Investigation of ewe and lamb mortality on a commercial farm in New Zealand

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Kimberly Giselle Capdevila Ospina

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Abstract

On-farm ewe mortality is an important issue that impacts the productivity and profitability of the New Zealand sheep systems. Additionally, it raises potential concerns regarding ewe welfare and consumer perception implications related to the increase of ewe deaths. Ewe mortality ranges from 2.0 to 20.8% per annum and is increasingly recognised as an important problem on New Zealand sheep farms.

This thesis established the ewe mortality rates, period of risk and the association between productive parameters and ewe deaths on a commercial sheep farm in New Zealand, with further investigation into the causes of ewe and lamb mortality around lambing. This study utilised a cohort of 1789 two-tooth ewes on a commercial sheep farm located in the Waikato region. Data were collected from the start of mating (March 2019) to weaning (December 2019), a period of 262 days. Additionally, the ewes were monitored daily over a period of 24 days, both prior to and during the first weeks of lambing, by a researcher who utilised a drone for greater access when possible.

Results showed that over half the ewe deaths during the study period occurred during the lambing period, hence, this was the period of highest risk for ewe death. Twin and triplet-bearing ewes had higher risk of mortality than single-bearing ewes. During the lambing period, being cast was the main cause of ewe death (66%), while other causes included vaginal prolapse and dystocia. Change of conceptus-adjusted live weight (CALW) at mating and BCS at ram removal tended to be lower in the ewes that died, however, further investigation is required to establish productive parameters associated with ewe mortality.

The findings of this thesis suggest that it might be possible to reduce ewe mortality around lambing, especially in multiple-bearing ewes, by daily monitoring to identify and resolve cast ewes. If this were done it is likely that the ewe and therefore her future lambs would be saved. This study only included one farm in a single year, however, and the repeatability of these results should be evaluated in further years and in other flocks.

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List of Abbreviations

BCS	Body condition score
CAA	Civil Aviation Authority of New Zealand
CALW	Conceptus adjusted live weight
LW	Live weight
NIWA	New Zealand’s National Climate Database
OR	Odds ratio
PD	Pregnancy diagnosis
VCSN	Virtual Climate Station Network

1.Introduction

Ewe mortality affects the productivity and profitability of the New Zealand sheep industry (Farrell et al., 2019). Ewe mortality is an important issue for New Zealand farmers due to the financial impact, welfare implications and consumer perceptions associated with increased mortality. That is why it is important that farmers reduce ewe deaths (Cranston et al., 2017; Griffiths et al., 2017).

Based on the calculation of Griffiths et al. (2017), a one percent reduction in the mortality of breeding ewes would result in 200,000 fewer ewe deaths and an economic saving of at least NZ$20 million per annum. Likewise, on New Zealand North Island Hill Country farms a reduction in ewe wastage, including losses due to death and premature culling, from 21 to 5% would increase farm cash profit by 33% (Farrell et al., 2019).

Ewe mortality rates, timing and causes have not been extensively reported in New Zealand with much of the published literature dating from the 1970s. Since then, sheep farming systems have changed, with one example being the increase in lambing percentages and lamb carcass weights alongside a decline in sheep numbers overall (Morris and Hickson, 2016). In recent years, risk factors for Merino ewe mortality have been identified in Australia, leading to management strategies to reduce the mortality rate (Kelly et al., 2014).Therefore, ewe mortality timing, causes, and relationship with productive parameters need to be investigated in New Zealand sheep production systems.

This thesis will investigate ewe mortality on a commercial farm in New Zealand. The literature review chapter summarises the literature to date on ewe mortality rates, impacts, timing, risk factors and possible causes. The focus is on New Zealand sheep production systems, but literature has been sourced from countries with similar grass-fed production, topography, and/or environmental conditions. Improving our understanding of the timing, causes and risk factors associated with ewe mortality may allow for the development of guidelines to reduce or prevent ewe mortality, thereby improving animal welfare, as well as increasing the profitability of sheep farming and as a result the overall profitability of the sheep industry.

