and the risk of being dry at docking

Mean liveweights of ewes at breeding, CALW at PD and CALW at pre-lambing are presented in Table 5.4. There was no association between ewe liveweight at breeding and the risk of being dry at docking for 2010 and 2011-born ewes on Farm A (p=0.321 and p=0.431, respectively) or Farm B (p=0.096). However for Farm C the risk of being dry at docking increased with increasing liveweight at breeding (OR=1.19 (95% CI=1.06–1.33); p=0.003).

For 2011-born ewes from Farm A the risk of being dry at docking decreased with increasing CALW at PD (OR=0.90 (95% CI=0.84–0.96); p=0.003). However for 2010-born ewes from Farm A and ewes from Farm B the risk of being dry at docking increased with increasing CALW at PD (OR=1.11 (95% CI=1.03–1.20); p=0.005, and OR=1.08 (95% CI=1.02–1.16); p=0.011, respectively). There was no association between CALW at PD and risk of being dry at docking for ewes from Farm C (p=0.885).

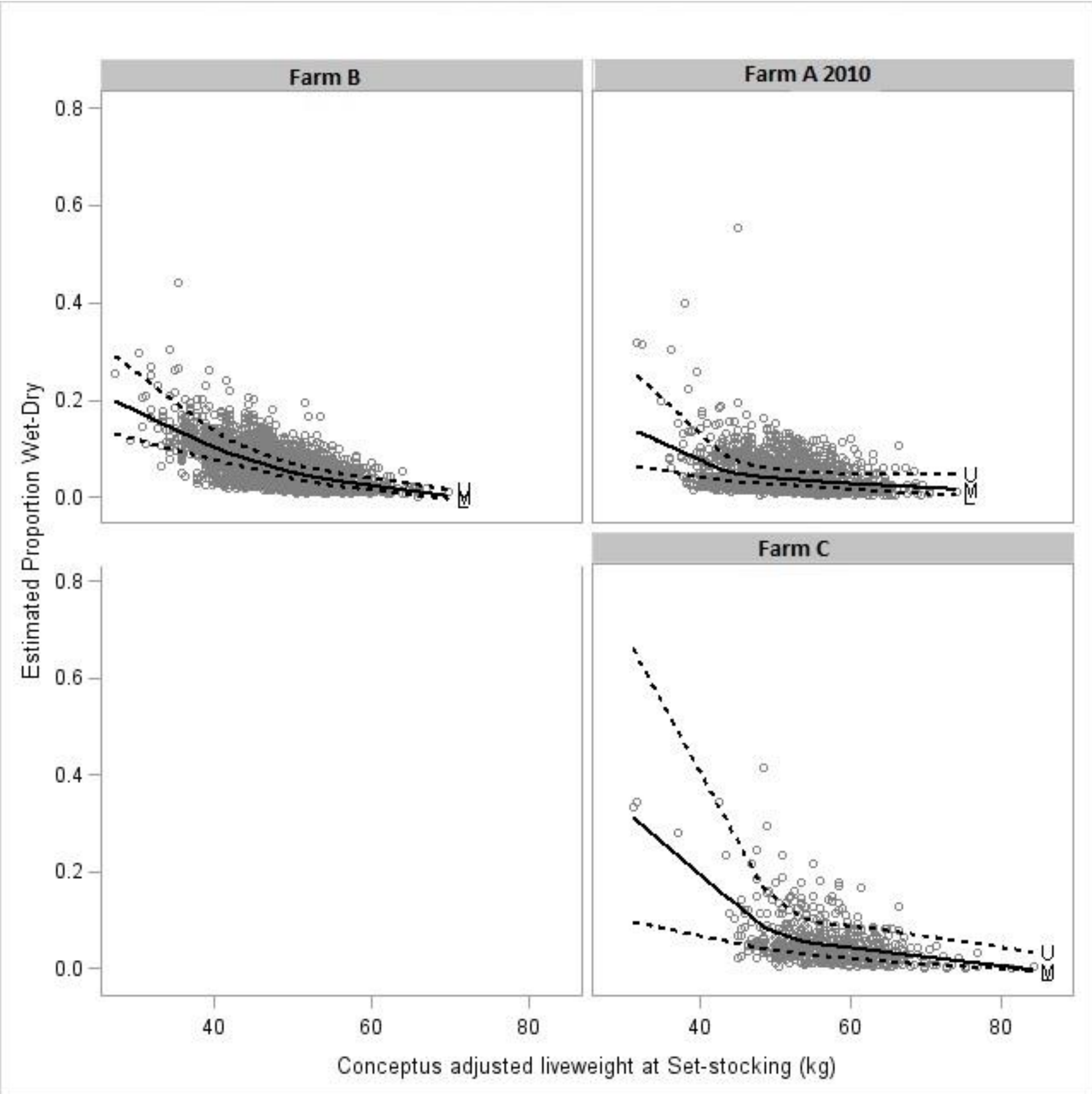
The risk of being dry at docking decreased with increasing pre-lambing CALW on all farms (Figure 5.1); for 2010-born ewes from Farm A the OR=0.87 (95% CI=0.81–0.92) (p<0.001); for Farm B the OR=0.88 (95% CI=0.83–0.92) (p<0.001) and for Farm C the OR=0.86 (95% CI=0.79–0.95) (p=0.002).

**Table 5.4 Mean (±SD) liveweight (LW) at breeding, conceptus adjusted liveweight (CALW) at pregnancy diagnosis (PD) and pre-lambing (kg), of ewes born between 2010 and 2014 from three farms, which were 18-months-old at breeding**

| | Farm A 2010-born | Farm A 2011-born | Farm B 2011-born | Farm C 2014-born |
|---|---|---|---|---|
| Breeding LW | 53.6±6.1 | 53.1±5.3 | 54.1±4.7 | 60.0±4.8 |
| PD CALW | 49.7±5.6 | 48.6±4.7 | 42.4±4.6 | 52.4±4.1 |
| Pre-lambing CALW | 51.2±5.7 | NA | 47.8±5.5 | 57.0±6.3 |

NA=data not collected

**Figure 5.1 Association between the estimated proportion of ewes that were 18-months-old at breeding that were dry at docking and pre-lambing conceptus adjusted liveweight (kg), on three farms. The solid line is the predicted geometric mean (M), the dotted lines the 95% CI**



#### Association between changes in CALW and the risk of being dry at docking

The risk of being dry at docking decreased with increasing CALW gain from breeding to PD for the ewes on Farm B (OR=0.95 (95% CI=0.90–0.99) p=0.026) and Farm C (OR=0.86 (95% CI=0.76–0.96) p=0.006). There was no association between change in CALW from breeding to PD and risk of being dry at docking for 2010 or 2011-born ewes from Farm A ($p > 0.3$).

The risk of being dry at docking decreased with increasing CALW gain from PD to pre-lambing for all farms (Figure 5.2). For 2010-born ewes from Farm A the OR=0.89 (95% CI=0.84–0.94) ($p<0.001$); for Farm B the OR=0.85 (95% CI=0.81–0.89) ($p<0.001$) and for Farm C the OR=0.88 (95% CI=0.80–0.96) (p=0.003).

#### Association between BCS at breeding, pregnancy diagnosis and pre-lambing and the risk of being dry at docking

There was no association between BCS at breeding, PD or pre-lambing and the risk of being dry at docking for 2010-born ewes from Farm A, Farm B or Farm C ($p>0.05$). However the risk of being dry at docking decreased with increasing BCS at PD for 2011-born ewes from Farm A (OR=0.30 (95% CI=0.16–0.56) p=0.0002) (Figure 5.3).

#### Relationship between previous ewe lamb reproductive outcomes and subsequent risk of being dry at docking

Farm B was the only farm to have two-tooth ewes that were not bred as ewe lambs. On this farm, the mean pre-mating liveweight of two-tooth ewes that were not bred as ewe lambs (52.8 (95% CI=45.1–60.4) kg) was similar to that of ewes that had been bred as ewe lambs (55.1 (95% CI=45.3–65.0) kg). In addition, the risk of being dry at docking for two-tooth ewes did not differ between ewes that had or had not been bred as ewe lambs (p=0.35).

Mean pre-mating liveweights were similar for two-tooth ewes that were lactating and those that were dry at docking as ewe lambs for 2010-born ewes on Farm A (51.8 (95% CI=41.8–61.8) *vs.* 57.7 (95% CI=45.7–69.7) kg), for ewes on Farm B (53.8 (95% CI 44.9–62.6) *vs.* 59.4 (95% CI=49.1–69.6) kg), and on Farm C (59.5 (95% CI=50.4–68.6) *vs.* 63.5 (95% CI=53.8–73.1) kg). For 2010-born ewes on Farm A, the risk of being dry at docking was greater for two-tooth ewes that were previously dry at docking as ewe lambs than those that were lactating at docking as ewe lambs (OR=1.7 (95% CI=1.1–2.8) p=0.018). However this difference was not observed for ewes on Farm B or Farm C (p=0.519, p=0.652, respectively).

**Figure 5.2 Association between the estimated proportion of ewes that were 18-months-old at breeding that were dry at docking and change in conceptus adjusted liveweight (kg) between pregnancy diagnosis and pre-lambing, on three farms. The solid line is the predicted geometric mean (M), the dotted lines the 95% CI**

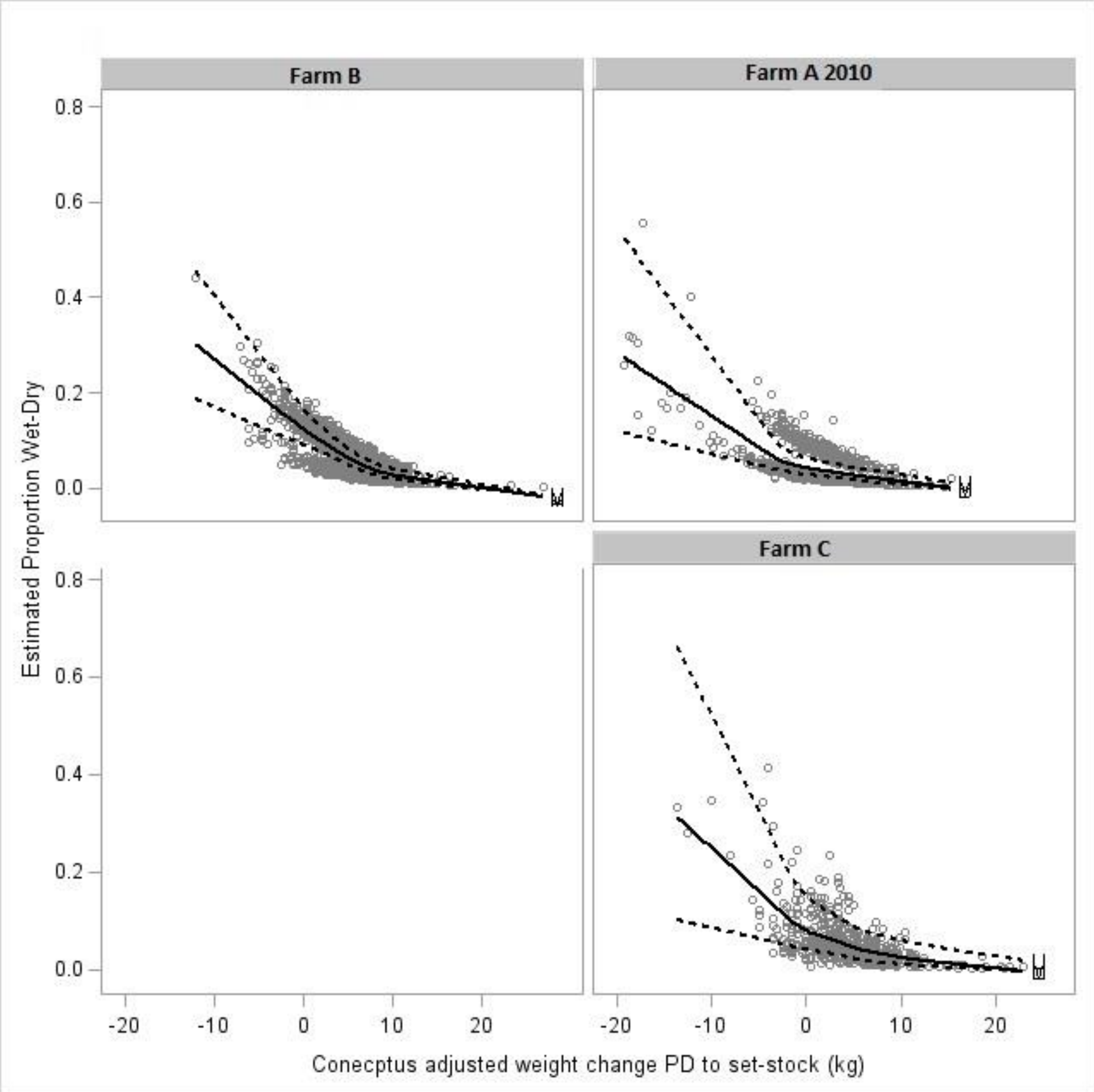
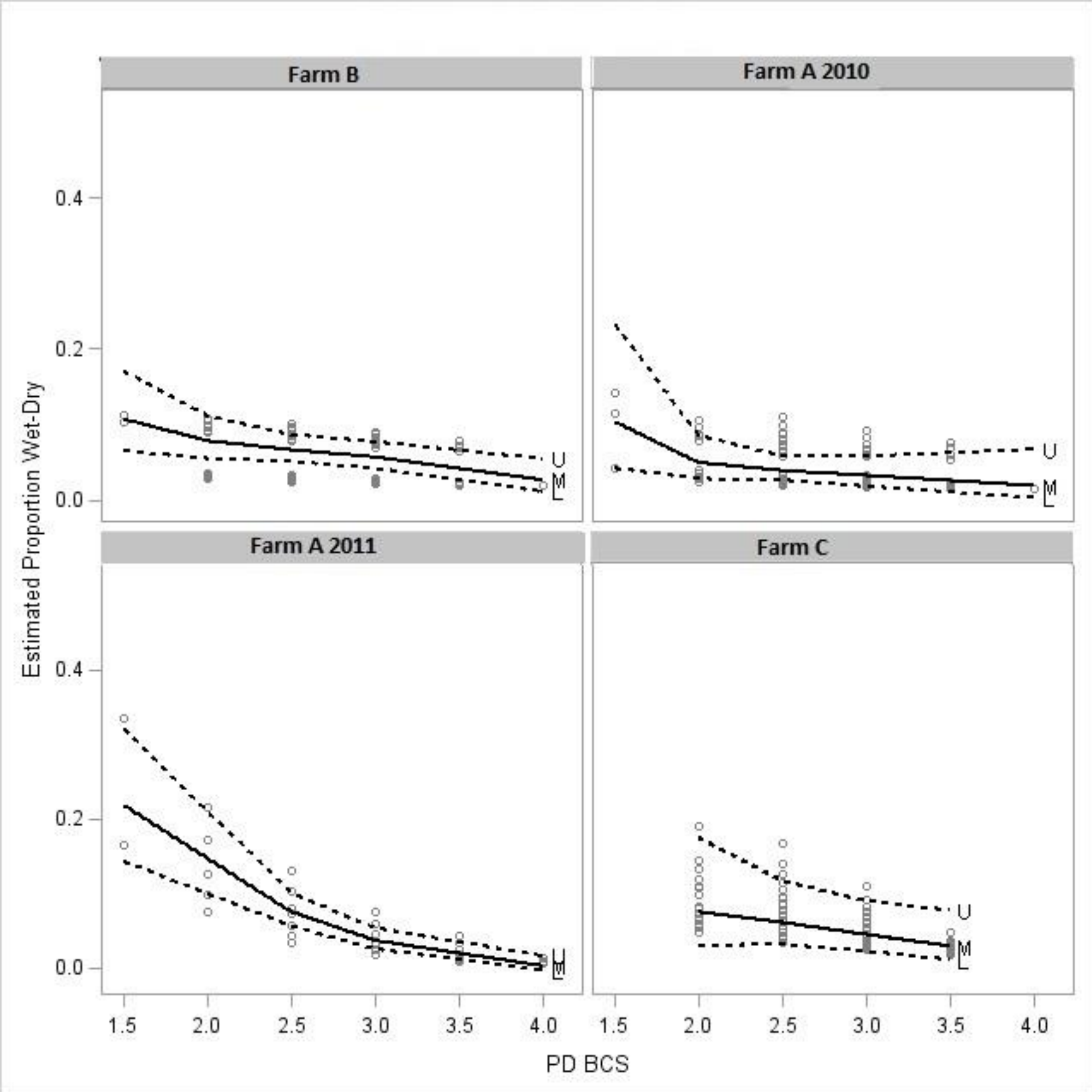


**Figure 5.3 Association between the estimated proportion of ewes that were 18-months-old at breeding that were dry at docking and body condition score at pregnancy diagnosis (PD BCS), on three farms. The solid line is the predicted geometric mean (M), the dotted lines the 95% CI**



## Discussion

The results of the present study demonstrated a negative association between CALW pre-lambing, and change in CALW between PD and pre-lambing, and the risk of ewes being dry at docking, thus supporting the hypothesis that heavier two-tooth ewes would be less likely to be dry at docking. There are scant existing reports describing the proportion of two-tooth ewes that are dry at docking, but our results are consistent with previous studies in both mature ewes and ewe lambs regarding lamb survival. In the current study lamb survival was not measured, but for a ewe to be identified as dry at docking it was assumed that most of the losses were lamb deaths after birth. Poor ewe nutrition has been reported to contribute to lamb losses (Hinch and Brien 2014; Corner-Thomas *et al.* 2015); likely due to poor fetal growth, organ development and energy reserves, or poor quality or reduced colostrum production, or poor ewe maternal behaviour (Hinch and Brien 2014; Kenyon *et al.* 2014a; Corner-Thomas *et al.* 2015). It has also been demonstrated that under-nutrition in pregnancy or reduced ewe liveweight can negatively affect lamb birth weight (Kelly 1992; Oldham *et al.* 2011; Schreurs *et al.* 2012), and low lamb birth weights are associated with an increased risk of lamb mortality (West *et al.* 2017; Oldham *et al.* 2011). In addition, mortality rates of lambs were highly correlated with liveweight of ewes in pregnancy, with increases in ewe liveweight associated with reduced lamb mortality (Kelly 1992; Oldham *et al.* 2011). Chapter 4 reported similar findings in ewe lambs, with ewe lambs that were heavier in mid-pregnancy and late-pregnancy being less likely to be dry at docking.

The results of the present study did not support the hypothesis that two-tooth ewes of greater BCS would be less likely to be dry at docking. This is in agreement with previous studies which have reported either no effect or a positive effect of ewe BCS on lamb survival to weaning (Kleemann and Walker 2004; Oldham *et al.* 2011; Kenyon *et al.* 2014b). In ewe lambs, there was no association between risk of being dry at docking and breeding BCS, but there was a small positive association with PD and pre-lambing BCS, such that ewe lambs with a greater BCS were less likely to be dry at docking (as previously discussed in Chapter 4). BCS provides the assessor with an estimate of the proportion of fat in the live animal (Russel *et al.* 1969). If feed supply is limited, or if ewe demand is high, these fat stores can be mobilised. It is possible that increased ewe BCS may be associated with reduced risk of being dry at docking when on-farm feed shortages occur. However, as feed supply was not measured in the present study, this could not be assessed. Future studies should examine the potential benefit of greater BCS under varying feeding levels.