Although this thesis aims to examine ewe mortality, this study methodology allowed a brief investigation of lamb mortality. Lamb mortality around lambing reduces sheep farmer´s revenue and impacts the farm development and growth (Everett-Hincks and Duncan, 2008; Kerslake et al., 2010). Lamb losses limits the economic returns on-farm, animal welfare and consumer perceptions (Gascoigne et al., 2017). A summary of the available literature of rates, risk factors and causes of lamb mortality and the importance of increasing lamb survival was included in the literature review chapter.

2. Literature review

2.1 Ewe mortality

2.1.1 Mortality is a restrictive factor within the New Zealand sheep industry

The sheep industry is an important contributor to the New Zealand economy (Beef and Lamb New Zealand 2019a). For the year ended 30 June 2018, sheep production exports contributed NZ$4.13 billion to the economy, with an estimated total production of 449,036 tonnes of meat (Ministry for Primary Industries 2019a, b). New Zealand contributes approximately 40% of the ovine meat exported worldwide (FAO, 2019). In New Zealand lamb mortality has been widely studied (Everett-Hincks and Dodds, 2008; Everett-Hincks and Duncan, 2008; Kerslake et al., 2005; Schreurs et al., 2010), although, ewe mortality has received little attention and generally has not been accurately recorded (Bush et al., 2006a; Ghazali, 2007).

Reducing ewe mortality in New Zealand has important implications for both financial and welfare reasons. Further, looking ahead ewe mortality may affect consumer purchasing decisions due to an increased demand for products from ethical production systems, sometimes termed “clean, green and ethical” (Cranston et al., 2017; Ferguson et al., 2014; Griffiths et al., 2017; Martin and Kadokawa, 2006).

2.1.2 Financial implications

On-farm ewe mortality is a source of significant economic loss for New Zealand sheep farmers (Griffiths et al., 2017). These costs result from the direct cost of the dead ewe, a greater replacement rate, and a reduction in the number of lambs weaned (Griffiths et al., 2017). Based on the data reported by Beef and Lamb New Zealand (2019c), a reduction of 1% in mortality from the current population of 17.2 million breeding ewes in New Zealand (equating to 172,000 fewer ewes being lost) would, if ewes were theoretically valued at NZ$100, result in a monetary increase of NZ$17.2 million to the New Zealand industry (Farrell et al., 2019; Griffiths et al., 2017).

Ewe wastage involves both on-farm mortality and the premature culling of ewes, therefore, ewe mortality directly affects the ewe wastage rate (Farrell et al., 2019; Griffiths et al., 2017). Edwards and Juengel (2016) reported a marked increase in the reproductive performance of ewes lambing from one year-old to two years-old, with a further, slower increase at three and four years-old. Reduced longevity and flock average age has been linked with reduced flock productivity as young ewes display lower reproductive performance (Farrell et al., 2019; Griffiths et al., 2017). That means ewe mortality and early culling can have a significant effect on the sheep industry (Byun, 2012). In a recent model, Farrell et al. (2019) estimated that a reduction in the ewe wastage rate from 21 to 5% in New Zealand North Island sheep farms would result in a cash profit increase of 33% for the farmer.

Bio-economic modelling of the Australian sheep production system revealed that improving ewe survival by 4% could improve the profitability of the industry by AU$303 million (Young et al., 2014). Furthermore, it is relevant to highlight that the cash profit of reduced ewe mortality and increased ewe survival is a combination of both the value of the ewe and the value of additional surviving lambs (Griffiths et al., 2017; Young et al., 2014).

2.1.3. Welfare and consumer perception implications

Ewe mortality is often used as an indicator of the animal welfare and health status of individual farms (Doughty et al., 2019). Given that welfare and survival are linked, taking measures to decrease the mortality and identifying the associated factors will likely improve animal welfare. Although the cause of ewe death is often unknown, mortality can be a direct indicator of animal welfare (Doughty et al., 2019). One consideration may be the reported higher risk of death among multiple-bearing ewes in the peri-partum period (Ferguson et al., 2014). In New Zealand, the national lambing percentage (lambs weaned / lambs mated) has increased from 97% in 1990 to 139% in 2019 (Stats NZ, 2019), due to the selection pressure for higher ewe fecundity, which in turn may have had a greater impact on ewe welfare. In addition, there is an increasing demand from consumers for products perceived as ethical

(Martin and Kadokawa, 2006). Consumers may have negative perceptions of the sheep industry if ewe mortality rate is high (Cranston et al., 2017; Doughty et al., 2019; Griffiths et al., 2017). Therefore, addressing ewe mortality levels has a positive impact on animal welfare and the overall industry.