The results of the present study were variable in their support of the hypothesis that two-tooth ewes that were lactating at docking as ewe lambs would be less likely to be dry at docking as two-tooth ewes. This was true for one cohort but not for the other two cohorts. This result is in agreement with previous studies in which there was either no effect, or a positive effect of ewe lamb breeding on subsequent reproductive performance (Kenyon *et al.* 2004b, 2014a). It was proposed that the effect of ewe lamb breeding on future reproductive performance is dependent on the impact on subsequent liveweight (Kenyon *et al.* 2014a). In the present study, liveweight at breeding of two-tooth ewes was similar between those that were lactating or dry at docking as ewe lambs. Additionally reduced liveweight at breeding was not associated with an increased risk of being dry at docking in two-tooth ewes. Some New Zealand farmers routinely cull ewes that are dry at docking (Amer *et al.* 2009), presumably because they think they are more likely to be dry at docking in subsequent seasons, however the results of the present study suggest this is not a valid assumption for all farms.

The negative relationships between both pre-lambing CALW and change in CALW and risk of being dry at docking were similar between cohorts, differing only in magnitude. This would suggest target pre-lambing CALW are therefore best assigned on an individual cohort basis. Regarding change in CALW from PD to pre-lambing, preventing any loss of CALW would be a reasonable target for all cohorts. For a typical twin bearing ewe this will require a gain of 12–17 kg of absolute (measured) liveweight by pre-lambing (Corner *et al.* 2008). Recommending target BCS from the current results is less clear, as the association between BCS and risk of being dry at docking was variable between cohorts. Moreover, a wide range of ewe, lamb and environmental factors can influence lamb survival and therefore likelihood of a ewe being dry at docking. Levels of feeding during pregnancy and lactation were not measured in the present study, so we cannot determine the potential influence of nutrition on these results. Further investigation into these relationships on additional commercial farms with varying levels of feed availability would be of benefit to allow clear conclusions to be drawn.

## Conclusions

There were negative associations between ewe CALW pre-lambing, and CALW gain between PD and pre-lambing, and risk of being dry at docking. For all cohorts, heavier ewes and those that gained CALW were less likely to be dry at docking than lighter ewes or those that lost CALW, however the relationship between pre-lambing liveweight and liveweight gain and risk of being dry at docking varied between cohorts.

# Chapter 6

# Associations between lamb survival to weaning and dam udder and teat scores

**Publications:** This chapter is based on the following publication:

**Griffiths KJ, Ridler AL, Compton CWR, Corner-Thomas RA, Kenyon PR.** Associations between lamb survival to weaning and dam udder and teat scores. *New Zealand Veterinary Journal* 67, 163-171, 2019

## Abstract

AIMS: To examine a range of udder and teat traits in Romney ewes and to describe the frequency with which different scores occur, and to investigate associations between lamb survival to weaning and ewe udder and teat scores.

METHODS: Mixed-age, mature Romney ewes (n=1,009) were enrolled from a commercial sheep flock located in the Wellington region of New Zealand in January 2017. A range of udder and teat traits were scored in all ewes, using visual assessment and palpation, at pre-mating (February), pre-lambing (October), docking (November) and weaning (January 2018). During the lambing period, each newborn lamb was matched to its dam, with lamb mortalities recorded until weaning. Associations between udder and teat scores and lamb survival to weaning were examined using multivariable models for each udder-scoring time.

RESULTS: Records from 981 ewes and 1,822 lambs were included in analyses, with 252 (13.8%) lambs recorded dead before weaning. Lambs born to ewes with pre-mating udder scores of lump or hard had 4.9 (95% CI=2.6-9.6, p=0.003) and 3.0 (95% CI=1.5-6.1, p<0.001) increased odds of failure to survive to weaning, respectively, compared with lambs whose dams had normal udder scores. Lambs born to ewes with mastitis at docking or weaning had 3.0 (95% CI=1.5-5.9, p=0.001) and 3.9 (95% CI=1.3-11.6, p=0.013) increased odds of failure to survive to weaning, respectively, compared with lambs whose dams did not have mastitis. Offspring of dams with asymmetrical udders at docking or weaning had 3.3 (95% CI=2.2-4.9, p<0.001) and 2.5 (95% CI=1.5-4.0, p<0.001) increased odds of failure to survive, respectively, compared with lambs whose dams had symmetrical udders.

CONCLUSION: Pre-mating udder palpation scores of hard or lump were associated with increased odds of lambs not surviving to weaning compared with normal scores, and could be used to identify ewes that are likely to be unsuitable for retaining in the breeding flock. Farmers could also use clinical mastitis scores and udder symmetry scores at docking or weaning to identify ewes whose lambs had greater odds of failure to survive to weaning. However, these scores do not provide an indication of future performance, therefore further investigation into the impact of the present season’s score on future seasons’ lamb survival is required.

## Introduction

The majority of income for New Zealand commercial sheep flocks is through the sale of lambs. Therefore, farmers currently aim to maximise the total weight of lamb available for sale, which is a combination of both the number and the weight of the individual lambs. Lambs are solely dependent on their dams for milk for survival in early life, with milk remaining an important source of digestible energy and protein to weaning late in lactation (Hayman *et al.* 1955; Clark 1980). It is well established that perinatal and neonatal lamb loss is a significant issue for sheep farmers (Stafford 2013; Dwyer *et al.* 2016; Allworth *et al.* 2017), and that ewes with defective udders contribute to this loss (Hayman *et al.* 1955; Watson and Buswell 1984). However, there appears to have been little recent scientific investigation of udder morphology in New Zealand.

Data from commercial New Zealand flocks suggests that between 2-6% of ewes have defective udders at weaning (Clark 1980; West *et al*. 2017; Peterson *et al.* 2017). Internationally, udder defects are recognised as important causes of wastage of ewes, as a result of increased on-farm mortality and increased premature culling (Madel 1981; Watson and Buswell 1984; Annett *et al.* 2011). In New Zealand, a recent survey indicated that >85% of commercial farmers examined their ewes' udders at least once yearly (Corner-Thomas *et al.* 2016). However in that survey the timing of the examination and subsequent fate of ewes were not determined, although presumably the udder examination was used to assist in culling decisions.

There is currently no standardised udder scoring method that New Zealand sheep farmers can use, and the optimal time to identify ewes that are unlikely to successfully rear their lambs is unknown. Therefore ewes may be culled unnecessarily or, conversely, ewes that are not suitable for lamb rearing may be retained within the flock. Udder morphology scoring is commonly performed in dairy ewes to improve both machine milkability and ewe udder health (Casu *et al.* 2006, 2010). However there appears to be little data regarding application and relevance of udder morphology scores in non-dairy breeds.

The aims of the present study were to firstly, examine a range of udder and teat traits in Romney ewes and to describe the frequency with which different scores occur at four key management times; pre-mating, pre-lambing, docking and weaning, and secondly, to investigate associations between lamb survival to weaning and dam udder and teat scores. It was hypothesised that lambs born to ewes with poor udder and teat scores would have lower survival than those born to ewes with more desirable udder and teat scores.

# Materials and Methods

## Farm and animals

The study utilised data collected during 2017 from mixed-age, mature Romney ewes that were born in 2013 or 2014 and were part of a commercial sheep flock located near Masterton, in the Wellington region of New Zealand. Ewes were individually identified using both an electronic identification tag and a visual identification tag (Allflex, Palmerston North, NZ). All ewes enrolled in the study flock had lambed previously. All ewes and their lambs were grazed under commercial grazing conditions on pasture containing predominantly ryegrass and white clover.

## Reproductive management and lamb survival

Ewes (n=1,009) were joined with entire rams (n=8) on 7 May 2017, for two oestrus cycles (34 days). Pre-mating, mean ewe liveweight was 69.3 (SD 6.3) kg. During mid-pregnancy (28 July 2017), pregnancy diagnosis was undertaken by an experienced commercial operator using transabdominal ultrasonography. Ewes were identified as either non-pregnant (no fetus), or pregnant with single (one fetus), twin (two fetuses) or triplet (three fetuses) lambs. Triplet, twin and single-bearing ewes were then split into separate groups and managed under commercial conditions so that the pasture allowance was greatest for the triplet, then twin, then single bearing ewes, although no pasture measurements were taken. Ewes were shorn in mid-pregnancy.

On 1 October 2017, 11 days prior to the planned start of lambing (pre-lambing) groups of ewes were put into individual paddocks at a rate of approximately seven, nine and 12 ewes per hectare for triplet, twin and single-bearing ewes, respectively. Prior to lambing, mean ewe liveweights were 73.6 (SD 6.4), 70.7 (SD 6.1) and 67.3 (SD 6.8) kg for triplet, twin and single-bearing ewes, respectively.

During the lambing period, intensive lambing observations were conducted twice daily. This involved matching each newborn lamb (both alive and dead; n=1,840) with its dam, tagging each lamb with an electronic identification tag (Allflex, Palmerston North, NZ), and recording lamb sex, birth-rank (single, twin or triplet) and birth-weight. Throughout the lambing and lactation period, all lamb deaths were recorded.

On 6 and 7 November 2017, ewes and their lambs were gathered into handling facilities for weighing, ear marking, tail removal, and castration of male lambs (docking). Lambs were also weighed at weaning, which occurred on 3 January 2018. Lamb survival to weaning was defined as a lamb that was present at weaning.

### Ewe udder scores

The udders and teats of all ewes were scored prior to the start of mating (pre-mating), 11 days before planned start of lambing (pre-lambing), and at docking and weaning. The udder scoring system used was developed following consultation with experts from within New Zealand (veterinarians, farmers and animal scientists), and with reference to a review of existing sheep udder morphology scoring systems, as described by Casu *et al.* (2006, 2010). As there were limited existing data related to non-dairy breed ewes, a range of appearance and palpation traits related to both the teats and udder were assessed, as described in Table 6.1. Due to the small number of ewes in some categories, some scores were subsequently combined for analyses, as described in Table 6.1.

**Table 6.1 Description of the traits and scores used to assess udder morphology in ewes at different times between mating and weaning. Due to small numbers of ewes in some categories, scores were subsequently combined for analyses**

| Trait | Ewe position | Score | Description | Analysis score |
|---|---|---|---|---|
| Udder Palpation | Sitting | 7 | Diffuse hard consistency of udder | Hard |
| | | 6 | Firm consistency of udder with small nodule(s) (lumps) > 2cm in size | Lump |
| | | 5 | Firm consistency of udder with small nodule(s) (lumps) < 2cm in size | Lump |
| | | 4 | Soft consistency of udder with small nodule(s) (lumps) > 2cm in size | Lump |
| | | 3 | Soft consistency of udder with small nodule(s) (lumps) < 2cm in size | Lump |
| | | 2 | Diffuse firm consistency of udder | Normal |
| | | 1 | Diffuse soft consistency of udder | Normal |
| Teat Palpation | Sitting | 5 | Teat obstruction (‘blind teat’) | Abnormal |
| | | 4 | Dense, vertical cord in centre of teat (‘straw’) | Abnormal |
| | | 3 | Hard consistency | Abnormal |
| | | 2 | Thickened teat end | Abnormal |
| | | 1 | Soft consistency | Normal |
| Udder Depth | Standing | 5 | The distance between the udder cleft and the abdominal wall, taking as a reference the line joining the hocks. For a score of 5 the udder cleft is at the level of the abdominal wall, a score of 3 the udder cleft is at hock level | 5 |
| | | 4 | | 4 |
| | | 3 | | 3 |
| | | 2 | | 2 |
| | | 1 | | 2 |
| Udder Suspension | Standing | 5 | The ratio between the udder attachment width and udder depth. For a score of 5 the attachment width is much larger than depth, a score of 3 the udder is apparently ‘square’, a score of 1 the width is much narrower than depth | 5 |
| | | 4 | | 4 |
| | | 3 | | 3 |
| | | 2 | | 2 |
| | | 1 | | 2 |
| Udder Separation | Standing | 5 | Measure of separation of the two udder halves. For a score of 1 there is no separation, a score of 5 the udder is very clearly divided into two halves | 3 |
| | | 4 | | 3 |
| | | 3 | | 3 |
| | | 2 | | 2 |
| | | 1 | | 1 |
| Teat Placement | Standing | 5 | Measure of the external height of the teat cistern, the distance between the teat and the lowest part of the udder. For a score of 5 the teat is lateral, a score of 1 the teat is ventral | 5 |
| | | 4 | | 4 |
| | | 3 | | 3 |
| | | 2 | | 2 |
| | | 1 | | 2 |
| Clinical Mastitis | Sitting | Yes | Visible udder inflammation +/- abnormal milk/purulent discharge | Yes |
| | | No | | No |
| Lump Midline | Sitting | Yes | Presence of a superficial lump located in the midline, immediately cranial to the udder | Yes |
| | | No | | No |
| Udder Symmetry | Standing | Asymmetrical | Measure of the visible symmetry of the udder halves while the udder is hanging naturally | Asymmetrical |
| | | Symmetrical | | Symmetrical |

### Statistical analyses

Records from 981 ewes and 1,822 lambs were included in the statistical analyses. Non-pregnant ewes (n=16) were removed from the study flock after pregnancy diagnosis and were thus excluded from the study. A further 12 ewes were excluded due to either on-farm mortality or culling for welfare reasons. Lambs that were recorded as born-dead (n=18) were excluded from analysis.

All statistical analyses were conducted using SAS version 9.4 (SAS Institute Inc., Cary, NC, USA,). The main predictor variables for modelling were udder and teat scores, which were measured at the ewe-level. The outcome variable was lamb survival to weaning (yes or no, which was measured at the lamb-level and was also the unit of analysis. Firstly, at each udder-scoring time, univariate screening was conducted to examine the relationship between all predictor variables and the outcome variable. If variables were associated ($p< 0.2$) they were included in initial multivariable models. Results from each scoring time were analysed separately, with pre-mating and pre-lambing scores considered as predictive, and docking and weaning scores considered as explanatory of lamb survival to weaning.

Multivariable generalised estimating equation models, using an exchangeable correlation structure to account for clustering between lambs born to the same ewe, were developed for each time when udder and teat scores were recorded. Forward manual variable selection was used to build the preliminary models, with variables retained where Wald test p-values were < 0.05, after which the effect of adding variables in different orders was investigated (but without effect on the chosen model). Finally, interaction terms that were biologically plausible were considered. In addition to the predictor variables determined by univariate analyses, all final models included the variables lamb sex (male or female), lamb birth rank (single, twin or triplet born) and lamb birthweight. The fit of the final model was evaluated using the Hosmer and Lemeshow goodness of fit test (Hosmer and Lemeshow 2000). OR for failure of a lamb to survive to weaning and probability of mortality, with 95% CI, for lambs born to ewes with different scores were calculated from final models.

## Results

Of the 1,822 lambs, triplet, twin and single-born lambs accounted for 255 (14.0%), 1,368 (75.1%) and 199 (10.9%) lambs respectively, and 891 (48.9%) were male. The mean birthweights of triplet, twin and single-born lambs were 4.1 (SD 0.8), 5.1 (SD 0.8) and 6.1 (SD 0.9) kg, respectively. In total, 252 lambs were reported as dead prior to weaning; 13.8% overall mortality rate from birth to weaning. At weaning, mean lamb age was 84.4 (SD 5.4) days, and mean weaning weights of triplet, twin and single-born lambs were 22.9 (SD 5.3), 26.7 (SD 4.5) and 32.7 (SD 5.0) kg, respectively.

### Associations between lamb survival to weaning and ewe udder and teat scores

*Univariate analyses*

The number of ewes recorded with different scores for udder traits at each recording time is shown in Table 6.2, and the number of lambs born to ewes with different scores is shown in Table 6.3. Results of univariate analyses examining associations between different traits and survival of lambs to weaning are presented in Table 6.4.

At pre-mating, 6.0% of the ewes had hard udders or lumps detected by palpation, and 6.9% had one or both abnormal teats detected by palpation (Table 6.2). The odds of a lamb not surviving to weaning were greater if they were the offspring of ewes with udder palpation scores of hard or lump, or had one or both teats recorded as abnormal on palpation, compared to those whose dams had normal scores (Table 6.4).

At pre-lambing, 5.0% of the ewes had abnormal udders detected by palpation, and 6.4% of ewes had abnormal teat palpation scores (Table 6.2). The odds of a lamb not surviving to weaning were greater if they were the offspring of ewes with an udder palpation score of lump, or had one or both teats recorded as abnormal, compared to those whose dams had normal scores (Table 6.4).

At docking, the prevalence of ewes recorded with abnormal udders was 7.5%, abnormal teats was 34.9%, and clinical mastitis was 4.6% (Table 6.2). The odds of a lamb not surviving to weaning were greater if they were the offspring of ewes with udder palpation scores of hard or lump, or ewes with clinical mastitis, compared to those whose dams had normal udder palpation scores or did not have clinical mastitis (Table 6.4). However, the odds of survival to weaning was similar for offspring of dams with normal or abnormal teat palpation scores. The odds of a lamb not surviving to weaning were markedly reduced in offspring born to ewes with an udder depth score of two, three or four compared with five at docking, however only 9/981 (0.9%) ewes had a score of 5 at docking.

At the weaning the prevalence of ewes with abnormal udders was 7.4%, clinical mastitis was 3.1%, and asymmetrical udders was 10.2% (Table 6.2). The odds of a lamb not surviving to weaning were greater if they were the offspring of ewes with udder palpation scores of hard or lump, ewes with clinical mastitis, or ewes with asymmetrical udders, compared to those whose dams had normal udder palpation scores, did not have clinical mastitis, or had symmetrical udders, respectively (Table 6.4).