2.1.4. Rates of ewe mortality

In the literature, reports of ewe mortality rates in New Zealand have been highly variable. Data from surveys and on-farm studies have reported mortality rates to be between 2.0 and 20.8% per annum (Anderson and Heuer, 2016; Davis, 1979; Gautam et al., 2018; Ghazali, 2007; Griffiths et al., 2017; Quinlivan and Martin, 1971). The annual industry survey of sheep farms across New Zealand, generated from a sample survey of around 530 farms, reported that ewe losses were between 1.4 to 8.7% (Beef and Lamb New Zealand 2019b). Similarly, reports of ewe mortality in Australia were in the range from 2.7 to 19.1% per annum (Bush et al., 2006a; Doughty et al., 2019; Kelly et al., 2014).

The timing and cause of ewe mortality are not generally recorded due to the extensive management systems used in New Zealand and the large average flock sizes and farm dimensions (size and topography) (Davis, 1979; Doughty et al., 2019). In addition, infrequent interactions of farmers with individual ewes within a flock, and the extensive management systems utilised, result in difficulties identifying ewes that have died. As a result assumptions are made regarding mortality as missing ewes are generally believed to have died (Annett et al., 2011; Doughty et al., 2019; Gautam et al., 2018; Griffiths et al., 2017). Missing ewes, however, could have become mixed with a different group or mob and thus may have been erroneously counted as ‘missing’ (Ghazali, 2007). These assumptions may help to explain the variability in the mortality rates from farmer reported data (Bush et al., 2006a; Doughty et al., 2019). For instance, only 48% of Australian farmers quantified and recorded ewe mortality rates (Trompf et al., 2011). It has been suggested that identifying and studying flocks with high loss rates is vital to detect timing and specific causes of death (Bush et al., 2006a; Davis, 1979; Harris and Nowara, 1995).

2.1.5. Timing of ewe mortality

The timing of ewe mortality is also not accurately reported, although there is a clear seasonal distribution in the literature (Bush et al., 2006a; Doughty et al., 2019; Harris and Nowara, 1995). Most ewes die or go missing between mating and the end of the lambing period (Davis, 1979; Ghazali, 2007; Quinlivan and Martin, 1971), and in particular during the lambing and peri-partum period (Ghazali, 2007; Griffiths et al., 2017; Harris and Nowara, 1995). Davis (1979) reported that in the Hawke's Bay region of New Zealand the risk of mortality was greatest during the lambing season (July and August).

In the United Kingdom, the greatest ewe mortality rates were reported during the pre-lambing period, with 23% of annual deaths occurring during this time (Annett et al., 2011). In that study, however, post-weaning mortality accounted for 31% of the annual ewe mortality among Blackface flocks (Annett et al., 2011). Similarly, in a two-year experiment in Australia, Dever (2017) reported the highest incidence of ewe mortality was between pre-lambing and 6 weeks after lambing. The majority of authors reported that the spring season as the most critical period for ewe mortality, although a study of Australian Merino flocks reported that the risk of death increased in Autumn and Winter (Kelly et al., 2014).

A summary of the literature reporting timing and rates of ewe mortality in New Zealand, Australia, and other countries with similar extensive grazing conditions is shown in Tables 2.1, 2.2 and 2.3. It is important to note that some of the studies focussed on other research questions but also reported on ewe mortality data.

Table 2.1. Summary of studies conducted in New Zealand reporting ewe mortality, including the source of data, method, number of flocks/farms, number of sheep, death assumption of missing ewes, breed, year, and average mortality rates, range mortality rates and time period.

Author	Method	n flocks or farms	n ewes [1] (range)	Missing ewes assumed dead	Breeds	Regions [2]	Year	Ewe mortality [3]		
								Average (%)	**Range (%)**	**Time period**
Griffiths (2020)	Longitudinal study	3 farms	13142 (818 - 8326)	Yes	Composite (Coopworth and East Friesian) and Romney	Waikato and Wairarapa .North Island NZ	2011-2017	12 [D] 31 [D]	3.5-20.8 (year 1-5) 7-40.2 (year 6)	Per annum
								Up to 11.1% of the annual ewe mortality in the flock occurred between the pregnancy diagnosis and weaning interval (year 1-5)		
Gautam et al. (2018) Anderson and Heuer (2016)	Longitudinal study	17 farms	109320 (785 - 20104)	Yes	Merino, Romney, Corriedale and crossbreed	North and South Islands NZ	2012-2014	7 [E]	2.8-15.7	Per annum
Ghazali (2007)	Data analysis	1 farm	20708 [A]	Yes	Romney	Wairarapa NZ	1997-2005	8.65	7-10.8	Per annum
	Case study	1 farm	531	Yes	Romney		2006	3.1	NR	during lambing season
Tarbotton and Webby (1999)	Survey and on-farm study	8 farms	2624 (286 -374)	Yes	Romney and Coopworth	King Country and Taupo. NZ	1997	3.9	2.5-7.5	Scanning to docking

Davis (1979)	Survey	9 farms	23 710 [B] (1470 - 3600)	NR	NR	Hawke´s Bay NZ	1971-1972	4.9	NR	Per annum
								33% of the annual ewe mortality occurred during the lambing period (July-August)		
Pyke (1974)	On-farm study	1 farm	90 to 308 [C]	NR	NR	King Country region NZ	1965-1974	9.6	4.9-27.1	Per annum
Quinlivan and Martin (1971)	Survey	2419 flocks	564514	NR	Romney	North and South Islands NZ	1965-1968	2	NR	From mating to the end of lambing
Hickey (1960)	Mixed, case study and survey	NR	83113	NR	NR	NZ	1954-1959	8.4	NR	Per annum

[1] Number of ewes unless another category is specified. Total number of ewes in the project, and range in each farm or flock. [A] Average sheep population at risk per year. [B] Mixed-sex, >6 months-old. [C] Variation per year in the farm.

[2] NZ = New Zealand.

[3] Annual ewe mortality rates unless another period is specified. [D] calculated from data reported in its appendix. [E] selected farms based on estimations of at least 5% of Ovine Johne´s disease, so might be biased.

NR= No reported

Table 2.2. Summary of studies conducted in Australia reporting ewe mortality, including the source of data, method, number of flocks/farms, number of sheep, death assumption of missing ewes, breed, year, average mortality rate, range mortality rate and time period.

Author	Method	n flocks or farms	n ewes [1] (range)	Missing ewes assumed dead	Breeds	Regions [2]	Year	Ewe mortality [3]		
								Average (%)	**Range (%)**	**Time period**
Doughty et al. (2019)	Database analysis	8 farms	5000	NR	Merino and crosses	New South Wales, Victoria, South Australia and Western Australia AU	2007-2011	15.5	NR	from weaning to 660 days of age
Dever (2017)	Longitudinal study	5 farms	1200 [A] (240)	Yes	Border Leicester x Merino	Northern Tablelands, New South Wales. AU	2013-2014	6.3-6.7	6.5	Per annum
Kelly et al. (2014)	Experiment and case study	6 farms	1440	Yes	Merino	Northern Tablelands AU	2007-2009	10 75% during autumn and winter	6-22	During two years
Bush et al. (2006a); (2006b)	Mixed, case study and survey	12 flocks	123000 [B] (3500 - 20,600)	Yes	Merino	Southern New South Wales AU	2002-2004	9.2 [D]	2.7-19.1	Per annum
Harris and Nowara (1995)	Survey	227 flocks[A]	135686 [C] (299 - 667)	Yes	Merino and crosses	Mallee region of Western Victoria, AU	1987-1989	5.7 Merino 10.1 Non Merino	5.1-13.6	Autumn

[1] Number of ewes unless another category is specified. Total number of ewes in the project, and range in each farm or flock. [A] Only Twin-bearing ewes. [B] Mixed-sex, >6 months-old. [C] calculated from data reported in the source, from mature and ewe lambs flocks.