**Table 6.2 Number (%) of ewes (n=981) in one flock that were recorded with different scores for udder traits (see Table 6.1) on four occasions between mating and weaning**

| Trait | Analysis score | Pre-mating | Pre-lambing | Docking | Weaning |
|---|---|---|---|---|---|
| Udder palpation | Hard | 29 (3.0%) | 5 (0.5%) | 16 (1.6%) | 15 (1.5%) |
| | Lump | 29 (3.0%) | 44 (4.5%) | 58 (5.9%) | 58 (5.9%) |
| | Normal | 923 (94.0%) | 932 (95.0%) | 907 (92.5%) | 908 (92.6%) |
| | Missing data | 0 (0%) | 0 (0%) | 0 (0%) | 0 (0%) |
| Teat palpation | Abnormal-both | 9 (0.9%) | 12 (1.2%) | 231 (23.6%) | 208 (21.2%) |
| | Abnormal-one | 59 (6.0%) | 51 (5.2%) | 111 (11.3%) | 52 (5.3%) |
| | Normal | 913 (93.1%) | 918 (93.6%) | 639 (65.1%) | 721 (73.5%) |
| | Missing data | 0 (0%) | 0 (0%) | 0 (0%) | 0 (0%) |
| Udder depth | 5 | 851 (86.8%) | 87 (8.9%) | 9 (0.9%) | 40 (4.1%) |
| | 4 | 107 (10.9%) | 756 (77.1%) | 172 (17.5%) | 458 (46.7%) |
| | 3 | 9 (0.9%) | 132 (13.4%) | 711 (72.6%) | 444 (45.3%) |
| | 2 | 1 (0.1%) | 5 (0.5%) | 70 (7.1%) | 5 (0.5%) |
| | Missing data | 13 (1.3%) | 1 (0.1%) | 19 (1.9%) | 34 (3.4%) |
| Udder suspension | 5 | 477 (48.6%) | 33 (3.4%) | 0 (0.0%) | 2 (0.2%) |
| | 4 | 357 (36.4%) | 351 (35.8%) | 35 (3.6%) | 240 (24.5%) |
| | 3 | 118 (12.0%) | 418 (42.6%) | 741 (75.5%) | 561 (57.2%) |
| | 2 | 16 (1.6%) | 177 (18.0%) | 186 (19.0%) | 144 (14.7%) |
| | Missing data | 13 (1.3%) | 2 (0.2%) | 19 (1.9%) | 34 (3.4%) |
| Udder separation | 3 | 11 (1.1%) | 43 (4.4%) | 59 (6.0%) | 68 (6.9%0 |
| | 2 | 139 (14.2%) | 289 (29.5%) | 376 (38.3%) | 342 (34.9%) |
| | 1 | 811 (82.7%) | 643 (65.5%) | 505 (51.5%) | 521 (53.1%) |
| | Missing data | 20 (2.0%) | 6 (0.6%) | 41 (4.2%) | 50 (5.1%) |
| Teat placement | 5 | 244 (24.9%) | 62 (6.3%) | 26 (2.7%) | 88 (9.0%) |
| | 4 | 211 (21.5%) | 273 (27.8%) | 205 (20.9%) | 258 (26.3%) |
| | 3 | 404 (41.2%) | 480 (48.9%) | 522 (53.2%) | 457 (46.6%) |
| | 2 | 92 (9.4%) | 156 (15.9%) | 141 (14.4%) | 103 (10.5%) |
| | Missing data | 30 (3.0%) | 10 (1.0%) | 87 (8.8%) | 75 (7.6%) |
| Clinical mastitis | Yes | 12 (1.2%) | 8 (0.8%) | 45 (4.6%) | 30 (3.1%) |
| | No | 957 (97.6%) | 972 (99.1%) | 919 (93.7%) | 921 (93.9%) |
| | Missing data | 12 (1.2%) | 1 (0.1%) | 17 (1.7%) | 30 (3.0%) |
| Lump midline | Yes | 11 (1.1%) | 5 (0.5%) | 25 (2.5%) | 31 (3.2%) |
| | No | 958 (97.7%) | 974 (99.3%) | 939 (95.7%) | 920 (93.8%) |
| | Missing data | 12 (1.2%) | 2 (0.2%) | 17 (1.7%) | 30 (3.0%) |
| Udder symmetry | Asymmetrical | 55 (5.6%) | 48 (4.9%) | 107 (10.9%) | 100 (10.2%) |
| | Symmetrical | 914 (93.2%) | 932 (95.0%) | 855 (87.2%) | 847 (86.3%) |
| | Missing data | 12 (1.2%) | 1 (0.1%) | 19 (1.9%) | 34 (3.5%) |

**Table 6.3 Number of lambs born to ewes in one flock that were recorded with different scores for udder traits (see Table 6.1) on four occasions between mating and weaning. The number and percentage of lambs in each score category that did not survive to weaning are presented in brackets**

| Trait | Score | Pre-mating | Pre-lambing | Docking | Weaning |
|---|---|---|---|---|---|
| Udder palpation | Hard | 52 (16, 30.8%) | 10 (1, 10.0%) | 31 (11, 35.5%) | 29 (9, 31.0%) |
| | Lump | 52 (19, 36.5%) | 88 (26, 29.6%) | 119 (28, 23.5%) | 114 (22, 19.3%) |
| | Normal | 1,718 (217, 12.6%) | 1,724 (225, 13.1%) | 1,672 (213, 12.7%) | 1,679 (221, 13.2%) |
| | Total | 1,822 (252, 13.8%) | 1,822 (252, 13.8%) | 1,822 (252, 13.8%) | 1,822 (252, 13.8%) |
| Teat palpation | Abnormal-both | 17 (5, 29.4%) | 21 (7, 33.3%) | 434 (44, 10.1%) | 404 (26, 6.4%) |
| | Abnormal-one | 114 (29, 25.4%) | 101 (27, 26.7%) | 224 (41, 18.3%) | 104 (19, 18.3%) |
| | Normal | 1,691 (218, 12.9%) | 1,700 (218, 12.8%) | 1,164 (167, 14.4%) | 1,314 (207, 15.8%) |
| | Total | 1,822 (252, 13.8%) | 1,822 (252, 13.8%) | 1,822 (252, 13.8%) | 1,822 (252, 13.8%) |
| Udder depth | 5 | 1,572 (204, 13.0%) | 126 (12, 9.5%) | 12 (10, 83.3%) | 70 (49, 70.0%) |
| | 4 | 206 (36, 17.5%) | 1,410 (189, 13.4%) | 281 (72, 25.6%) | 814 (87, 10.7%) |
| | 3 | 17 (8, 47.1%) | 273 (46, 16.9%) | 1,341 (126, 9.4%) | 860 (82, 9.5%) |
| | 2 | 3 (2, 66.7%) | 12 (4, 33.3%) | 150 (24, 16.0%) | 13 (6, 46.2%) |
| | Total | 1,798 (250, 13.9%) | 1,821 (251, 13.8%) | 1,784 (232, 13.0%) | 1,757 (224, 12.7%) |
| Udder suspension | 5 | 864 (107, 12.4%) | 47 (7, 14.9%) | 0 (0, 0.0%) | 3 (0, 0.0%) |
| | 4 | 670 (96, 14.3%) | 627 (78, 12.4%) | 61 (24, 39.3%) | 438 (74, 16.9%) |
| | 3 | 232 (39, 16.8%) | 789 (107, 13.6%) | 1,350 (156, 11.6%) | 1,030 (113, 11.0%) |
| | 2 | 32 (8, 25.0%) | 357 (58, 16.3%) | 373 (52, 13.9%) | 286 (37, 12.9%) |
| | Total | 1,798 (250, 13.9%) | 1,820 (250, 13.7%) | 1,784 (232, 13.0%) | 1,757 (224, 12.7%) |
| Udder separation | 3 | 18 (3, 16.7%) | 89 (21, 23.6%) | 118 (29, 24.6%) | 126 (17, 13.5%) |
| | 2 | 251 (46, 18.3%) | 538 (65, 12.1%) | 708 (90, 12.7%) | 630 (66, 10.5%) |
| | 1 | 1,513 (193, 12.8%) | 1,184 (160, 13.5%) | 916 (103, 11.2%) | 971 (138, 14.2%) |
| | | 1,782 (242, 13.6%) | 1,811 (246, 13.6%) | 1,742 (222, 12.7%) | 1,727 (221, 12.8%) |
| Teat placement | 5 | 440 (46, 10.5%) | 114 (17, 14.9%) | 49 (9, 18.4%) | 166 (16, 9.6%) |
| | 4 | 409 (55, 13.5%) | 510 (65, 12.8%) | 392 (44, 11.2%) | 473 (60, 12.7%) |
| | 3 | 751 (103, 13.7%) | 897 (120, 13.4%) | 953 (93, 9.8%) | 849 (99, 11.7%) |
| | 2 | 164 (35, 21.3%) | 283 (45, 15.9%) | 257 (41, 16.0%) | 191 (32, 16.8%) |
| | | 1,764 (239, 13.5%) | 1,804 (247, 13.7%) | 1,651 (187, 11.3%) | 1,679 (207, 12.2%) |

| | | | | | |
|---|---|---|---|---|---|
| Clinical mastitis | Yes | 22 (5, 22.7%) | 15 (5, 33.3%) | 89 (29, 32.6%) | 55 (19, 34.6%) |
| | No | 1,778 (245, 13.8%) | 1,806 (246, 13.6%) | 1,699 (207, 12.2%) | 1,711 (206, 12.0%) |
| | | 1,800 (250, 13.9%) | 1,821 (251, 13.8%) | 1,788 (236, 13.2%) | 1,766 (225, 12.7%) |
| Lump midline | Yes | 19 (2, 10.5%) | 10 (2, 20.0%) | 47 (1, 2.1%) | 63 (6, 9.5%) |
| | No | 1,781 (248, 13.9%) | 1,810 (248, 13.7%) | 1,741 (235, 13.5%) | 1,703 (219, 12.9%) |
| | | 1,800 (250, 13.9%) | 1,820 (250, 13.7%) | 1,788 (236, 13.2%) | 1,766 (225, 12.7%) |
| Udder symmetry | Asymmetrical | 102 (25, 24.5%) | 97 (27, 27.8%) | 215 (62, 28.8%) | 193 (46, 23.8%) |
| | Symmetrical | 1,698 (225, 13.3%) | 1,724 (224, 13.0%) | 1,569 (170, 10.8%) | 1,564 (178, 11.4%) |
| | | 1,800 (250, 13.9%) | 1,821 (251, 13.8%) | 1,784 (232, 13.0%) | 1,757 (224, 12.7%) |

**Table 6.4 Results of univariate analyses showing the OR (95% CI) for failure of a lamb to survive to weaning for lambs born to ewes in one flock that were recorded with different scores for udder traits (see Table 6.1) on four occasions between mating and weaning**

| Trait | Score | Pre-mating | | Pre-lambing | | Docking | | Weaning | |
|---|---|---|---|---|---|---|---|---|---|
| | | OR | 95% CI | OR | 95% CI | OR | 95% CI | OR | 95% CI |
| Udder palpation | Hard | 3.1 | 1.8 - 5.6 | 0.7 | 0.1 - 5.9 | 3.8 | 1.8 - 8.0 | 3.0 | 1.4 - 6.6 |
| | Lump | 4.0 | 2.2 - 7.1 | 2.8 | 1.7 - 4.5 | 2.1 | 1.3 - 3.3 | 1.6 | 1.0 - 2.6 |
| | Normal | Ref | | Ref | | Ref | | Ref | |
| Teat palpation | Abnormal-both | 2.8 | 1.0 - 8.1 | 3.4 | 1.4 - 8.5 | 0.7 | 0.5 - 1.0 | 0.4 | 0.2 - 0.6 |
| | Abnormal-one | 2.3 | 1.5 - 3.6 | 2.5 | 1.6 - 3.9 | 1.3 | 0.9 - 2.0 | 1.2 | 0.7 - 2.0 |
| | Normal | Ref | | Ref | | Ref | | Ref | |
| Udder depth | 5 | Ref | | Ref | | Ref | | Ref | |
| | 4 | 1.4 | 1.0 - 2.1 | 1.5 | 0.8 - 2.7 | 0.1 | 0.1 - 0.3 | 0.1 | 0.1 - 0.1 |
| | 3 | 6.0 | 2.3 - 15.6 | 1.9 | 1.0 - 3.8 | 0.1 | 0.1 - 0.1 | 0.1 | 0.1 - 0.1 |
| | 2 | 13.4 | 1.2 - 148.6 | 4.8 | 1.2 - 18.1 | 0.1 | 0.1 - 0.2 | 0.4 | 0.1 - 1.2 |
| Udder suspension | 5 | Ref | | Ref | | n.a. | | a | |
| | 4 | 1.2 | 0.9 - 1.6 | 0.8 | 0.4 - 1.9 | Ref | | Ref | |
| | 3 | 1.4 | 1.0 - 2.1 | 0.9 | 0.4 - 2.1 | 0.2 | 0.1 - 0.3 | 0.6 | 0.4 - 0.8 |
| | 2 | 2.4 | 1.0 - 5.4 | 1.1 | 0.5 - 2.6 | 0.3 | 0.1 - 0.5 | 0.7 | 0.5 - 1.1 |
| Udder separation | 3 | Ref | | Ref | | Ref | | Ref | |
| | 2 | 1.1 | 0.3 - 4.0 | 0.4 | 0.3 - 0.8 | 0.4 | 0.3 - 0.7 | 0.8 | 0.4 - 1.3 |
| | 1 | 0.7 | 0.2 - 2.5 | 0.5 | 0.3 - 0.8 | 0.4 | 0.2 - 0.6 | 1.1 | 0.6 - 1.8 |
| Teat placement | 5 | Ref | | Ref | | Ref | | Ref | |
| | 4 | 1.3 | 0.9 - 2.0 | 0.8 | 0.5 - 1.5 | 0.6 | 0.3 - 1.2 | 1.4 | 0.8 - 2.4 |
| | 3 | 1.4 | 0.9 - 2.0 | 0.9 | 0.5 - 1.5 | 0.5 | 0.2 - 1.0 | 1.2 | 0.7 - 2.2 |
| | 2 | 2.3 | 1.4 - 3.8 | 1.1 | 0.6 - 2.0 | 0.8 | 0.4 - 1.9 | 1.9 | 1.0 - 3.6 |
| Clinical mastitis | Yes | Ref | | Ref | | Ref | | Ref | |
| | No | 0.5 | 0.2 - 1.5 | 0.3 | 0.1 - 0.9 | 0.3 | 0.2 - 0.5 | 0.3 | 0.1 - 0.5 |
| Lump midline | Yes | Ref | | Ref | | Ref | | Ref | |
| | No | 1.4 | 0.3 - 6.0 | 0.6 | 0.1 - 3.0 | 7.2 | 1.0 - 52.2 | 1.4 | 0.6 - 3.3 |
| Udder symmetry | Asymmetrical | 2.1 | 1.3 - 3.4 | 2.6 | 1.6 - 4.1 | 3.3 | 2.4 - 4.7 | 2.4 | 1.7 - 3.5 |
| | Symmetrical | Ref | | Ref | | Ref | | Ref | |

Ref = the reference category for each variable
[a]Small numbers of lambs (n = 3) in category therefore omitted
n.a. Not applicable, as there were no ewes in this category

*Multivariable analyses*

Pre-mating udder palpation scores were predictive of failure of lambs to survive to weaning, with the offspring of dams with udder scores of lump or hard having increased odds of failure to survive to weaning compared with lambs whose dams had normal udders (Table 6.5).

Pre-lambing, udder palpation scores, teat palpation scores and udder symmetry scores were predictive of failure of lambs to survive to weaning (Table 6.5). Lambs born to ewes with udder scores of lump, or one or both teats recorded as abnormal, had increased odds of failure to survive compared with lambs whose dams had normal udders. In addition, lambs born to ewes with asymmetrical udders pre-lambing had increased odds of failure to survive compared to offspring of ewes with symmetrical udders.

At docking, udder depth, clinical mastitis and udder symmetry scores were explanatory of failure of lambs to survive to weaning (Table 6.5). The offspring of dams with udder depth scores of five or four, compared with two, had increased odds of failure to survive. Lambs born to ewes that had mastitis or asymmetrical udders at docking had increased odds of failure to survive, compared with lambs whose dams did not have mastitis, or had symmetrical udders, respectively.

At weaning, udder depth, clinical mastitis and udder symmetry scores were explanatory of failure of lambs to survive to weaning (Table 6.5). The offspring of dams with udder depth scores of five, compared with two, had increased odds of failure to survive. Lambs born to ewes that had mastitis or asymmetrical udders at weaning had increased odds of failure to survive, compared with lambs whose dams did not have mastitis, or had symmetrical udders, respectively.

**Table 6.5 Results of final multivariable models showing the OR (95% CI) for failure of a lamb to survive to weaning in lambs born to ewes with different scores for udder traits (see Table 6.1) recorded on four occasions between mating and weaning, with the absolute probability of mortality for lambs born to ewes with different scores**

| | Time point | Trait | Score | OR (95%CI) | p-value | Probability of mortality[a] (95%CI) |
|---|---|---|---|---|---|---|
| **Predictive** | Pre-mating | Udder palpation | Hard | 3.0 (1.5 – 6.1) | 0.003 | 28.7% (16.6 – 44.9%) |
| | | | Lump | 4.9 (2.6 – 9.6) | <0.0001 | 39.9% (25.6 – 56.3%) |
| | | | Normal | Ref | | 11.8% (9.6 – 14.6%) |
| | Pre-lambing | Udder palpation | Hard | 0.3 (0.1 – 3.4) | 0.359 | 9.9% (1.2 – 49.9%) |
| | | | Lump | 1.8 (1.0 – 3.2) | 0.050 | 27.5% (18.1 – 39.4%) |
| | | | Normal | Ref | | 11.4% (9.8 – 13.3%) |
| | | Teat palpation | Abnormal-both | 3.8 (1.2 – 12.0) | 0.024 | 32.2% (12.9 – 60.4%) |
| | | | Abnormal-one | 2.1 (1.1 – 3.6) | 0.019 | 24.5% (15.5 – 36.4%) |
| | | | Normal | Ref | | 11.3% (9.6 – 13.1%) |
| | | Udder symmetry | Asymmetrical | 2.0 (1.1 – 3.6) | 0.019 | 25.7% (17.0 – 36.9%) |
| | | | Symmetrical | Ref | | 11.4% (9.8 – 13.3%) |
| **Explanatory** | Docking | Udder depth | 5 | 54.8 (9.9 – 302.2) | <0.0001 | 85.5% (55.4 – 96.5%) |
| | | | 4 | 3.2 (1.7 – 6.2) | 0.0005 | 23.4% (18.1 – 29.6%) |
| | | | 3 | 0.8 (0.5 – 1.4) | 0.451 | 7.9% (6.5 – 9.6%) |
| | | | 2 | Ref | | 13.6% (8.4 – 21.3%) |
| | | Clinical mastitis | Yes | 3.0 (1.5 – 5.9) | 0.001 | 27.7% (16.7 – 42.2%) |
| | | | No | Ref | | 9.6% (8.2 – 11.3%) |
| | | Udder symmetry | Asymmetrical | 3.3 (2.2 – 4.9) | <0.0001 | 26.1% (19.7 – 33.4%) |
| | | | Symmetrical | Ref | | 8.5% (7.1 – 10.2%) |

| | | | | | |
|---|---|---|---|---|---|
| Weaning | Udder depth | 5 | 9.6 (1.8 – 51.6) | 0.008 | 72.8% (57.3 – 84.2%) |
| | | 4 | 0.4 (0.1 – 1.8) | 0.231 | 8.6% (6.8 – 10.7%) |
| | | 3 | 0.3 (0.1 – 1.3) | 0.097 | 7.5% (5.9 – 9.6%) |
| | | 2 | Ref | | 40.2% (13.3 – 74.6%) |
| | Clinical mastitis | Yes | 3.9 (1.3 – 11.6) | 0.013 | 39.3% (21.2 – 60.9%) |
| | | No | Ref | | 8.8% (7.4 – 10.4%) |
| | Udder symmetry | Asymmetrical | 2.5 (1.5 – 4.0) | <0.001 | 20.7% (14.7 – 28.5%) |
| | | Symmetrical | Ref | | 8.3% (6.9 – 10.0%) |

*****The variables presented for each time point are those that were included in the final multivariable model for that time point. In addition, known explanatory variables of lamb sex (male or female), lamb birth rank (single, twin or triplet born) and lamb birthweight were included in each model.
[a]The probability of mortality represents an absolute probability of mortality for each category.
Ref = the reference category for each variable

## Discussion

To our knowledge, this study is the first undertaken for many years in New Zealand that describes the prevalence of a range of udder and teat traits in Romney ewes in a commercial flock. Comparable data tend to focus on one specific trait, e.g. mastitis, rather than considering a range of traits (Quinlivan 1968), or udders may only have been classified simply as defective or normal (Hayman *et al*. 1955; Quinlivan 1968). The results of the multivariable analyses in the present study support the hypothesis that lambs born to ewes with poor udder and teat scores would have lower survival than lambs born to ewes with more desirable udder and teat scores. However, these relationships varied between traits and between observation times.

Physical palpation allows detection of abnormalities in the udders of ewes. The percentage of ewes with normal udder palpation scores varied between 92.6 – 95.0%, with the remainder having palpation scores classified as either lump or hard. This result is consistent with previous studies, in which between 2.3 – 6.0% of ewes were reported to have defective udders (Hayman *et al.* 1955; Quinlivan 1968) however in those studies the type of defect was not well defined. The findings from the present study support the practice of hands-on udder palpation prior to breeding.

For commercial farmers, it would likely be optimal if they could identify ewes that are unsuitable for retention in the breeding flock prior to breeding, and if they were able to make culling decisions based on udder health at only one time during the year. Early identification of these unsuitable ewes could reduce unnecessary feed and management inputs, as these resources would be more efficiently utilised by those ewes that are more likely to successfully rear their offspring to weaning. In this study, pre-mating udder palpation score was associated with lamb survival, with odds of failure to survive to weaning being greater for lambs born to ewes with scores of lump or hard compared with normal. This finding indicates farmers should consider proactively identifying these ewes prior to breeding.

A number of traits measured prior to lambing, udder palpation, teat palpation and udder symmetry, were predictive of lamb survival to weaning. Although abnormal udder and teat scores were associated with increased lamb mortality in the current season, further work is required to assess repeatability of scores in the subsequent season, or whether these abnormalities would be suitable for treatment.

The docking and weaning models were retrospective, in that the majority of lamb deaths occurred prior to docking, so at these times it is likely that ewes had already lost either all or some of their lambs. The odds of failure to survive to weaning was greater for lambs whose dams had mastitis at docking and weaning compared with dams who did not have mastitis, in agreement with previous reports (Hayman *et al.* 1955; Arsenault *et al.* 2008). The percentage of ewes with mastitis in the present study varied between 0.8 – 4.6%, similar to the findings of Quinlivan (1968, 1972) and Clark (1972), and slightly less than that reported by Peterson *et al.* (2017). Presence of clinical mastitis is something farmers can readily assess when ewes are yarded for other management interventions during lactation, for example at docking. In a review of mastitis in dairy small ruminants, Bergonier *et al.* (2003) discussed the chronic persistence of small ruminant mastitis, with elimination relying on culling of affected animals or targeted treatment. However at present it is not known if non-dairy breed ewes that have mastitis in one season are more likely to have mastitis in a subsequent season than ewes without mastitis, or if the mastitis will be associated with an increased risk of undesirable udder scores at the following breeding. Further investigations to answer this question in longitudinal studies of New Zealand commercial flocks would be of benefit.

In the present study, udder symmetry at docking and weaning were associated with lamb survival, with the odds of failing to survive to weaning being greater in lambs whose dams had asymmetrical compared with symmetrical udders. To our knowledge, there is no previous description of the relationship between udder symmetry and lamb survival and it is a quick and easy trait for farmers to assess. Udder symmetry could be used to identify ewes that have likely lost a lamb in the current lactation, however it is unknown if asymmetry in one lactation will affect subsequent lactation performance and lamb survival in the following year. Further longitudinal studies in New Zealand commercial flocks are required to assess this.

Udder morphology scores described in milking-sheep, such as udder suspension, udder separation and teat placement, appeared to have little association with lamb survival to weaning. The only morphology score that was associated with failure to survive to weaning in the multivariable models was udder depth, at both docking and weaning. The inclusion of udder depth during lactation is not surprising, as an udder depth score of five was likely identifying ewes that were not lactating. Combined, the present data suggest the use of morphological scores developed for dairy sheep are of limited value in non-dairy breeds, in the context of predicting lamb survival to weaning.

In the present study, small numbers of ewes in some categories, e.g. udder palpation scores 3 – 6, meant scores had to be combined for analysis. However the merged scores would be easy and quick for farmers to utilise on-farm, e.g. udder palpation scores of normal *vs*. lump *vs*. hard. Another limitation of the study was that it was performed on only one commercial farm over one year. However the farm used is representative of a North Island hill country commercial sheep farm, based on flock and farm size and productivity parameters (Anonymous 2018). The lamb mortality rate also reflects the typically reported lamb mortality of 15% (Stafford 2013). In addition, the prevalence of the various udder and teat abnormalities were comparable to those previously reported (Hayman *et al.* 1955; Quinlivan 1968, 1972; Clark 1972). It is likely the results and conclusions drawn from the present study can be extrapolated to the wider New Zealand commercial sheep population, but further longitudinal studies on more flocks and farms are required to both validate these results and to provide more robust support for any recommendations.

## Conclusions

In conclusion, pre-mating udder palpation scores of hard or lump were associated with increased odds of lambs not surviving to weaning compared with normal scores, and could be used to identify ewes that are likely to be unsuitable for retaining in the breeding flock. Farmers could also use the udder symmetry scores, clinical mastitis scores and udder depth scores at docking or weaning to identify ewes whose lambs had greater odds of failure to survive to weaning. However these scores do not provide an indication of future performance, therefore further investigation into the impact of the present season’s score on future seasons’ lamb survival is required. These results should also be considered in association with the results of the following Chapter (Chapter 7).

# Chapter 7

# Associations between lamb growth to weaning and dam udder and teat scores

**Publications:** This chapter is based on the following publication:

**Griffiths KJ, Ridler AL, Compton CWR, Corner-Thomas RA, Kenyon PR.** Associations between lamb growth to weaning and dam udder and teat scores. *New Zealand Veterinary Journal* 67, 172-179, 2019

## Abstract

AIMS: To investigate associations between lamb growth to weaning and dam udder and teat scores measured at pre-mating, pre-lambing, docking and weaning.

METHODS: Mature Romney ewes (n=1,009) were enrolled from a commercial sheep flock located near Masterton, in the Wellington region of New Zealand in 2017. A range of udder and teat traits were scored in all ewes, using visual assessment and palpation, at pre-mating, pre-lambing, docking and weaning. During the lambing period, each newborn lamb was matched to its' dam and lamb sex, birthweight and birth-rank were recorded. A rearing rank was allocated to each live lamb at weaning, when all lambs were weighed (n=1,570), allowing calculation of daily growth rates (g/day). Associations between udder and teat scores and lamb growth rates to weaning were examined using multivariable models for each udder-scoring time.

RESULTS: Growth rates of lambs whose dams had udder palpation scores of hard, or both teats recorded as abnormal, pre-mating were lower than lambs whose dams had normal scores (229.9 (95% CI=213.2-246.6) *vs.* 254.5 (95% CI=245.6-263.5) g/day; p=0.011) and (227.4 (95% CI=208.3-246.6) *vs.* 247.9 (95% CI=235.7-260.2) g/day; p=0.024), respectively. Growth rates of lambs whose dams had clinical mastitis at docking or weaning were lower than those without mastitis (215.8 (95% CI=199.9-231.7) *vs.* 235.4 (95% CI=225.4-255.0) g/day; p=0.007) and (220.0 (95% CI=205.2-234.8) *vs.* 254.7 (95% CI=248.9-260.5) g/day; p<0.001), respectively. Growth rates of lambs whose dams had asymmetrical udders at docking or weaning were lower than lambs whose dams had symmetrical udders (204.6 (95% CI=189.7-219.5) *vs.* 240.2 (95% CI=225.4-255.0) g/day; p<0.001) and (223.3 (95% CI=213.9-232.7) *vs.* 242.2 (95% CI=229.4-255.0) g/day; p=0.014), respectively.

CONCLUSION: Pre-mating udder palpation and teat palpation scores can be used to identify ewes whose lambs are predicted to have lower growth to weaning. Assuming a mean lamb age at weaning of 84.4 days, lambs born to ewes with a pre-mating score of hard would be expected to have a mean weaning weight that was 2.1 kg less than those whose dams had normal scores. Udder palpation, udder symmetry and clinical mastitis scores during lactation were also associated with lamb growth rates.

## Introduction

The ability of a commercial New Zealand sheep farmer with a pasture-based production system to maximise the total weight of lamb available for sale directly influences the farm's ability to generate income (Bohan *et al.* 2018). Both the number and the weight of the individual lambs drive the total weight of lamb available for sale per ewe. Thus improving both lamb survival and growth to weaning improves total weaning weight, which is in turn closely correlated with the total weight of lambs sold. Lambs are dependent on their dam for milk for both survival and growth, with milk remaining an important source of digestible energy and protein to weaning (Hayman *et al.* 1955; Glover 1972; Clark 1980). The quantity and quality of milk produced by the ewe is known to directly influence lamb growth (Hayman *et al.* 1955; Clark 1980). Lambs born to ewes with poor udder health, low milk yield, poor colostrum quality or quantity have poorer growth rates (Hayman *et al*. 1955; Watson and Buswell 1984; Arsenault *et al.* 2008). Mastitis has an important impact on udder health and reduces both the quality and quantity of milk produced (Albenzio *et al*. 2002; Leitner *et al.* 2004).

Udder morphology scoring is commonly used in dairy ewes for selection purposes to improve both udder health, and associated milk quality, and machine milkability (Casu *et al.* 2006, 2010). In addition, udder morphology scores, such as udder depth, are associated with milk production, with ewes with larger udders generally producing more milk (Labussiere 1988). Therefore, udder morphology measures may be useful in non-dairy sheep for estimating lamb growth to weaning. Ideally, farmers could select ewes to keep or cull based on the predicted performance of their lambs, i.e. culling those ewes whose lambs are predicted to have poor survival or poor growth to weaning. If such an udder and teat scoring system could be developed related to lamb survival and growth, it would enable farmers to identify ewes that are either unsuitable for retention in the flock, or alternatively require selective treatment.

In Chapter 6, we report the frequency of different scores for udder traits in ewes on four occasions between mating and weaning. We also found that lambs born to ewes with poor udder scores had lower survival to weaning than lambs born to ewes with desirable udder scores. However these relationships varied between traits and measurement times, indicating the importance of measuring specific udder traits and examining ewes at the most appropriate times.

The aim of the present study was to investigate associations between lamb growth to weaning and dam udder and teat scores measured at pre-mating, pre-lambing, docking and weaning. It was hypothesised that lambs born to ewes with poor udder and teat scores would have lower growth rates to weaning than those born to ewes with more desirable udder and teat scores.

## Materials and Methods

### Farm and animals

The present study utilised data collected during 2017 from mixed-age, mature Romney ewes (n=1,009) that were born in 2013 or 2014 and were part of a commercial sheep flock located near Masterton, in the Wellington region of New Zealand. The enrolment, general and reproductive management of the study flock has been described in detail in the previous chapter (Chapter 6).

Prior to lambing, ewes were weighed and body condition score was assessed to the nearest 0.5 score using a 1-5 scale (1=thin, 5=obese; Jefferies 1961). In order to eliminate the potential influence of conceptus weight on ewe pre-lambing measured liveweight, predicted conceptus adjusted liveweights (CALW) of the ewes, calculated as described by Freer *et al.* (1997), were used in the analyses. Prior to lambing, mean ewe CALW were 65.0 (SD 6.1), 63.1 (SD 5.7) and 62.2 (SD 6.8) kg for triplet, twin and single-bearing ewes, respectively.

During the lambing period (commencing 1 October 2017), intensive lambing observations were conducted twice daily, matching each newborn lamb with its' dam, and recording the lamb's birth-date, sex, birth-rank (single, twin or triplet-born) and birth-weight. All dead lambs were collected throughout the lambing and lactation period. These observations were used to assign a rearing rank to each live lamb at weaning. Single-reared indicated the lamb was the only lamb reared to weaning (either a single born lamb, a twin born lamb whose sibling died, or a triplet born lamb where both siblings died), twin-reared indicated the lamb was one of two lambs that were reared to weaning (either a twin born lamb pair where both survived, or a triplet born set in which one lamb died), and triplet-reared indicated the lamb was one of three triplet-born lambs, all of which were reared to weaning. Lamb weights were recorded at weaning, which occurred on 3 January 2018. Lamb growth to weaning was calculated as mean growth rate (g/day) from birth to weaning.

### Ewe udder scores

The udders and teats of all ewes were scored immediately prior to the start of mating (pre-mating), 11 days before the planned start of the lambing (pre-lambing), and at docking and weaning. The system used for scoring was the same as that described in the previous chapter (Chapter 6) and is summarised in Table 7.1. Due to the small number of ewes in some categories, some scores were subsequently combined for analyses, as described in Table 7.1.

**Table 7.1 Description of the traits and scores used to assess udder morphology in ewes at different times between mating and weaning. Due to small numbers of ewes in some categories, scores were subsequently combined for analyses**

| Trait | Ewe position | Score | Description | Analysis score |
|---|---|---|---|---|
| Udder Palpation | Sitting | 7 | Diffuse hard consistency of udder | Hard |
| | | 6 | Firm consistency of udder with small nodule(s) (lumps) > 2cm in size | Lump |
| | | 5 | Firm consistency of udder with small nodule(s) (lumps) < 2cm in size | Lump |
| | | 4 | Soft consistency of udder with small nodule(s) (lumps) > 2cm in size | Lump |
| | | 3 | Soft consistency of udder with small nodule(s) (lumps) < 2cm in size | Lump |
| | | 2 | Diffuse firm consistency of udder | Normal |
| | | 1 | Diffuse soft consistency of udder | Normal |
| Teat Palpation | Sitting | 5 | Teat obstruction ('blind teat') | Abnormal |
| | | 4 | Dense, vertical cord in centre of teat ('straw') | Abnormal |
| | | 3 | Hard consistency | Abnormal |
| | | 2 | Thickened teat end | Abnormal |
| | | 1 | Soft consistency | Normal |
| Udder Depth | Standing | 5<br>4<br>3<br>2<br>1 | The distance between the udder cleft and the abdominal wall, taking as a reference the line joining the hocks. For a score of 5 the udder cleft is at the level of the abdominal wall, a score of 3 the udder cleft is at hock level | 5<br>4<br>3<br>2<br>2 |
| Udder Suspension | Standing | 5<br>4<br>3<br>2<br>1 | The ratio between the udder attachment width and udder depth. For a score of 5 the attachment width is much larger than depth, a score of 3 the udder is apparently 'square', a score of 1 the width is much narrower than depth | 5<br>4<br>3<br>2<br>2 |
| Udder Separation | Standing | 5<br>4<br>3<br>2<br>1 | Measure of separation of the two udder halves. For a score of 1 there is no separation, a score of 5 the udder is very clearly divided into two halves | 3<br>3<br>3<br>2<br>1 |
| Teat Placement | Standing | 5<br>4<br>3<br>2<br>1 | Measure of the external height of the teat cistern, the distance between the teat and the lowest part of the udder. For a score of 5 the teat is lateral, a score of 1 the teat is ventral | 5<br>4<br>3<br>2<br>2 |
| Clinical Mastitis | Sitting | Yes<br>No | Visible udder inflammation +/- abnormal milk/purulent discharge | Yes<br>No |
| Lump Midline | Sitting | Yes<br>No | Presence of a superficial lump located in the midline, immediately cranial to the udder | Yes<br>No |
| Udder Symmetry | Standing | Asymmetrical<br>Symmetrical | Measure of the visible symmetry of the udder halves while the udder is hanging naturally | Asymmetrical<br>Symmetrical |

### Statistical analyses

All statistical analyses were conducted using SAS version 9.4 (SAS Institute Inc., Cary, NC, USA). The main predictor variables for modelling were udder and teat scores, which were measured at the ewe-level. The outcome variable was lamb growth rate from birth to weaning, which was measured at the lamb-level and was the unit of analysis. Scores from each recording time were analysed separately, with pre-mating and pre-lambing scores considered as predictive, and docking and weaning scores considered as explanatory of lamb growth to weaning. Firstly, at each scoring time, univariate screening was conducted to examine the relationship between all predictor variables, and the outcome variable. If variables were associated ($p < 0.2$) they were included in initial multivariable models.

Multivariable generalised estimating equation models, using an exchangeable correlation structure to account for clustering between lambs born to the same ewe were developed for each time when udder and teat scores were recorded. Forward manual variable selection was used to build the preliminary models, with variables retained where $p < 0.05$, after which the effect of adding variables in different orders was investigated (but without effect on the chosen model). Finally, interaction terms that were biologically plausible were considered. In addition to the predictor variables determined by univariate analyses, all final models included the variables lamb sex (male or female), lamb birthweight, lamb birth rank (single, twin or triplet-born), lamb rearing rank (single, twin or triplet-reared), ewe pre-lambing body condition score and ewe pre-lambing CALW. Back-transformed logit mean growth rates, with 95% CI, for lambs born to ewes with different scores were calculated from final models.

## Results

This study included records from 1,570 lambs that survived to weaning, and their 926 respective dams. The number of lambs that were alive at weaning that were born to ewes with different scores for udder traits at each recording time is shown in Table 7.2. At weaning, the mean lamb age was 84.4 (SD 5.4) days, and mean weaning weights of triplet, twin and single-reared lambs were 22.4 (SD 5.2), 26.3 (SD 4.4) and 31.0 (SD 5.9) kg, respectively.