[2] AU = Australia. [3] Annual ewe mortality rates unless another period is specified. [D] Selected farms based on estimations of at least 5% of Ovine Johne´s disease, so might be biased. NR= No reported

Table 2.3. Summary of studies conducted in countries/regions other than New Zealand or Australia reporting ewe mortality, including source of data, method, number of flocks/farms, number of sheep, death assumption of missing ewes, breed, year, average mortality rate, range mortality rate and time period.

Author	Method	n flocks or farms	n ewes [1] (range)	Missing ewes assumed dead	Breeds	Regions [2]	Year	Ewe mortality [3] Average (%)	Range (%)	Average (%)
Annett et al. (2011)	Longitudinal study	6 farms	1143 (153- 223)	Yes	Blackface and crosses	Northern Ireland	2003-2008	NR	28-36 5.6-7.2	Per annum
								Up to 35% of the annual ewe mortality during post-weaning.		
Morgan-Davies et al. (2008)	On farm study	2 flocks	1487 (643-843)		Scottish Blackface and crosses with Texel	West, Perthshire, Dunblane, Kilmarnock and East Kilbride. Scotland. UK	1999-2000, 2002-2004	6.6[B]	5- 8.2	Per annum
Nass (1977)	On farms study	3 farms	2203-8750[A] per year	Yes	NR	Idaho, USA	1973-1975	6.7	6.8-10.1	Per annum
Gunn (1967)	Data analysis	3 farms	2500 (550-1350)	Yes	Cheviot, Blackface	Edinburgh, Scotland UK	1955-1965		3-4	Per annum
								70% of the annual ewe mortality during late pregnancy and early lactation		

[1] Number of ewes unless another category is specified. Total number of ewes in the project, and range in each farm or flock [A] Variation per year of total number of ewes. [2] UK = United Kingdom, USA = United States of America. [3] Annual ewe mortality rates unless another period is specified. [B] calculated from data reported in the source. NR= No report

2.1.6. Risk factors and productive parameters associated with ewe mortality

Identifying the risk factors associated with ewe mortality is crucial to enable the development of strategies to prevent ewe deaths. Few studies have reported the relationship between productive parameters such as live weight, body condition score (BCS), litter size, worm egg count and ewe mortality (Doughty et al., 2019; Ghazali, 2007; Griffiths, 2020; Kelly et al., 2014; Morgan-Davies et al., 2008). For instance, in the United Kingdom, Morgan-Davies et al. (2008) reported mid-pregnancy BCS was a good indicator of ewe survival based on a four-year study of two flocks, whereby they reported that ewes with BCS below 2.25 had a higher risk of mortality than ewes with BCS ≥2.5.

In Australian Merino flocks, low body weight and BCS have been associated with an increased risk of mortality (Doughty et al., 2019; Horton et al., 2016; Kelly et al., 2014). For instance, Horton et al. (2016) reported that Merino ewes with low weight (<33.4 kg) or low BCS(<2.5) were at higher risk of death than ewes in good condition. In the study by Doughty et al. (2019), the relative risk of death in ewes with a live weight under 40 kg was 4.5 in comparison with ewes between 40-45 kg. Regarding BCS, the relative risk of death was 4.6 for ewes with a BCS of 2.0 compared to those with a BCS of 3.0. Similarly, Kelly et al. (2014) reported that for each one kilogram decrease in ewe live weight, the mortality risk increased by 1-fold, whereas a one unit decrease in BCS increased the risk of ewe death by seven-fold. The suggested guideline to decrease Merino ewe mortality was to ensure that ewes were maintained at a body condition score of greater than 2.5 and live weight greater than 35 kg (Doughty et al., 2019; Kelly et al., 2014).

More recently in a longitudinal study in New Zealand, Griffiths (2020) reported a reduction of risk mortality in ewes with greater BCS at pre-mating in 4 of the 6 years of the study. The odd ratios of ewe mortality were between 24.4% and 53.6% lower for a one unit increase in the pre-mating BCS. No other study has published data in New Zealand about the links between BCS, LW and levels of ewe mortality.

Breed of ewe is another risk factor when considering ewe mortality. Differences in ewe mortality between breeds have been reported but there is limited data available. For instance, a survey of 227 Australian ewe flocks reported higher mortality rates in non-Merino flocks (Poll Dorset and Border Leicester; 10.9%) than in Merino flocks (5.7%) (Harris and Nowara, 1995). Similarly, in the United Kingdom a study carried out over 5 years monitored purebred Blackface (BF) and four different cross-breeds (Swaledale x BF, Cheviot X BF, Lleyn X BF; Texel X BF). Cheviot x Blackface crosses showing a tendency for a lower mortality rate than other crosses (Annett et al., 2011). To these authors' knowledge, no other studies have examined the breed differences in ewe mortality either in New Zealand or Australia.

Additional risk factors for ewe mortality are the incidence of fly strike and internal parasite status (Doughty et al., 2019; Kelly et al., 2014). In Australia, Merino ewes with faecal egg counts greater than 1200 eggs per gram (epg) had a 3.6 times greater risk of mortality than their counterparts with epg levels between 400 and 800. Similarly, studies of Merino ewes reported that 1.8% of ewes that had been affected by fly strike died within 7 days of the fly strike event (Doughty et al., 2019). Similarly, Merino and crossbreed ewes that were identified with fly strike with a severity level of 2 (medium) or 3 (heavy), had a mortality rate of 6.5% and 14.6% within 10 days, respectively (Horton et al., 2018a). The study also reported an additional finding whereby ewe mortality reached 4.1% the following year for ewes diagnosed with severity level 2 fly strike compared to ewes that did not have fly strike (Horton et al., 2018a). These risk factors have not been evaluated under New Zealand conditions.

Ewe pregnancy rank (number of lambs diagnosed at scanning) may also be a risk factor for ewe mortality. An on-farm study conducted in the Wairarapa region of New Zealand reported the single-bearing ewes had a higher risk of mortality than twin-bearing ewes (Ghazali, 2007). In contrast, an on-farm study in Scotland found that ewe pregnancy rank had no influence ewe mortality, which was attributed to differential management between singles and twin-bearing ewes after mid-pregnancy scanning (Morgan-Davies et al., 2008). There are, however, no other studies that examined the relationship between pregnancy status rank and ewe mortality rates in New Zealand.

Age is another factor that can influence ewe mortality rates. In Australian Merino ewe flocks, greater ewe mortality was reported in flocks ≥ 3 years (8.5%) than those ≤ 1 year (3%) (Harris and Nowara, 1995). There was, however, no significant difference in the annual mortality rates of young (≤ 1-year-old) and old (≥ 3 years-old) non-Merino ewe flocks (Poll Dorset and Border Leicester) (Harris and Nowara, 1995). In the Wairarapa region of New Zealand, Ghazali (2007) identified that ewes that were ≥ 2 years- of age had higher mortality rates than one-year-old (two-tooth) ewes. More recently, Griffiths (2020) reported lower ewe mortality rates in a cohort of ewes that first lambed as a 1-year-old when they were 5 years-old (3.5-20.8%) than 6 years-old (7-40.2%). There was a general assumption that mature aged ewes were resilient to death when standard industry management procedures were applied (Doughty et al., 2019; Kelly et al., 2014), however, that was not supported by the results presented above.