**Table 7.2 Number (%) of lambs that survived to weaning in one flock that were born to ewes that were recorded with different scores for udder traits (see Table 7.1) on four occasions between mating and weaning. Note some ewes did not have all traits recorded on all occasions**

| Trait | Levels (scores) | Pre-mating | Pre-lambing | Docking | Weaning |
|---|---|---|---|---|---|
| Udder palpation | Hard | 36 (2.3%) | 9 (0.6%) | 20 (1.3%) | 20 (1.3%) |
| | Lump | 33 (2.1%) | 62 (3.9%) | 91 (5.8%) | 92 (5.9%) |
| | Normal | 1,501 (95.6%) | 1,499 (95.5%) | 1,459 (92.9%) | 1,458 (92.9%) |
| | Total | 1,570 | 1,570 | 1,570 | 1,570 |
| Teat palpation | Abnormal-both | 12 (0.8%) | 14 (0.9%) | 390 (24.9%) | 378 (24.1%) |
| | Abnormal-one | 85 (5.4%) | 74 (4.7%) | 183 (11.7%) | 85 (5.4%) |
| | Normal | 1,473 (93.8%) | 1,482 (94.4%) | 997 (63.5%) | 1,107 (70.5) |
| | Total | 1,570 | 1,570 | 1,570 | 1,570 |
| Udder depth | 5 | 1,368 (88.4%) | 114 (7.3%) | 2 (0.1%) | 21 (1.4%) |
| | 4 | 170 (11.0%) | 1,221 (77.8%) | 209 (13.5%) | 727 (47.4%) |
| | 3 | 9 (0.6%) | 227 (14.5%) | 1,215 (78.3%) | 778 (50.8%) |
| | 2 | 1 (0.1%) | 8 (0.5%) | 126 (8.1%) | 7 (0.5%) |
| | Total | 1,548 | 1,570 | 1,552 | 1,533 |
| Udder suspension | 5 | 757 (48.9%) | 40 (2.6%) | 0 (0.0%) | 3 (0.2%) |
| | 4 | 574 (37.1%) | 549 (35.0%) | 37 (2.4%) | 364 (23.7%) |
| | 3 | 193 (12.5%) | 682 (43.4%) | 1,194 (76.9%) | 917 (59.8%) |
| | 2 | 24 (1.6%) | 299 (19.0%) | 321 (20.7%) | 249 (16.2%) |
| | Total | 1,548 | 1,570 | 1,552 | 1,533 |
| Udder separation | 3 | 15 (1.0%) | 68 (4.4%) | 89 (5.9%) | 109 (7.2%) |
| | 2 | 205 (13.3%) | 473 (30.2%) | 618 (40.7%) | 564 (37.5%) |
| | 1 | 1,320 (85.7%) | 1,024 (65.4%) | 813 (53.5%) | 833 (55.3%) |
| | Total | 1,540 | 1,565 | 1,520 | 1,506 |
| Teat placement | 5 | 394 (25.8%) | 97 (6.2%) | 40 (2.7%) | 150 (10.2%) |
| | 4 | 354 (23.2%) | 445 (28.6%) | 348 (23.8%) | 413 (28.1%) |
| | 3 | 648 (42.5%) | 777 (49.9%) | 860 (58.7%) | 750 (51.0%) |
| | 2 | 129 (8.5%) | 238 (15.3%) | 216 (14.8%) | 159 (10.8%) |
| | Total | 1,525 | 1,557 | 1,464 | 1,472 |
| Clinical mastitis | Yes | 17 (1.1%) | 10 (0.6%) | 60 (3.9%) | 36 (2.3%) |
| | No | 1,533 (98.9%) | 1,560 (99.4%) | 1,492 (96.1%) | 1,505 (97.7%) |
| | Total | 1,550 | 1,570 | 1,552 | 1,541 |
| Lump midline | Yes | 17 (1.1%) | 8 (0.5%) | 46 (3.0%) | 57 (3.7%) |
| | No | 1,533 (98.9%) | 1,562 (99.5%) | 1,506 (97.0%) | 1,484 (96.3%) |
| | Total | 1,550 | 1,570 | 1,552 | 1,541 |
| Udder symmetry | Asymmetrical | 77 (5.0%) | 70 (4.5%) | 153 (9.9%) | 147 (9.6%) |
| | Symmetrical | 1,473 (95.0%) | 1,500 (95.5%) | 1,399 (90.1%) | 1,386 (90.4%) |
| | Total | 1,550 | 1,570 | 1, 552 | 1,533 |

**Associations between lamb growth to weaning and ewe udder and teat scores**

*Univariate analyses*

The results of all univariate analyses examining associations between growth rates of lambs to weaning and different scores for udder traits in ewes at each recording time are presented in Table 7.3.

*Multivariable analyses*

Each of the final multivariable models included the lamb-level explanatory variables lamb birth rank, lamb rearing rank and lamb sex. The estimated mean growth rates for different categories of each of these variables from the models for each recording time are presented in Table 7.4. The udder traits that were included in final models for each recording time are shown in Table 7.5.

Pre-mating: growth rates of lambs whose dams had udder palpation scores of hard, or both teats recorded as abnormal, pre-mating were lower compared with lambs whose dams had normal scores (Table 7.5).

Pre-lambing: growth rates of lambs whose dams had udder palpation scores of hard or lump pre-lambing were less than those whose dams had normal scores (Table 7.5). Additionally, the offspring of dams who had clinical mastitis pre-lambing had lower growth rates compared with lambs whose dams did not have clinical mastitis (Table 7.5).

Docking: growth rates of lambs whose dams had udder palpation scores of hard or lump at docking were lower compared with lambs whose dams had normal scores (Table 7.5). The growth rates of lambs were higher if their dams had udder depth scores of two, three or four compared with five at docking, and were lower for lambs whose dams had clinical mastitis or asymmetrical udders at docking, compared with those whose dams did not have clinical mastitis or had symmetrical udders, respectively (Table 7.5).

Weaning: growth rates of lambs whose dams had udder palpation scores of hard or lump at weaning were lower compared with those whose dams had normal udder scores (Table 7.5). Additionally, lambs whose dams had clinical mastitis or asymmetrical udders at weaning had lower growth rates compared with lambs whose dams did not have clinical mastitis or had symmetrical udders, respectively (Table 7.5).

**Table 7.3 Results of univariate analyses showing the mean (95% CI) growth rate (g/day) between birth and weaning of lambs born to ewes in one flock that were recorded with different scores for udder traits (see Table 7.1) on four occasions between mating and weaning**

| Trait and score | Pre-mating | P-value [a] | Pre-lambing | P-value [a] | Docking | P-value [a] | Weaning | P-value [a] |
|---|---|---|---|---|---|---|---|---|
| Udder palpation | | | | | | | | |
| Hard | 241.2 (223.0-259.3) | 0.053 | 222.2 (186.0-258.4) | 0.047 | 222.2 (198.0-246.5) | 0.003 | 212.5 (188.4-236.6) | <0.001 |
| Lump | 257.6 (238.3-276.8) | 0.224 | 240.1 (226.0-254.3) | 0.01 | 239.6 (228.1-251.2) | <0.001 | 231.9 (220.2-243.5) | <0.001 |
| Normal | 258.6 (255.7-261.4) | Ref | 259.1 (256.2-261.9) | Ref | 259.8 (256.9-262.7) | Ref | 260.3 (257.5-263.2) | Ref |
| Teat palpation | | | | | | | | |
| Abnormal-both | 231.8 (200.4-263.3) | 0.092 | 278.2 (248.1-308.4) | 0.212 | 258.9 (253.3-264.5) | 0.536 | 255.5 (249.9-261.2) | 0.108 |
| Abnormal-one | 248.2 (236.3-260.0) | 0.085 | 237.5 (224.8-250.3) | 0.001 | 240.9 (232.8-249.0) | <0.001 | 233.4 (221.4-245.4) | <0.001 |
| Normal | 258.9 (256.0-261.8) | Ref | 259 (256.1-261.9) | Ref | 261 (257.5-264.5) | Ref | 260.9 (257.6-264.2) | Ref |
| Udder depth | | | | | | | | |
| 5 | 258.7 (255.7-261.6) | 0.079 | 282.1 (271.9-292.4) | 0.038 | 228.5 (152.1-304.9) | 0.724 | 261.9 (236.4-287.4) | 0.881 |
| 4 | 253.8 (245.4-262.2) | 0.066 | 257.3 (254.2-260.5) | 0.382 | 262.2 (254.5-269.8) | 0.002 | 260.2 (256.1-264.3) | 0.797 |
| 3 | 248.6 (212.3-284.8) | 0.066 | 250.7 (243.4-258.0) | 0.599 | 260 (256.8-263.1) | <0.001 | 258.3 (254.4-262.3) | 0.73 |
| 2 | 356 (247.4-464.7) | Ref | 240.3 (202.0-278.5) | Ref | 242.3 (232.7-252.0) | Ref | 265.6 (224.6-306.5) | Ref |
| Udder suspension | | | | | | | | |
| 5 | 258.8 (254.8-262.8) | 0.386 | 271.2 (253.4-289.0) | 0.015 | N/A | N/A | 279.3 (217.0-341.7) | 0.358 |
| 4 | 257.6 (253.0-262.2) | 0.448 | 263.2 (258.5-267.9) | <0.001 | 259.5 (241.5-277.6) | 0.403 | 261.8 (256.0-267.6 | 0.01 |
| 3 | 258.1 (250.2-266.1) | 0.439 | 257.9 (253.7-262.1) | 0.008 | 260.7 (257.5-263.9) | 0.009 | 260.8 (257.2-264.4) | 0.006 |
| 2 | 248.8 (226.6-271.0) | Ref | 247.6 (241.3-254.0) | Ref | 251.4 (245.3-257.5) | Ref | 249.9 (243.0-256.8) | Ref |
| Udder separation | | | | | | | | |
| 3 | 262 (233.9-290.0) | 0.753 | 253.1 (239.7-266.5) | 0.589 | 263.8 (252.1-275.5) | 0.37 | 261.1 (250.7-271.4) | 0.416 |
| 2 | 262 (254.2-269.7) | 0.289 | 261.7 (256.6-266.8) | 0.131 | 260 (255.6-264.4) | 0.528 | 265.1 (260.5-269.7) | 0.005 |
| 1 | 257.5 (254.4-260.5) | Ref | 256.9 (253.5-260.4) | Ref | 258.2 (254.3-262.0) | Ref | 256.5 (252.7-260.2) | Ref |
| Teat placement | | | | | | | | |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 5 | 258.8 (253.3-264.4) | 0.736 | 254.2 (243.1-265.3) | 0.179 | 259.5 (242.6-276.4) | 0.967 | 258.6 (249.8-267.4) | 0.657 |
| 4 | 260.1 (254.2-266.0) | 0.916 | 253 (247.8-258.3) | 0.024 | 254.8 (249.0-260.7) | 0.295 | 259.6 (254.3-265.0) | 0.461 |
| 3 | 256.7 (252.3-261.0) | 0.451 | 260.5 (256.6-264.4) | 0.513 | 262.4 (258.7-266.1) | 0.542 | 261.8 (257.9-265.8) | 0.212 |
| 2 | 260.7 (251.1-270.3) | Ref | 263.3 (256.1-270.4) | Ref | 259.9 (252.5-267.3) | Ref | 255.8 (247.2-264.4) | Ref |
| Clinical mastitis | | | | | | | | |
| Yes | 227 (200.7-253.3) | 0.02 | 228.5 (194.1-262.9) | 0.091 | 235.4 (221.0-249.9) | 0.001 | 223.3 (204.5-242.1) | 0.0002 |
| No | 258.4 (255.6-261.2) | Ref | 258.3 (255.5-261.1) | Ref | 259.6 (256.8-262.5) | Ref | 259.9 (257.1-262.7) | Ref |
| Lump midline | | | | | | | | |
| Yes | 260.8 (234.4-287.2) | 0.837 | 253.3 (212.1-294.5) | 0.818 | 260 (244.1-276.1) | 0.867 | 249.9 (235.4-264.3) | 0.203 |
| No | 258 (255.2-260.9) | Ref | 258.1 (255.3-260.9) | Ref | 258.7 (255.9-261.5) | Ref | 259.4 (256.6-262.3 | Ref |
| Udder symmetry | | | | | | | | |
| Asymmetrical | 242 (229.5-254.6) | 0.01 | 239.1 (226.2-252.3) | 0.004 | 232.7 (223.9-241.5) | <0.001 | 241.2 (232.2-250.2) | <0.001 |
| Symmetrical | 258.9 (256.0-261.8) | Ref | 259 (256.2-261.9) | Ref | 261.6 (258.7-264.5) | Ref | 261.2 (258.3-264.1) | Ref |

[a] Significance of difference when compared with the reference category
Ref = the reference category for each variable
N/A = not-applicable, there were no lambs in this category

**Table 7.4 Estimated mean (95% CI) growth rate (g/day) between birth and weaning of lambs that differed in birth rank, lamb rearing rank and sex, from final multivariable models that examined associations between udder traits of ewes recorded on four occasions between mating and weaning**

| Trait | Pre-mating | P-value [a] | Pre-lambing | P-value [a] | Docking | P-value [a] | Weaning | P-value [a] |
|---|---|---|---|---|---|---|---|---|
| Birth rank | | | | | | | | |
| Triplet | 217.3 (203.0-231.7) | Ref | 212.5 (198.1-226.8) | Ref | 205.4 (190.7-220.1) | Ref | 211.8 (199.1-224.6) | Ref |
| Twin | 238 (225.9-250.0) | 0.006 | 232.4 (221.3-243.6) | 0.008 | 223.1 (210.5-235.7) | 0.021 | 234.2 (225.7-242.7) | 0.004 |
| Single | 266.5 (250.0-283.1) | <0.001 | 261.2 (245.3-277.1) | <0.001 | 248.4 (231.8-265.0) | <0.001 | 257.9 (243.8-272.0) | <0.001 |
| Rearing rank | | | | | | | | |
| Triplet | 222.2 (203.6-240.7) | Ref | 217.2 (199.7-234.8) | Ref | 204.8 (185.8-223.8) | Ref | 215.6 (199.3-231.9) | Ref |
| Twin | 235.6 (223.5-247.8) | 0.143 | 230.8 (218.9-242.8) | 0.141 | 219.9 (207.5-232.4) | 0.104 | 228.7 (219.4-238.0) | 0.167 |
| Single | 264 (251.7-276.3) | <0.001 | 258.1 (245.8-270.3) | <0.001 | 252.1 (240.0-264.3) | <0.001 | 259.6 (249.7-269.5) | <0.001 |
| Sex | | | | | | | | |
| Male | 246.6 (235.6-257.6) | Ref | 241.3 (230.9-251.6) | Ref | 231.2 (219.8-242.6) | Ref | 240.6 (233.1-248.0) | Ref |
| Female | 234.6 (223.6-245.6) | <0.001 | 229.5 (219.2-239.8) | <0.001 | 220.1 (208.9-231.2) | <0.001 | 228.7 (221.4-236.0) | <0.001 |

[b] Significance of difference when compared with the reference category
Ref = the reference category for each variable

**Table 7.5 Results of final multivariable models [a] showing the estimated mean (95% CI) growth rate (g/day) between birth and weaning of lambs born to ewes with different scores for udder traits (see Table 7.1) recorded on four occasions between mating and weaning**

| Time point | Trait [a] | Score | Growth rate (g/day) | 95% CI | p-value [b] |
|---|---|---|---|---|---|
| Pre-mating | Udder palpation | Hard | 229.9 | 213.2-246.6 | 0.011 |
| | | Lump | 237.4 | 212.8-261.9 | 0.183 |
| | | Normal | 254.5 | 245.6-263.5 | Ref |
| | Teat palpation | Abnormal both | 227.4 | 208.3-246.6 | 0.024 |
| | | Abnormal one | 246.4 | 231.5-261.3 | 0.864 |
| | | Normal | 247.9 | 235.7-260.2 | Ref |
| Pre-lambing | Udder palpation | Hard | 219.3 | 197.0-241.6 | 0.03 |
| | | Lump | 226.9 | 213.3-240.5 | 0.004 |
| | | Normal | 246.7 | 236.6-256.8 | Ref |
| | Clinical mastitis | Yes | 224.1 | 209.3-238.9 | 0.008 |
| | | No | 246.7 | 235.6-257.7 | Ref |
| Docking | Udder palpation | Hard | 202.4 | 184.8-220.0 | <0.0001 |
| | | Lump | 228.8 | 218.1-239.4 | 0.019 |
| | | Normal | 240.5 | 232.7-248.4 | Ref |
| | Udder Depth | 5 | 161.5 | 116.5-206.5 | Ref |
| | | 4 | 235.6 | 225.9-245.3 | 0.005 |
| | | 3 | 247.2 | 241.1-253.3 | <0.0001 |
| | | 2 | 239.3 | 229.0-249.6 | 0.001 |
| | Clinical mastitis | Yes | 215.8 | 199.9-231.7 | 0.007 |
| | | No | 235.4 | 225.7-245.1 | Ref |
| | Udder symmetry | Asymmetrical | 204.6 | 189.7-219.5 | <0.0001 |
| | | Symmetrical | 240.2 | 225.4-255.0 | Ref |
| Weaning | Udder palpation | Hard | 216.4 | 203.8-229.0 | <0.0001 |
| | | Lump | 224.1 | 211.6-236.6 | <0.0001 |
| | | Normal | 251.1 | 244.3-257.9 | Ref |
| | Clinical mastitis | Yes | 220.0 | 205.2-234.8 | <0.0001 |
| | | No | 254.7 | 248.9-260.5 | Ref |
| | Udder symmetry | Asymmetrical | 223.3 | 213.9-232.7 | 0.014 |
| | | Symmetrical | 242.2 | 229.4-255.0 | Ref |

a Traits for each time are those that were included in the final multivariable model for that time, in addition to the explanatory variables lamb birth rank, rearing rank, birthweight, sex (see Table 7.4), ewe pre-lambing body condition score and pre-lambing conceptus-adjusted liveweight.
b Significance of difference when compared with the reference category
Ref = the reference category for each variable

## Discussion

The results of the present study support the hypothesis that lambs born to ewes with poor udder and teat scores would have lower growth rates from birth to weaning than lambs born to ewes with more desirable scores. However, these relationships varied between traits and management times. Similarly, in the previous chapter (Chapter 6) we found that the relationship between lamb survival and udder and teat scores varied between traits and management times.

In this study, udder palpation score at all observation times was associated with lamb growth to weaning, with lower growth rates in lambs born to ewes with abnormal scores compared to those born to ewes with normal scores. There are limited comparable data available; Hayman *et al.* (1955) reported lambs born to ewes with defective udders grew up to 34g/day less than those born to ewes with normal udders, while Grant *et al.* (2016) reported offspring of ewes with intramammary lumps grew 10g/day less than those without lumps. Based on the results of the present study, and assuming a mean lamb age at weaning of 84.4 days, lambs born to ewes with abnormal udder palpation scores would on average be 1.0–2.9 kg lighter at weaning than those born to ewes with normal udder palpation scores. For example, lambs born to ewes with a pre-mating score of hard would be expected to have a mean weaning weight that was 2.1 kg less than those whose dams had normal scores, although this would vary between lambs and ewes.

If farmers wish to identify ewes whose lambs are predicted to have poorer performance, the results of the present study indicate pre-mating udder palpation score would be an appropriate trait to assess. When combined with the results of our analysis of traits associated with lamb survival (Chapter 6), these results indicate that offspring of ewes with pre-mating udder palpation scores of hard have greater odds of failure to survive to weaning, and, should they survive, have lower growth rates to weaning compared with offspring whose dams had normal udder palpation scores.

The present study also identified associations between lamb growth to weaning and udder palpation scores at pre-lambing, docking and weaning. However any effective interventions for ewes with abnormal udder palpation scores at pre-lambing and docking have not been evaluated, and therefore any economic benefit of intervention is also unknown. In addition, there is a lack of New Zealand data to demonstrate whether these ewes would also have undesirable udder traits the following season. Results from Great Britain indicated that abnormal udder palpations were repeated between lactations, with greater odds of a ewe having an intramammary mass if she had previous intramammary masses in pregnancy or the previous lactation (Grant *et al.* 2016). Therefore, additional longitudinal investigation in New Zealand flocks is warranted, including the mechanisms and biology of the abnormal udder scores, the economic benefit of culling ewes with abnormal scores, and management interventions to improve udder health of these ewes in both the current and future seasons.

To the authors' knowledge, this study is the first to describe an association between teat palpation score and lamb growth. Lambs born to ewes with both teats recorded as abnormal pre-mating were on average approximately 1.7 kg lighter at weaning than lambs from ewes with normal teat scores, based on a mean age at weaning of 84.4 days. Anecdotal reports suggest a number of commercial farmers routinely assess their ewes' teats prior to breeding, culling those that have a palpable 'straw' in the centre of both teats, and the results of the present study add support to this practice. However it should be noted that there was no association between teat palpation score pre-mating and lamb survival in the final multivariable model (Chapter 6); neither was there a relationship between lamb growth rates and abnormal teat palpation scores at pre-lambing, docking or weaning, highlighting the importance of timing of teat palpation.