Extreme environmental conditions are associated with greater lamb mortality, however, the effect on ewe mortality has not been largely reported (Horton et al., 2016). A study of eight Australian Merino flocks examined ewe mortality in respect to weather conditions and found that unexpected cold weather or increment of chill index may present a risk factor (Horton et al., 2016). The chill index included the wind speed, the average temperature, and the daily rainfall during the entire day. They also reported that ewes with short wool (≤ 190 days) that were exposed to cold conditions (a chill index of >1176 or a chill increase of >168) were six times more likely to die than when exposed to warmer conditions (a chill index of ≤1176) and with long wool (> 190 days). Ewe live weight and BCS were other risk factors identified in that study. When ewes had short wool and were exposed to cold conditions ewe mortality rates were higher for ewes with low live weight (<33.4 kg) and BCS (<2.5) than heavier better conditioned ewes (Horton et al., 2016). Similarly, sheep were more susceptible to cold stress within 12 days of being shorn, especially if they had lost weight during the previous 4 weeks, thus leading to increase in mortality levels (Hutchinson and McRae, 1969). Moreover, in a two-year study on hair sheep in tropical conditions, ewe mortality rate reached a peak of 15% during the rainy season, with precipitation reaching 1430 mm over the season (Nava-López et al., 2006). Although ewes are unlikely to die under extreme weather conditions in New Zealand, abrupt weather changes can increase stress and thus increase vulnerability to other causes of death, for example parasites and metabolic issues (Horton et al., 2016). Further investigation of ewe mortality rates after sudden weather changes is required in New Zealand.

2.1.7. Unlocking the causes of ewe mortality

Establishing the cause of ewe mortality can often be challenging (Bush et al., 2006a; Doughty et al., 2019). Although several diseases and etiological agents have been reported to cause ewe mortality, available data remain limited. Causes of ewe mortality may be affected by ewe age, farm type, season, physiological state and the production system. The most frequently reported causes of mortality are internal parasites (Bush et al., 2006a; Kelly et al., 2014), dystocia (Davis, 1979; Ghazali, 2007; Nass, 1977), Johne's disease (Bush et al., 2006a; Gautam et al., 2018; Ghazali, 2007), malnutrition (Bush et al., 2006a; Harris and Nowara, 1995), fly strike (Doughty et al., 2019), heliotrope poisoning (Harris and Nowara, 1995), clostridial enterotoxaemia (Bush et al., 2006a; Nass, 1977), pregnancy toxaemia (Bush et al., 2006a; Davis, 1979), and pneumonia (Ghazali, 2007; Nass, 1977). The causes of ewe mortality may differ between farms and more than one cause can be involved (Bush et al., 2006a; Doughty et al., 2019). The main causes of death of ewes available from surveys and on-farm studies are summarised in Table 2.4.

During the lambing season, causes of ewe death include dystocia and peri-partum diseases (Ghazali, 2007). Dystocia, vaginal prolapse, pregnancy toxaemia, and mastitis are commonly reported as principal causes during this period (Davis, 1979; Ghazali, 2007; Harris and Nowara, 1995). Dystocia is also reported as one of the main causes of lamb mortality and also is likely to cause ewe mortality (Tarbotton and Webby, 1999). Ewes being cast (ewe accidentally immobilised, often in dorsal recumbency) has been described in a farmer's manual as another cause of ewe death in the peripartum period (Geenty, 1997), however in other studies undertaken in New Zealand there has been a low incidence of ewes reported as cast (Anderson and Heuer, 2016; Davis, 1979; Ghazali, 2007).

It has been suggested that the risk of ewe mortality would decline with improved nutrition, as malnutrition is often an associated factor (Bush et al., 2006a; Ghazali, 2007; Ridler et al., 2017). A study of 494 necropsied ewes prematurely culled due to poor BCS reported that 40% had health conditions that were likely treatable and another 40% had conditions that would likely have improved with better nutrition, while only 20% had conditions which were terminal (Ridler et al., 2017). Likewise, malnutrition, and its association with other factors, was responsible for 19.2% of the ewe mortality in Merino flocks (Bush et al., 2006a).

Not all the causes of ewe mortality are known. Reports indicate that 7 to 20% of ewe deaths had no cause that could be determined due to autolysis or undefined diagnosis from necropsy findings (Bush et al., 2006a; Ghazali, 2007). Moreover, the proportion of missing ewes, those that were absent from the flock and therefore presumed dead, has been reported to be between 6 and 20% of the whole flock (Annett et al., 2011; Bush et al., 2006a; Davis, 1979; Doughty et al., 2019; Ghazali, 2007; Griffiths et al., 2017; Nass, 1977; Ridler et al., 2017).