In the present study, offspring of ewes with clinical mastitis had lower growth rates. This is in agreement with previous studies in which lambs born to ewes with mastitis had reduced growth rates (Hayman *et al*. 1955; Watson and Buswell 1984; Arsenault *et al.* 2008). A variety of bacterial species have been identified as being involved in ovine mastitis in New Zealand commercial ewes (Quinlivan 1968, 1972; Clark 1980), with *Staphylococcus aureus* being of particular importance at lambing (Quinlivan 1972). In the present study ewe mastitis at pre-lambing, docking and weaning was associated with lamb growth to weaning. At pre-lambing and docking treatment may be the most appropriate course of action, if both effective and economically feasible. However bacteriological cure in ewes is difficult to achieve (Gelasakis *et al.* 2015), and it may be best to cull these ewes prior to the next breeding season. Additionally, *S. aureus* has been associated with permanent udder damage in some cases (Quinlivan 1972; Clark 1980), and a carrier state has been described in both dairy and non-dairy sheep (Quinlivan 1972; Bergonier *et al.* 2003). Therefore, to allow New Zealand farmers to make informed decisions about ewes diagnosed with mastitis, further studies are required examining likelihood of mastitis in subsequent lactations, economic consequence of mastitis in non-dairy flocks, and longitudinal studies examining both efficacy and economic viability of treatment of mastitis.

The only udder morphology scores associated with lamb growth were udder depth at docking and udder symmetry at both docking and weaning. The offspring of dams with udder depth scores of five at docking had lower growth rates compared with lambs born to dams with scores of four, three or two. This was not unexpected, as a score of five represents a very small udder, more typical of that seen in a non-lactating ewe. Also in commercial Romney ewes in New Zealand, a positive correlation was found between ewe udder dimensions and milk yield, although udder dimensions did not give an accurate prediction of lamb growth rates (van der Linden *et al.* 2010). However, in that study, only single-born and reared lambs were included, and the methods used to measure udder dimensions were different to the present study.

The findings of the present study highlight that different traits are associated with lamb growth rate when assessed at different times. Some, such as udder palpation score, was associated when assessed at any time between mating and weaning, while others were only associated at specific times. Future research is required to assess repeatability of udder scores over time (i.e. in subsequent lactations to allow for prediction of future offspring performance), the economic consequences of keeping (or culling) ewes whose lambs have increased risk of failure to survive or poorer growth to weaning, and to investigate management interventions to improve udder health. In addition, further studies designed to investigate the biological cause for each of the scores at each time would be useful to enhance our understanding of ewe udder and teat health. Combined, this will enable development of a farmer-friendly scoring system to identify ewes suitable for either targeted culling or selective treatment, as appropriate.

It is important to note the limitations of the present study, namely that it was performed on only one farm using ewes from a single commercial flock during one year. However, as discussed in the previous chapter, the farm used can be considered representative of a North Island hill country commercial sheep farm based on farm and flock size and productivity parameters. Additionally, the statistical analysis did not allow for comparison of the model estimates between the four management times at which scoring was undertaken, nor the repeatability of scores within ewes within the season. As the study was only conducted during one year, we are also unable to compare between seasons, or to examine the relationship between the present season's scores and subsequent season's performance.

## Conclusion

In conclusion, udder palpation score, teat palpation score, udder depth, udder symmetry and clinical mastitis scores were all associated with lamb growth to weaning. Farmers can use pre-mating udder palpation scores and teat palpation scores to identify ewes whose lambs are predicted to have lower growth rates to weaning. Farmers can also use udder palpation, udder depth, udder symmetry and clinical mastitis scores during lactation to identify ewes whose lambs may have lower growth rates to weaning.

# General Discussion

At the commencement of this PhD in 2015 very little was known about wastage in commercial ewe flocks in New Zealand, or indeed internationally. However, Farrell *et al.* (2019), through use of bio-economic modelling, demonstrated that increased ewe wastage in New Zealand commercial flocks results in a reduction in farm productivity and the subsequent ability to generate profit. They also further highlighted the lack of published data and the need for accurate estimates of ewe wastage on commercial New Zealand farms (Farrell *et al.* 2019). The present PhD was undertaken with the broad objective of establishing the extent, timing and cause (premature culling or mortality) of ewe wastage in four cohorts of ewes from three commercial New Zealand flocks, while also identifying and investigating factors associated with increased ewe wastage. Ewe wastage is the combination of both premature culling and on-farm mortality. Premature ewe culling in relation to a breeding flock is defined as a ewe that is culled prior to the potential end of her productive lifespan. Therefore, to investigate wastage in commercial flocks, both premature culling and on-farm ewe mortality had to be considered.

To maximise flock performance commercial farmers aim to maximise the total weight of lambs available for sale (which is a combination of both the number and weight of the individual lambs) while concurrently increasing the efficiency of production. Alongside this, farmers should also consider lamb production on a per ewe basis (total weight of lamb available for sale per ewe presented for breeding) (Conington *et al* 2001; Byrne *et al.* 2012). However, in New Zealand, the extensive flock management utilised results in a lack of direct dam-offspring matching, with few commercial farmers able to match lambs to their respective dams. This means proxy's such as non-pregnant at pregnancy diagnosis and udder palpation to identify ewes that are dry at docking (not actively lactating) are used to inform farmer decision making regarding ewe removal from the flock based on lamb production (Garrick 1998; Amer *et al.* 2009). There is surprisingly little research directly examining culling strategies in New Zealand commercial ewe flocks. However, it is likely commercial farmers select ewes to cull based on either known poor performance (for example dry at pregnancy diagnosis or dry at docking), predicted poor performance (i.e. ewes whose lambs are predicted to have poor survival or poor growth to weaning) or poor ewe health. There is also very little recently published data concerning ewe mortality in New Zealand commercial flocks; however, Anderson and Heuer (2016) recently reported annual on farm mortality rates that ranged from 2.8% - 15.7%, with a mean flock mortality of 7.3%.

## Experimental Chapter Summaries

### Chapter 3: Investigating ewe wastage in New Zealand commercial flocks

The objectives of this chapter were:

- To establish the extent, timing and cause of ewe wastage in commercial New Zealand flocks
- To investigate the association between reproductive outcomes as a ewe lamb and risk of wastage
- To investigate if pre-mating body condition score (BCS) could be used as a predictor of ewe wastage in the following production year

As reported by Farrell *et al.* (2019), there is a lack of research on wastage in commercial ewe flocks in New Zealand. Therefore, this chapter had the following three aims: firstly, to establish and describe the extent, timing and general cause of ewe wastage (premature culling or mortality) in four cohorts of ewes from three commercial New Zealand ewe flocks. Secondly, to investigate the association between reproductive outcomes as a ewe lamb and risk of wastage. The final aim was to investigate if pre-mating BCS could be used as a predictor of ewe wastage in that production year.

This study used data collected from 13,142 individually identified commercial ewes from four cohorts on three farms during the period 2011 – 2017, as the ewes aged from replacement ewe lambs (approximately 6 months of age) to 6-year-old ewes. Of the 13,142 enrolled ewes, 50.4% (n=6,629) exited their respective flocks due to premature culling, 40.0% (n=5,253) due to on-farm dead/missing, with only 5.1% (n=676) culled due to age and 4.4% (n=584) right censored, giving a total of 90.4% (n=11,882) that exited due to wastage. Annual mortality rates across years and cohorts ranged from 3.5% - 40.2%. In Year 1, wastage for each cohort ranged from 7.6% - 45.4% of ewe lambs enrolled. Ewes that were bred as a ewe lamb and dry at PD as a ewe lamb had 28.1% greater odds of wastage due to premature culling compared to ewes that were not presented for breeding as a ewe lamb (p=0.032). There was no difference in risk of wastage due to premature culling of those that were bred as a ewe lamb and dry at docking (p=0.471) or those that were bred as a ewe lamb and wet at docking (p=0.818), compared to those that were not presented for breeding as a ewe lamb. There was no association between reproductive outcomes as a ewe lamb and risk of wastage due to dead/missing (p>0.2 for all groups). In all years, pre-mating BCS could be used as a predictor of ewe wastage with odds of wastage lower with increasing ewe BCS. For example, in Year 2 for the Farm A 2011-born cohort, the cumulative incidence of wastage due to premature culling was 25.4% for ewes that were BCS 2.0 at breeding, compared to only 8.7% for ewes that were BCS 3.5 at breeding, while the cumulative incidences of wastage due to dead/missing were 11.1% and 7.6% for ewes that were BCS 2.0 and 3.5 respectively.

To our knowledge, this is the first study that reports both lifetime wastage and detailed annual wastage in commercial New Zealand ewe flocks. Wastage as a ewe lamb represents an area in which improvements can be made. To reduce ewe lamb wastage, farmers need to consider on-farm mortality rates, management practices to improve ewe lamb reproductive performance, and evaluation of their culling policies. In addition, further investigation into causes of, and risk factors associated with, ewe mortality in New Zealand flocks is required. Ewes with greater pre-mating BCS had lower odds of wastage due to both premature culling and mortality, therefore farmers should focus on improving pre-mating BCS. To achieve this, farmers should assess BCS of their ewes at weaning, enabling poor BCS ewes to be identified, drafted off and managed to gain BCS before re-breeding (Kenyon *et al.* 2014b).

### Chapter 4: Associations between liveweight and body condition score and the ability of ewe lambs to successfully rear their offspring

The objective of this chapter was:

- To investigate associations between liveweight and body condition score (BCS), and the risk of ewe lambs (aged 7-8 months at breeding) being dry at docking

Ewe lamb breeding is a means to increase the number of lambs available for sale each year while concurrently increasing the ewe lamb's lifetime productivity (Kenyon *et al.* 2011; Corner *et al.* 2013). However, for ewe lamb breeding to be efficient and successful, the ewe lamb needs to rear her lamb(s). In addition, ewe lambs that fail to rear a lamb may be prematurely culled from their flocks, resulting in increased ewe wastage. The aim of this chapter was to investigate associations between liveweight and body condition score (BCS) at breeding, pregnancy diagnosis (PD) and immediately prior to lambing (set stocking) and the ability of ewe lambs to rear their offspring to docking, for three cohorts of ewe lamb from two commercial New Zealand farms.

For the Farm A 2010-born cohort, 31.0% (793/2,559) of ewe lambs were dry at docking, while for the Farm A 2011-born and Farm B cohorts this was 17.2% (528/3,078) and 15.3%

(234/1,534) respectively. There was an association between conceptus adjusted liveweight (CALW) at PD and at set-stocking, such that ewe lambs with heavier CALW were less likely to be dry at docking ($p<0.0001$). There was also an association between CALW change from PD to set-stocking and the risk of being dry ($p<0.0001$); such that the more ewe lambs gained in CALW the less likely there were to be dry at docking. There was an association between BCS at PD ($p=0.0013$) and BCS at set-stocking ($p=0.007$) and risk of being dry, such that ewe lambs that were of greater BCS were less likely to be dry at docking.

Combined, these findings enable commercial New Zealand farmers to identify ewe lambs within a flock that are at increased risk of being dry at docking. Farmers are then able to plan management and monitoring prior to breeding, and throughout pregnancy, to ensure ewe lamb weight and BCS targets are monitored, met and achieved, therefore reducing the risk they will be dry at docking.

### Chapter 5: Associations between liveweight, body condition score and previous reproductive outcomes and the risk of ewes bred at 18-months of age being dry at docking

The objective of this chapter was:

- To investigate associations between liveweight, body condition score (BCS) and previous reproductive outcomes, and the risk of two-tooth ewes (aged 18 months at breeding) being dry at docking

Losses of lambs from pregnancy diagnosis until docking remain an issue for commercial farmers both in New Zealand and internationally (Stafford 2013; Allworth *et al.* 2017). Failure of a ewe to successfully rear a lamb to weaning reduces both the total weight of lambs for sale, and overall flock efficiency (Mackay *et al*. 2012). However, few studies have directly examined factors associated with ewe being dry at docking in New Zealand. Additionally, some New Zealand farmers routinely cull ewes that are dry at docking (Amer *et al.* 2009), resulting in increased ewe wastage. The aims of this chapter were: firstly, to investigate associations between liveweight and body condition score (BCS) of two-tooth ewes (18-months-old at breeding) at breeding, pregnancy diagnosis (PD) and pre-lambing and the risk of being dry (non-lactating) at docking for four cohorts of ewes from three commercial New Zealand sheep farms. Secondly, to investigate the association between previous reproductive outcomes as ewe lambs, and risk of being dry at docking as two-tooth ewes.

Overall, 5.4% (437/8,025) of ewes were dry at docking. For the Farm A 2010-born cohort 3.7% (82/2,190) of ewes were dry at docking, while for the Farm A 2011-born, Farm B and Farm C cohorts this was 5.8% (122/2,114), 6.5% (201/3,096) and 5.1% (32/625) respectively. There were negative associations between ewe conceptus adjusted liveweight (CALW) pre-lambing ($p \leq 0.002$ for all cohorts), and CALW gain between PD and pre-lambing ($p \leq 0.003$ for all cohorts), and risk of being dry at docking. For all cohorts, heavier ewes and those that gained CALW were less likely to be dry at docking than lighter ewes or those that lost CALW. There was no association between BCS at breeding, PD or pre-lambing and the risk of being dry at docking for Farm A 2010-born, Farm B or Farm C cohorts ($p>0.05$). For 2010-born ewes on Farm A, the risk of being dry at docking was greater for two-tooth ewes that were previously dry at docking as ewe lambs than those that were lactating at docking as ewe lambs ($p=0.018$), but this difference was not observed for ewes on Farm B or Farm C ($p>0.5$).

The negative relationships between both pre-lambing CALW and change in CALW and risk of being dry at docking were similar between cohorts, differing only in magnitude. This would suggest target pre-lambing CALW are therefore best assigned on an individual cohort basis. Regarding change in CALW from PD to pre-lambing, preventing any loss of CALW would be a reasonable target for all cohorts. For a typical twin bearing ewe this will require a gain of 12–17 kg of absolute (measured) liveweight by pre-lambing (Corner *et al.* 2008). As with Chapter 4, farmers could use this combined information to identify ewes within a flock that are at increased risk of being dry at docking. They could then alter management to target ‘at-risk ewes’ and to ensure weight and weight gain targets during pregnancy are monitored, met and achieved.

#### Chapter 6: Associations between lamb survival to weaning and dam udder and teat scores

The objectives of this chapter were:

- To examine a range of udder and teat traits and to describe the frequency with which different scores occur in a commercial New Zealand flock
- To investigate associations between lamb survival to weaning and ewe udder and teat scores

Commercially born lambs are solely dependent on their dams for milk for survival in early life, with milk remaining an important source of digestible energy and protein to weaning (Hayman *et al.* 1955; Clark 1980). It is well established that perinatal and neonatal lamb loss is a significant issue for sheep farmers (Stafford 2013; Dwyer *et al.* 2016; Allworth *et al.* 2017), and that ewes with defective udders contribute to this loss (Hayman *et al.* 1955; Watson and Buswell 1984). However, there appears to have been little recent scientific investigation of udder defects in New Zealand. Internationally, udder defects are recognised as an important cause of ewe wastage, as a result of increased on-farm mortality and increased premature culling (Madel 1981; Watson and Buswell 1984; Annett *et al.* 2011). In New Zealand, a recent survey indicated that >85% of commercial farmers examined their ewes' udders at least once yearly (Corner-Thomas *et al.* 2016), presumably to assist in culling decisions. However, there is currently no standardised udder scoring method that New Zealand sheep farmers can use. Therefore, ewes may be culled unnecessarily or, conversely, ewes that are not suitable for lamb rearing may be retained within the flock. This chapter aimed to examine a range of udder and teat traits in Romney ewes and to describe the frequency with which different scores occur, and to investigate associations between lamb survival to weaning and ewe udder and teat scores.

A range of udder and teat traits were scored using visual assessment and palpation, at pre-mating, pre-lambing, docking and weaning. Records from 981 ewes and 1,822 lambs were included in analyses, with 252 (13.8%) lambs recorded dead before weaning. The prevalence of ewes recorded with abnormal udders ranged from 5.0% - 7.5% at each of the measurement visits, while the prevalence of mastitis was 1.2% at pre-mating, 4.6% at docking and 3.1% at weaning. Pre-mating udder palpation scores of hard or lump were associated with increased odds of lambs not surviving to weaning compared with normal scores ($p<0.001$ and $p=0.003$ respectively), and could be used to identify ewes that are likely to be unsuitable for retaining in the breeding flock, and are therefore suitable candidates for culling. Farmers could also use clinical mastitis scores at docking ($p<0.0001$) or weaning ($p<0.0001$) to identify ewes whose lambs had greater odds of failure to survive to weaning, compared with lambs whose dams did not have mastitis. However, these scores do not provide an indication of future performance (as this would require subsequent seasons' data), therefore further investigation into the impact of the present season's score on future seasons' lamb survival is required.

### Chapter 7: Associations between lamb growth to weaning and dam udder and teat scores

The objective of this chapter was:

- To investigate associations between lamb growth to weaning and ewe udder and teat scores

The ability of a commercial New Zealand sheep farmer with a pasture-based production system to maximise the total weight of lamb available for sale directly influences the farm's ability to generate income (Bohan *et al.* 2018). Both the number and the weight of the individual lambs drive the total weight of lamb available for sale per ewe. Thus improving both lamb survival and growth to weaning improves total weaning weight, which is in turn closely correlated with the total weight of lambs sold. The quantity and quality of milk produced by the ewe is known to directly influence lamb growth (Hayman *et al.* 1955; Clark 1980). Lambs born to ewes with poor udder health, low milk yield, poor colostrum quality or quantity have poorer growth rates (Hayman *et al.* 1955; Watson and Buswell 1984; Arsenault *et al.* 2008).

Pre-mating udder palpation and teat palpation scores can be used to identify ewes whose lambs are predicted to have lower growth to weaning. Assuming a mean lamb age at weaning of 84.4 days, lambs born to ewes with a pre-mating udder palpation score of hard would be expected to have a mean weaning weight that was 2.1 kg less than those whose dams had normal scores. Udder palpation, udder symmetry and clinical mastitis scores during lactation were also associated with lamb growth rates. Growth rates of lambs whose dams had clinical mastitis or asymmetrical udders at docking or weaning were lower than those without mastitis, or with symmetrical udders respectively. Therefore, farmers can use these scores to identify ewes whose lambs may have lower growth rates to weaning in the present season. However, as the study was only conducted during one year, we are unable to compare between seasons, or to examine the relationship between the present season's scores and subsequent season's performance. Further longitudinal data collection is required to investigate this.

## Overall Relevance

Ewe wastage is a combination of both premature culling and on-farm mortality. However, there was very little published data regarding either premature culling or mortality of ewes in commercial New Zealand flocks. Throughout this thesis, the focus has been on ewe wastage, with the broad objective of establishing the extent, timing and cause of ewe wastage in commercial New Zealand flocks, while also identifying factors associated with increased ewe wastage.

To our knowledge, the study reported in Chapter 3 is the first that reports both lifetime wastage and detailed annual wastage in three commercial New Zealand ewe flocks. We identified ewe wastage as a potential issue for New Zealand commercial farms, which when combined with the results reported by Farrell *et al.* (2019), highlight the need for farmers to reduce wastage within their individual flocks if they wish to maximise overall flock productivity. Both premature culling and on-farm mortality were identified as contributing to wastage, therefore both need to be considered when implementing strategies to reduce ewe wastage. The results of Chapter 3 identify wastage as a ewe lamb as an area in which improvements can be made. To reduce ewe lamb wastage, farmers need to consider on-farm ewe lamb mortality rates, management practices to improve ewe lamb reproductive performance, and evaluation of culling policies (i.e. consider retaining rather than culling ewe lambs which are dry at docking). Chapter 3 also identified an increase in mortality rates over the PD-W period (i.e. over lambing), and highlights ewe mortality as an issue for New Zealand commercial ewes during lambing. However further investigation into causes of, and risk factors associated with, ewe mortality is required. In addition, the results of Chapter 3 support the hypothesis that ewes that had poorer pre-mating BCS would have a greater risk of wastage in that production year. Body condition scoring sheep is a quick, inexpensive and easily learned tool (Jefferies 1961; Russel *et al.* 1969) that would be easy for farmers to implement on-farm. Farmers should focus on improving pre-mating BCS; as they will not only improve ewe reproductive performance (Kenyon *et al.* 2014) but will also concurrently reduce ewe wastage. To achieve this, farmers should assess the BCS of their ewes at weaning, enabling poor BCS to be identified, drafted off and managed to gain BCS before breeding.

In Chapter 3, we identified that 8.0% (1,051/13,142) of total enrolled ewes were prematurely culled for being dry at docking. In Chapters 4 and 5, we identified 21.7% (1,554/7,171) of ewe lambs and 5.4% (437/8,025) of two-tooths which were identified as pregnant and with a known reproductive outcome in that year, were subsequently identified as dry at docking in that year. If a ewe is dry at docking this results in both reduced individual ewe productivity and flock productivity, and increased risk of ewe wastage (depending on a farm's culling policies). Therefore, Chapters 4 and 5 went on to identify firstly ewe lambs, and secondly two-tooth ewes, that were at increased risk of being dry at docking. The work presented in these chapters demonstrates clear associations between conceptus adjusted liveweight (CALW) and CALW changes during pregnancy and risk of being dry at docking. These results highlight the importance of monitoring ewe liveweight during pregnancy, to ensure ewes continue to gain

CALW. Weighing ewes is relatively quick and inexpensive, and as was done with this study, can be implemented when ewes are already in the yards at key management times such as weaning, pre-mating, PD and set-stocking. However, it is important to note, individual animal identification is required for CALW changes to be monitored on an individual ewe basis. The technology is available for this individual animal identification (Corner-Thomas *et al.* 2016). However, to date use rates are relatively low (Corner-Thomas *et al.* 2016), although usage on commercial farms appears to be increasing (Corner-Thomas *et al.* 2016). Farmers could use this weight and CALW weight change information to identify ewes within a flock that are at increased risk of being dry at docking. They could then alter management to target 'at-risk ewes' and to ensure weight and weight gain targets during pregnancy are monitored, met and achieved.

To our knowledge, the study reported in Chapters 6 and 7 is the first undertaken for many years in New Zealand that describes the prevalence of a range of udder and teat traits in Romney ewes in a commercial flock. Additionally, the results of Chapter 6 support the hypothesis that lambs born to ewes with poor udder and teat scores would have lower survival than lambs born to ewes with more desirable udder and teat scores. Similarly, the results of Chapter 7 support the hypothesis that lambs born to ewes with poor udder and teat scores would have poorer growth rates than lambs born to ewes with more desirable udder and teat scores. The udder scores presented in this thesis would be easy and quick for farmers to utilise on-farm, e.g. udder palpation scores of normal *vs.* lump *vs.* hard, which should ensure good uptake from commercial farmers. In addition, given >85% of commercial farmers are already assessing their ewes udders' (Corner-Thomas *et al.* 2016); the data presented in this thesis will assist in decision making as to which ewes to cull, and which to retain in the flock for lamb rearing. However, the results of Chapters 6 and 7 should be considered alongside further longitudinal investigation and economic analyses to provide robust support for recommendations.

In summary, farmers can utilise the information presented in the studies within this thesis to identify individual ewes within their flocks that are at increased risk of wastage and poor productivity. The present thesis highlights the value in encouraging farmers to collect and utilise data at key times to both improve ewe productivity and reduce likelihood of ewe wastage. Farmers should be encouraged to collect or calculate weight, BCS, udder scores, culling and mortality data on their own flocks at key management times (as described previously), and ideally on an individual basis. This would therefore enable proactive and informed decision-making and an alteration in management of these 'at-risk' ewes, rather than increased risk of mortality or reactive culling of ewes after the poor performance, both of which result in increased and unnecessary ewe wastage. Data collection will also enable farmers to identify trends in ewe wastage due to premature culling and mortality, assess culling policies, and identify areas where there is room for improvement and intervention is needed. However, given the complex nature of farming businesses, the data needs to be collected in a straightforward and practical way (as described previously), and it then needs to be analysed, interpreted and used for decision-making.

## Key limitations

The main limitations of the ewe wastage study arose from the extensive management of the commercial flocks and therefore limited frequency of interactions with individual ewes within the study cohorts. There were only four on-farm data collection visits each year, resulting in collection of interval-censored data. However, these visits did occur at key management times for commercial sheep farms, and enabled a balance between conducting research on commercial farms using large commercial flocks and generating a robust dataset. In addition, at each collection visit, not all information was collected for all ewes that remained within the study cohort. This was due to a combination of mis-mustering (ewes accidentally left in paddocks), ewes being in the incorrect mobs or incorrectly drafted on data collection days (they were managed as part of larger commercial flocks) or general recording error. However, given the study ewes were identified with EID tags and the study was conducted over a 6-year-period for each study cohort (with the exception of Farm C); it is likely that if these ewes were still present on the farm they would have had data collected at subsequent visits. There may also have been some loss of EID tags, which would have resulted in loss of effected ewes from the study flock and subsequent classification as dead/missing. The degree to which the EID tags may have been lost in the present study is unknown. However, EID ear-tag losses in Europe (where electronic identification of small ruminants is mandatory) are reported to be less than 4% per annum (Ribo *et al.* 2011), while EID ear-tag loss in a longitudinal study of double-tagged New Zealand commercial ewes was <1% per annum (Pers. Comm. Ridler). Ideally, the ewes in the wastage study would have been double-tagged, and in any future studies, double tagging of enrolled ewes is recommended. The frequency of visits also meant the flock managers and shepherds were relied upon to not only scan the EID tags of ewes that were selected for culling, but also to record and report reasons for culling. Overall, across the four study cohorts, 6.4% (425) ewes had no reason for culling reported.

Unfortunately, the extensive management of the flocks and frequency of observation combined with paddock terrain meant data was not collected on every death. If the ewe was absent from the last visit and was not recorded as present at any of the subsequent measurement visits, then it was classified as dead/missing in the interval between the 'last recorded date' (i.e. the visit the ewe was last recorded as present) and the visit immediately subsequent. Therefore, for analysis, missing ewes were classified in the same category as dead ewes (dead/missing), as it was presumed that they were most likely dead, however this was not certain. Cause of death was not established for any ewe; therefore, we are unable to provide information as to likely causes of the on-farm mortalities.

The wastage study used data collected from only four cohorts of ewes, from three commercial farms. However, although there were differences in wastage described between the study cohorts, the general trends were comparable (for example increased ewe mortality from PD-W), and the relationships between wastage and BCS were consistent across cohorts. However, further studies involving more flocks and farms are required to both validate these results and to provide more robust support for recommendations.

The key limitation of the udder study was that it was performed on only one farm during one year. However, the range of udder scores described and the frequency with which they occurred in the present study was comparable to that of another unpublished study involving 11 North Island (New Zealand) Hill Country commercial flocks (Ridler, unpublished). As the study was only conducted during one year, we were unable to compare between seasons, or to examine the relationship between the present season's scores and subsequent season's performance. Additionally, the statistical analysis did not allow for comparison of the model estimates between the four management times at which scoring was undertaken, nor the repeatability of scores within ewes within the season.

## Further Areas of Research

The present thesis has highlighted a number of areas that require further research to improve our understanding of wastage in commercial ewe flocks. The following suggested areas of initial research would build-on the data, results and conclusions presented in the present thesis.

Firstly, further analysis of the present ewe wastage dataset to investigate ewe mortality over the lambing period (PD-W). Chapter 3 described the timing of ewe wastage, and identified that mortality rates were greatest during the PD-W interval, accounting for 59.8% (3,143/5,253) of total ewe mortalities. This represents a cost to commercial farmers (cull value not obtained, reduced lifetime productivity, cost of replacement, loss of potential lambs), in addition to the potential cost to animal welfare. The present dataset can be analysed to investigate associations between ewe liveweight, BCS and reproductive performance at PD (single or multiple bearing) and risk of mortality over the lambing period. As there is a clearly defined interval (PD-W), predictor variables of liveweight, BCS and reproductive performance were measured at a single time (PD), and a single outcome variable (risk of mortality (dead/missing) over lambing), this can be investigated using multiple logistic regression.

Secondly, the commencement of two further studies which would complement the present wastage study. One of the key limitations of the present wastage study was the missing (presumed dead) ewes and that cause of death was not determined for any of the dead ewes. Given that Chapter 3 identified on-farm mortality accounted for 44.2% (5,253/11,882) of total ewe wastage, further investigation into exact timing, cause and risk factors associated with ewe mortality is required. As such, further studies are needed with the aim to investigate associations between productivity parameters (weight, BCS and reproductive performance) and on-farm ewe mortality, while also identifying timing of the mortality and where possible a likely cause of mortality. To address the limitations of the present wastage study, any new study should have a greater frequency of data collection visits, with visits occurring pre-breeding, immediately post-breeding, PD, set-stocking, docking and weaning. In addition, over the lambing period (predicted period of greatest mortality based on Chapter 3 results) researchers (rather than relying on farm-staff) would ideally monitor the ewes to identify dead ewes. Any dead ewes should have a basic field necropsy undertaken to establish a likely cause of death.

It is also important to establish wastage rates and causes across a wider range of commercial farms, although accurate data collection regarding ewe wastage is likely to be challenging on typical New Zealand farms. However, a survey designed to capture farmer reported rates of wastage would be a valuable first step, and has the potential to include data from a wide range of farm systems. The survey would need to be set-up to capture flock level data, rather than individual level data because, as previously discussed, most farmers will not have individual level data. For example: annual ewe mortality rates, ewe mortality rates over the lambing period, and culling policies and the proportion of the flock that are prematurely culled each year (and if possible, reasons for culling). Clear limitations of a survey study would be; reliance on farmer reported data, and potentially biased and/or poor response to survey.

One of the main limitations of the udder study was that it was conducted in only one year, so it was impossible to compare between seasons or to examine the relationship between the present season's scores and subsequent season's performance. To address this, longitudinal studies are needed to allow us to assess repeatability of udder scores in subsequent lactations to allow for prediction of future offspring performance. That longitudinal data could also be used to create models assessing the effect of retaining or culling ewes with various udder defects on overall flock productivity and profitability. In addition, it would be useful to investigate the biological cause of each of the udder scores at each time to enhance our understanding of ewe udder and teat health in New Zealand non-dairy ewes.

## Conclusions

The present PhD reports on ewe wastage and productivity in a sample of New Zealand commercial ewe flocks. We have identified ewe wastage as a potential issue for commercial New Zealand farms, with both premature culling and on-farm mortality contributing to ewe wastage. However, we also report risk factors associated with increased wastage and reduced productivity. Commercial farmers can use the information presented in each of the studies within this thesis to identify ewes within their flocks that are at increased risk of wastage and poor productivity. Identifying these ewes means farmers can intervene and alter management to improve outcomes, ultimately resulting in reduced unnecessary wastage and increased productivity for the New Zealand sheep industry.

**Appendix 1: Number (n) and percentage of total enrolled ewes (% TE) that were recorded as culled or dead/missing (D/M) during each interval in each year of the study, for each study cohort. Where PM-PD = the pre-mating to pregnancy diagnosis interval, PD-W = the pregnancy diagnosis to weaning interval, W-PM = the weaning to pre-mating interval, and total = the production year (defined from pre-mating to pre-mating the following year).**

| | | | Farm A 2010-born (n=3,717) | | | Farm A 2011-born (n=4,609) | | | Farm B (n=3,998) | | | Farm C (n=818) | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Culled | D/M | Total | Culled | D/M | Total | Culled | D/M | Total | Culled | D/M | Total |
| Year 1 | PM-PD | n | 0 | 79 | 79 | 0 | 237 | 237 | 0 | 82 | 82 | - | - | - |
| | | % TE | 0% | 2.1% | 2.1% | 0% | 5.1% | 5.1% | 0% | 2.1% | 2.1% | - | - | - |
| | PD-W | n | 501 | 383 | 884 | 770 | 486 | 1,256 | 0 | 178 | 178 | 66 | 33 | 99 |
| | | % TE | 13.5% | 10.3% | 23.8% | 16.7% | 10.6% | 27.3% | 0% | 4.4% | 4.4% | 8.1% | 4.0% | 12.1% |
| | W-PM | n | 0 | 51 | 51 | 511 | 90 | 601 | 0 | 43 | 43 | 43 | 7 | 50 |
| | | % TE | 0% | 1.4% | 1.4% | 11.0% | 2.0% | 13.0% | 0% | 1.1% | 1.1% | 5.3% | 0.9% | 6.2% |
| | Total | n | 501 | 513 | 1,014 | 1,281 | 813 | 2,094 | 0 | 303 | 303 | 109 | 40 | 149 |
| | | % TE | 13.5% | 13.8% | 27.3% | 27.7% | 17.7% | 45.4% | 0% | 7.6% | 7.6% | 13.4% | 4.9% | 18.3% |
| Year 2 | PM-PD | n | 2 | 67 | 69 | 96 | 43 | 139 | 0 | 98 | 98 | 0 | 7 | 7 |
| | | % TE | 0.05% | 1.8% | 1.9% | 2.1% | 0.9% | 3.0% | 0% | 2.5% | 2.5% | 0% | 0.9% | 0.9% |
| | PD-W | n | 70 | 231 | 301 | 56 | 171 | 227 | 204 | 157 | 361 | 24 | 3 | 27 |
| | | % TE | 1.9% | 6.2% | 8.1% | 1.2% | 3.7% | 4.9% | 5.1% | 4.0% | 9.1% | 2.9% | 0.3% | 3.2% |
| | W-PM | n | 173 | 47 | 220 | 250 | 35 | 285 | 53 | 59 | 112 | 29 | 13 | 42 |
| | | % TE | 4.7% | 1.3% | 6.0% | 5.4% | 0.8% | 6.2% | 1.3% | 1.5% | 2.8% | 3.5% | 1.6% | 5.1% |
| | Total | n | 245 | 345 | 590 | 402 | 249 | 651 | 257 | 314 | 571 | 53 | 23 | 76 |
| | | % TE | 6.7% | 9.3% | 16.0% | 8.7% | 5.4% | 14.1% | 6.4% | 8.0% | 14.4% | 6.4% | 2.8% | 9.2% |
| Year 3 | PM-PD | n | 129 | 39 | 168 | 0 | 56 | 56 | 0 | 85 | 85 | 0 | 9 | 9 |
| | | % TE | 3.5% | 1.0% | 4.5% | 0% | 1.2% | 1.2% | 0% | 2.1% | 2.1% | 0% | 1.1% | 1.1% |
| | PD-W | n | 62 | 199 | 261 | 33 | 93 | 126 | 70 | 166 | 236 | | | |
| | | % TE | 1.7% | 5.4% | 7.1% | 0.7% | 2.0% | 2.7% | 1.8% | 4.2% | 6.0% | | | |
| | W-PM | n | 110 | 56 | 166 | 31 | 0 | 31 | 115 | 14 | 129 | | | |
| | | % TE | 3.0% | 1.5% | 4.5% | 0.7% | 0% | 0.7% | 2.9% | 0.4% | 3.3% | | | |
| | Total | n | 301 | 294 | 595 | 64 | 149 | 213 | 185 | 265 | 450 | | | |
| | | % TE | 8.2% | 7.9% | 16.1% | 1.4% | 3.2% | 4.6% | 4.7% | 6.7% | 11.4% | | | |

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Year 4 | PM-PD | n | 0 | 48 | 48 | 0 | 72 | 72 | 0 | 385 | 385 |
| | | % TE | 0% | 1.3% | 1.3% | 0% | 1.6% | 1.6% | 0% | 9.6% | 9.6% |
| | PD-W | n | 78 | 131 | 209 | 43 | 100 | 143 | 94 | 111 | 205 |
| | | % TE | 2.1% | 3.5% | 5.6% | 1.0% | 2.1% | 3.1% | 2.4% | 2.8% | 5.2% |
| | W-PM | n | 5 | 31 | 36 | 29 | 44 | 73 | 36 | 59 | 95 |
| | | % TE | 0.1% | 0.8% | 0.9% | 0.6% | 1.0% | 1.6% | 0.9% | 1.5% | 2.4% |
| | Total | n | 83 | 210 | 293 | 72 | 216 | 288 | 130 | 555 | 685 |
| | | % TE | 2.2% | 5.6% | 7.8% | 1.6% | 4.7% | 6.3% | 3.3% | 13.9% | 17.2% |
| Year 5 | PM-PD | n | 40 | 26 | 66 | 1 | 47 | 48 | 0 | 78 | 78 |
| | | % TE | 1.1% | 0.7% | 1.8% | 0.02% | 1.0% | 1.0% | 0% | 2.0% | 2.0% |
| | PD-W | n | 57 | 80 | 137 | 413 | 7 | 420 | 75 | 153 | 228 |
| | | % TE | 1.5% | 2.2% | 3.7% | 9.0% | 0.2% | 9.2% | 1.9% | 3.8% | 5.7% |
| | W-PM | n | 649 | 0 | 649 | 758 | 0 | 758 | 540 | 74 | 614 |
| | | % TE | 17.5% | 0% | 17.5% | 16.4% | 0% | 16.4% | 13.5% | 1.9% | 15.4% |
| | Total | n | 746 | 106 | 852 | 1,172 | 54 | 1,226 | 615 | 305 | 920 |
| | | % TE | 20.1% | 2.9% | 23.0% | 25.4% | 1.2% | 26.6% | 15.4% | 7.7% | 23.1% |
| Year 6 | PM-PD | n | 0 | 24 | 24 | 4 | 0 | 4 | 0 | 5 | 5 |
| | | % TE | 0% | 0.6% | 0.6% | 0.09% | 0% | 0.09% | 0% | 0.1% | 0.1% |
| | PD-W | n | 314 | 2 | 316 | 11 | 34 | 45 | 84 | 425 | 509 |
| | | % TE | 8.4% | 0.05% | 8.5% | 0.2% | 0.7% | 0.9% | 2.1% | 10.7% | 12.8% |
| | W-PM | n | 33 | - | 33 | 88 | - | 88 | 555 | - | 555 |
| | | % TE | 0.9% | - | 0.9% | 1.9% | - | 1.9% | 13.9% | - | 13.9% |
| | Total | n | 347 | 26 | 373 | 103 | 34 | 137 | 639 | 430 | 1,069 |
| | | % TE | 9.3% | 0.7% | 10.0% | 2.2% | 0.7% | 2.9% | 16.0% | 10.8% | 26.8% |

**Appendix 2: Number (n) of ewes that were recorded as culled or dead/missing (D/M) during each interval in each year of study, for each study cohort. Where NP = number of ewes present within each cohort at the start of each interval, n = the number of ewes that were recorded as culled or D/M in that interval, and % RC = the percentage of ewes that were removed from the cohort that remained at the start of each interval. PM-PD = the pre-mating to pregnancy diagnosis interval, PD-W = the pregnancy diagnosis to weaning interval, W-PM = the weaning to pre-mating interval, and total = the production year (defined from pre-mating to pre-mating the following year).**

| | | | Farm A 2010-born (n=3,717) | | | Farm A 2011-born (n=4,609) | | | Farm B (n=3,998) | | | Farm C (n=818) | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Culled | D/M | Total | Culled | D/M | Total | Culled | D/M | Total | Culled | D/M | Total |
| Year 1 | PM-PD | NP | | | 3,717 | | | 4,609 | | | 3,998 | - | - | - |
| | | n | 0 | 79 | 79 | 0 | 237 | 237 | 0 | 82 | 82 | - | - | - |
| | | % RC | 0% | 2.1% | 2.1% | 0% | 5.1% | 5.1% | 0% | 2.1% | 2.1% | - | - | - |
| | PD-W | NP | | | 3,638 | | | 4,372 | | | 3,916 | | | 818 |
| | | n | 501 | 383 | 884 | 770 | 486 | 1,256 | 0 | 178 | 178 | 66 | 33 | 99 |
| | | % RC | 13.8% | 10.5% | 24.3% | 17.6% | 11.1% | 28.7% | 0% | 4.5% | 4.5% | 8.1% | 4.0% | 12.1% |
| | W-PM | NP | | | 2,754 | | | 3,116 | | | 3,738 | | | 719 |
| | | n | 0 | 51 | 51 | 511 | 90 | 601 | 0 | 43 | 43 | 43 | 7 | 50 |
| | | % RC | 0% | 1.9% | 1.9% | 16.4% | 2.9% | 19.3% | 0% | 1.2% | 1.2% | 6.0% | 1.0% | 7.0% |
| | Total | NP | | | 3,717 | | | 4,609 | | | 3,998 | | | 818 |
| | | n | 501 | 513 | 1,014 | 1,281 | 813 | 2,094 | 0 | 303 | 303 | 109 | 40 | 149 |
| | | % RF | 13.5% | 13.8% | 27.3% | 27.7% | 17.7% | 45.4% | 0% | 7.6% | 7.6% | 13.4% | 4.9% | 18.3% |
| Year 2 | PM-PD | NP | | | 2,703 | | | 2,515 | | | 3,695 | | | 669 |
| | | n | 2 | 67 | 69 | 96 | 43 | 139 | 0 | 98 | 98 | 0 | 7 | 7 |
| | | % RC | 0.07% | 2.5% | 2.6% | 3.8% | 1.7% | 5.5% | 0% | 2.7% | 2.7% | 0% | 1.1% | 1.1% |
| | PD-W | NP | | | 2,634 | | | 2,376 | | | 3,597 | | | 662 |
| | | n | 70 | 231 | 301 | 56 | 171 | 227 | 204 | 157 | 361 | 24 | 3 | 27 |
| | | % RC | 2.7% | 8.8% | 11.5% | 2.4% | 7.2% | 9.6% | 5.7% | 4.4% | 10.1% | 3.6% | 0.5% | 4.1% |
| | W-PM | NP | | | 2,333 | | | 2,149 | | | 3,236 | | | 635 |
| | | n | 173 | 47 | 220 | 250 | 35 | 285 | 53 | 59 | 112 | 29 | 13 | 42 |
| | | % RC | 7.4% | 2.0% | 9.4% | 11.6% | 1.6% | 13.2% | 1.6% | 1.8% | 3.4% | 4.6% | 2.1% | 6.7% |
| | Total | NP | | | 2,703 | | | 2,515 | | | 3,695 | | | 669 |
| | | n | 245 | 345 | 590 | 402 | 249 | 651 | 257 | 314 | 571 | 53 | 23 | 76 |
| | | % RC | 9.1% | 12.8% | 21.9% | 16.0% | 9.9% | 25.9% | 7.0% | 8.5% | 15.5% | 8.0% | 3.5% | 11.5% |
| Year 3 | PM-PD | NP | | | 2,113 | | | 1,864 | | | 3,124 | | | 593 |
| | | n | 129 | 39 | 168 | 0 | 56 | 56 | 0 | 85 | 85 | 0 | 9 | 9 |
| | | % RC | 6.1% | 1.8% | 7.9% | 0% | 3.0% | 3.0% | 0% | 2.7% | 2.7% | 0% | 1.5% | 1.5% |
| | PD-W | NP | | | 1,945 | | | 1,808 | | | 3,039 | | | |
| | | n | 62 | 199 | 261 | 33 | 93 | 126 | 70 | 166 | 236 | | | |
| | | % RC | 3.2% | 10.2% | 13.4% | 1.8% | 5.1% | 6.9% | 2.3% | 5.5% | 7.8% | | | |
| | W-PM | NP | | | 1,684 | | | 1,682 | | | 2,803 | | | |
| | | n | | 56 | | 31 | 0 | 31 | | 14 | 129 | | | |

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | % RC | 110 | 3.3% | 166 | 1.8% | 0% | 1.8% | 115 | 0.5% | 4.6% |
| | | | 6.5% | | 9.8% | | | | 4.1% | | |
| | Total | NP | | | 2,113 | | | 1,864 | | | 3,124 |
| | | n | 301 | 294 | 595 | 64 | 149 | 213 | 185 | 265 | 450 |
| | | % RC | 14.2% | 13.9% | 28.1% | 3.4% | 8.0% | 11.4% | 5.9% | 8.5% | 14.4% |
| Year 4 | PM-PD | NP | | | 1,518 | | | 1,651 | | | 2,674 |
| | | n | 0 | 48 | 48 | 0 | 72 | 72 | 0 | 385 | 385 |
| | | % RC | 0% | 3.2% | 3.2% | 0% | 4.4% | 4.4% | 0% | 14.3% | 14.3% |
| | PD-W | NP | | | 1,470 | | | 1,579 | | | 2,289 |
| | | n | 78 | 131 | 209 | 43 | 100 | 143 | 94 | 111 | 205 |
| | | % RC | 5.3% | 8.9% | 14.2% | 2.8% | 6.5% | 9.3% | 4.1% | 4.8% | 8.9% |
| | W-PM | NP | | | 1,261 | | | 1,436 | | | 2,084 |
| | | n | 5 | 31 | 36 | 29 | 44 | 73 | 36 | 59 | 95 |
| | | % RC | 0.4% | 2.5% | 2.9% | 2.1% | 3.1% | 5.2% | 1.7% | 2.8% | 4.5% |
| | Total | NP | | | 1,518 | | | 1,651 | | | 2,674 |
| | | n | 83 | 210 | 293 | 72 | 216 | 288 | 130 | 555 | 685 |
| | | % RC | 5.5% | 13.8% | 19.3% | 4.4% | 13.1% | 17.5% | 4.9% | 20.8% | 25.7% |
| Year 5 | PM-PD | NP | | | 1,225 | | | 1,363 | | | 1,989 |
| | | n | 40 | 26 | 66 | 1 | 47 | 48 | 0 | 78 | 78 |
| | | % RC | 3.3% | 2.1% | 5.4% | 0.07% | 3.4% | 3.5% | 0% | 3.9% | 3.9% |
| | PD-W | NP | | | 1,159 | | | 1,315 | | | 1,911 |
| | | n | 57 | 80 | 137 | 413 | 7 | 420 | 75 | 153 | 228 |
| | | % RC | 4.9% | 6.9% | 11.8% | 31.4% | 0.5% | 31.9% | 3.9% | 8.0% | 11.9% |
| | W-PM | NP | | | 1,022 | | | 895 | | | 1,683 |
| | | n | 649 | 0 | 649 | 758 | 0 | 758 | 540 | 74 | 614 |
| | | % RC | 63.5% | 0% | 63.5% | 84.6% | 0% | 84.6% | 32.1% | 4.4% | 36.5% |
| | Total | NP | | | 1,225 | | | 1,363 | | | 1,989 |
| | | n | 746 | 106 | 852 | 1,172 | 54 | 1,226 | 615 | 305 | 920 |
| | | % RC | 60.9% | 8.7% | 69.6% | 86.0% | 4.0% | 90.0% | 30.9% | 15.3% | 46.2% |
| Year 6 | PM-PD | NP | | | 373 | | | 137 | | | 1,069 |
| | | n | 0 | 24 | 24 | 4 | 0 | 4 | 0 | 5 | 5 |
| | | % RC | 0% | 6.4% | 6.4% | 2.9% | 0% | 2.9% | 0% | 0.5% | 0.5% |
| | PD-W | NP | | | 349 | | | 133 | | | 1,064 |
| | | n | 314 | 2 | 316 | 11 | 34 | 45 | 84 | 425 | 509 |
| | | % RC | 90.0% | 0.6% | 90.6% | 8.2% | 25.4% | 33.6% | 7.9% | 39.8% | 47.7% |
| | W-PM | NP | | | 33 | | | 88 | | | 555 |
| | | n | 33* | - | 33 | 88* | - | 88 | 555* | - | 555 |
| | | % RC | 100.0% | - | 100.0% | 100.0% | - | 100.0% | 100.0% | - | 100.0% |
| | Total | NP | | | 373 | | | 137 | | | 1,069 |
| | | n | 347 | 26 | 373 | 103 | 34 | 137 | 639 | 430 | 1,069 |
| | | % RC | 93.0% | 7.0% | 100.0% | 75.2% | 24.8% | 100.0% | 59.8% | 40.2% | 100.0% |

**Appendix 3: Of the ewes that were present at each of the pre-mating visits (Total), the number and percentage (%) of ewes in each of the body condition score (BCS) categories (1.0 – 5.0), for each enrolled cohort.**

| | | Farm A 2010-born | | Farm A 2011-born | | Farm B | | Farm C | |
|---|---|---|---|---|---|---|---|---|---|
| | | N | % | N | % | N | (%) | N | % |
| Year 1 | 1.0 | 0 | (0.0%) | 0 | (0.0%) | 0 | (0.0%) | * | * |
| | 1.5 | 23 | (0.7%) | 0 | (0.0%) | 1 | (0.03%) | * | * |
| | 2.0 | 463 | (13.4%) | 16 | (0.4%) | 50 | (1.34%) | * | * |
| | 2.5 | 1,288 | (37.1%) | 1,502 | (32.9%) | 1,533 | (41.2%) | * | * |
| | 3.0 | 1,101 | (31.7%) | 2,264 | (49.5%) | 1,739 | (46.8%) | * | * |
| | 3.5 | 490 | (14.1%) | 715 | (15.6%) | 361 | (9.7%) | * | * |
| | 4.0 | 88 | (2.5%) | 71 | (1.6%) | 32 | (0.9%) | * | * |
| | 4.5 | 16 | (0.5%) | 4 | (0.1%) | 3 | (0.1%) | * | * |
| | 5.0 | 0 | (0.0%) | 0 | (0.0%) | 0 | (0.0%) | * | * |
| | Total | 3,469 | | 4,572 | | 3,719 | | * | * |
| Year 2 | 1.0 | 0 | (0.0%) | 0 | (0.0%) | 0 | (0.0%) | 0 | (0.0%) |
| | 1.5 | 2 | (0.1%) | 4 | (0.2%) | 0 | (0.0%) | 0 | (0.0%) |
| | 2.0 | 185 | (7.0%) | 90 | (3.7%) | 103 | (2.8%) | 35 | (5.2%) |
| | 2.5 | 902 | (33.9%) | 1,210 | (49.2%) | 1,566 | (43.2%) | 268 | (39.9%) |
| | 3.0 | 936 | (35.2%) | 1,076 | (43.8%) | 1,860 | (51.3%) | 296 | (44.1%) |
| | 3.5 | 435 | (16.3%) | 76 | (3.1%) | 100 | (2.8%) | 65 | (9.7%) |
| | 4.0 | 154 | (5.8%) | 3 | (0.1%) | 0 | (0.0%) | 5 | (0.8%) |
| | 4.5 | 43 | (1.6%) | 0 | (0.0%) | 0 | (0.0%) | 0 | (0.0%) |
| | 5.0 | 0 | (0.0%) | 0 | (0.0%) | 0 | (0.0%) | 0 | (0.0%) |
| | Total | 2,662 | | 2,459 | | 3,629 | | 669 | |
| Year 3 | 1.0 | 0 | (0.0%) | 1 | (0.1%) | 0 | (0.0%) | 0 | (0.0%) |
| | 1.5 | 2 | (0.1%) | 48 | (2.6%) | 8 | (0.3%) | 0 | (0.0%) |
| | 2.0 | 218 | (10.6%) | 652 | (35.5%) | 87 | (2.9%) | 10 | (1.7%) |
| | 2.5 | 1,136 | (55.3%) | 965 | (52.5%) | 1,063 | (35.1%) | 151 | (26.0%) |
| | 3.0 | 634 | (30.9%) | 173 | (9.4%) | 1,645 | (54.3%) | 343 | (59.0%) |
| | 3.5 | 60 | (2.9%) | 0 | (0.0%) | 217 | (7.2%) | 74 | (12.7%) |
| | 4.0 | 4 | (0.2%) | 0 | (0.0%) | 11 | (0.4%) | 3 | (0.5%) |
| | 4.5 | 0 | (0.0%) | 0 | (0.0%) | 1 | (0.03%) | 0 | (0.0%) |
| | 5.0 | 0 | (0.0%) | 0 | (0.0%) | 0 | (0.0%) | 0 | (0.0%) |
| | Total | 2,054 | | 1,839 | | 3,032 | | 581 | |
| Year 4 | 1.0 | 1 | (0.1%) | 0 | (0.0%) | 0 | (0.0%) | - | - |
| | 1.5 | 1 | (0.1%) | 0 | (0.0%) | 1 | (0.04%) | - | - |
| | 2.0 | 59 | (4.0%) | 17 | (1.1%) | 30 | (1.3%) | - | - |
| | 2.5 | 524 | (35.5%) | 202 | (12.8%) | 356 | (15.5%) | - | - |
| | 3.0 | 665 | (45.1%) | 837 | (53.0%) | 1,171 | (50.8%) | - | - |
| | 3.5 | 216 | (14.6%) | 492 | (31.1%) | 716 | (31.1%) | - | - |
| | 4.0 | 10 | (0.7%) | 32 | (2.0%) | 30 | (1.3%) | - | - |
| | 4.5 | 0 | (0.0%) | 0 | (0.0%) | 0 | (0.0%) | - | - |
| | 5.0 | 0 | (0.0%) | 0 | (0.0%) | 0 | (0.0%) | - | - |
| | Total | 1,476 | | 1,580 | | 2,304 | | - | - |
| Year 5 | 1.0 | 1 | (0.1%) | 0 | (0.0%) | 0 | (0.0%) | - | - |
| | 1.5 | 1 | (0.1%) | 3 | (0.2%) | 14 | (0.7%) | - | - |
| | 2.0 | 28 | (2.3%) | 20 | (1.5%) | 251 | (13.0%) | - | - |
| | 2.5 | 352 | (29.2%) | 210 | (15.6%) | 789 | (40.8%) | - | - |
| | 3.0 | 600 | (49.8%) | 883 | (65.6%) | 747 | (38.6%) | - | - |
| | 3.5 | 204 | (16.9%) | 219 | (16.3%) | 126 | (6.5%) | - | - |
| | 4.0 | 20 | (1.7%) | 11 | (0.8%) | 8 | (0.4%) | - | - |
| | 4.5 | 0 | (0.0%) | 0 | (0.0%) | 0 | (0.0%) | - | - |
| | 5.0 | 0 | (0.0%) | 0 | (0.0%) | 0 | (0.0%) | - | - |
| | Total | 1,206 | | 1,346 | | 1,935 | | - | - |
| Year 6 | 1.0 | 1 | (0.3%) | 1 | (1.0%) | 0 | (0.0%) | - | - |
| | 1.5 | 7 | (1.9%) | 0 | (0.0%) | 0 | (0.0%) | - | - |
| | 2.0 | 32 | (8.8%) | 0 | (0.0%) | 2 | (0.2%) | - | - |
| | 2.5 | 141 | (39.0%) | 8 | (7.8%) | 69 | (6.6%) | - | - |
| | 3.0 | 147 | (40.6%) | 72 | (70.0%) | 607 | (57.8%) | - | - |
| | 3.5 | 30 | (8.3%) | 21 | (20.4%) | 312 | (29.7%) | - | - |
| | 4.0 | 4 | (1.1%) | 1 | (1.0%) | 61 | (5.8%) | - | - |
| | 4.5 | 0 | (0.0%) | 0 | (0.0%) | 0 | (0.0%) | - | - |
| | 5.0 | 0 | (0.0%) | 0 | (0.0%) | 0 | (0.0%) | - | - |
| | Total | 362 | | 103 | | 1,051 | | - | - |

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| | |
|---|---|
| Name of candidate: | Kate Griffiths |
| Name/title of Primary Supervisor: | Anne Ridler |
| Name of Research Output and full reference: | |
| [illegible] | |
| In which Chapter is the Manuscript /Published work: | Chapter 4 |
| Please indicate: | |
| • The percentage of the manuscript/Published Work that was contributed by the candidate: | 75% |
| and | |
| • Describe the contribution that the candidate has made to the Manuscript/Published Work: | |
| Defined the research questions. Data manipulation and analysis. Wrote the published work, submitted it and undertook all revisions. | |
| For manuscripts intended for publication please indicate target journal: | |
| | |
| Candidate's Signature: | |
| Date: | 12-8-2019 |
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| [illegible] | |
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| Date: | 12-8-2019 |
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|---|---|
| Name of candidate: | Kate Griffiths |
| Name/title of Primary Supervisor: | Anne Ridler |
| Name of Research Output and full reference: | |
| Griffiths KJ, Ridler AL, Compton CWR, Corner-Thomas RA, Kenyon PR. Associations between lamb survival to weaning and dam udder and teat scores. New Zealand Veterinary Journal 67, 163-171, 2019 | |
| In which Chapter is the Manuscript /Published work: | Chapter 6 |
| Please indicate: | |
| • The percentage of the manuscript/Published Work that was contributed by the candidate: | 90% |
| and | |
| • Describe the contribution that the candidate has made to the Manuscript/Published Work: | |
| Designed the study, obtained Animal Ethics permission and undertook the data collection. Defined the research questions. Data manipulation and analysis. Wrote the published work, submitted it and undertook all revisions. | |
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| Candidate's Signature: | |
| Date: | 12-8-2019 |
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| [illegible] | |
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| and | |
| • Describe the contribution that the candidate has made to the Manuscript/Published Work: | |
| Designed the study, obtained Animal Ethics permission and undertook the data collection. Defined the research questions. Data manipulation and analysis. Wrote the published work, submitted it and undertook all revisions. | |
| For manuscripts intended for publication please indicate target journal: | |
| | |
| Candidate's Signature: | [signature] |
| Date: | 12-8-2019 |
| Primary Supervisor's Signature: | Anne Ridler — Digitally signed by Anne Ridler Date: 2019.08.09 11:52:05 +12'00' |
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