Despite the wide range of causes of ewe death, the proportion and prevalence of each cause have not been well established (Bush et al., 2006a; Doughty et al., 2019; Ghazali, 2007). Most on-farm studies and surveys were undertaken in the 1970s (Davis, 1979; Hickey, 1960; Tarbotton and Webby, 1999) with only a few recent studies having been undertaken (Gautam et al., 2018; Ghazali, 2007; Griffiths et al., 2017; Ridler et al., 2017). Moreover, much of the available literature focus on specific diseases, such as the prevalence of Johne's disease (Bush et al., 2006a; Gautam et al., 2018).

Knowledge management and technology transfer to farmers is also important for the management of ewe mortality (Trompf et al., 2011). Reports from an Australian sheep extension programme that worked with farmers for over 24 months showed an increase in the proportion of farmers that recorded ewe mortality from 42 to 81%. Among these farmers, there was a 43% reduction in the reported ewe mortality rates, from 4.9 to 2.8% (Trompf et al., 2011). These results may be related to an improvement in ewe feeding conditions or a better understanding by farmers of the nutritional and reproductive management of their sheep production system.

Table 2.4. Summary of causes of ewe mortality and its percentage (%) in different studies

Author [1]	Ridler et al. (2017)[2]	Anderson and Heuer (2016)[3]	Ghazali (2007)		Bush et al. (2006a)[4]	Nava-López et al. (2006)	Harris and Nowara (1995)	Davis (1979)	(Nass, 1977)
Number of dead ewes or pathological studies	494	1558	16	28	392	241	survey	1003	108
Timing	Winter	All seasons	Flock 1	Flock 2. Lambing period	All seasons	All seasons	All seasons	All seasons	lambing and winter
Dystocia /birth complications		10.2	37	32	4.1	X	x	8.7	12
Vaginal prolapse		7.7	19	43				2.3	
Pregnancy toxaemia		3[A]					x	10.9	
Mastitis		1.5	6	4		X		2.3	x
Cast		2.2	6					3.2	
Bloat			6					0.6	5
Malnutrition					17.9	X			
Internal Parasites	~13				1			0.6	
Pneumonia [A] / post shearing stress	~10	28.4[B]			1.5	X		9.5	16
Ovine Johne´s disease (OJD)	~18			4	64				
Cutaneous myiasis					0.8		x	1.4	
Misadventure		4.8	13	10	0.5	X		3.0	9
Photosensibili sation					0.3		x		
Liver damage	~12							2.1	
Clostridial toxaemia					0.3	X	x	7.5	x
Septicemia								2.0	
Exposure		0.8						3.9	
Chronic facial eczema								3.4	
Dog tucker [B]		24.5							
Killed for mutton [C]		0.8							
Salmonella outbreak		5.6						2.7	
Unknown	~23	9.2	13	7	7.4	X	x	8.6	11
Others [D]	~24	1.2			2.2	X		27.3	47*

[1] [A] Pneumonia or lung alterations. [B] Used for dog food. [C] Used for mutton. [D] Neoplasia, feet and teeth problems, encephalitis, peritonitis, hypothermia, middle ear infection, internal haemorrhage. [2]These were causes of ill-thrift from ewes in poor condition (BCS ≤2). ~ Approximately. [3] Causes reported and recorded by farmers; some are more related to wastage than ewe mortality. [E] Metabolic causes. [F] Dead due to poor condition (BCS~1), the main causes involved were OJD, parasites, poor teeth, poor feet and respiratory diseases. [4] Mixed-sex, >6 months-old X =reported as a cause of ewe mortality but not quantified

2.1.8. Common findings during necropsy

Necropsy is a useful tool to identify the potential causes of ewe mortality. Necropsy is the post-mortem examination of the organ systems, and it can provide information about the lesions of the organs and therefore the likely cause of death (Roberts, 2012). The procedure and methods of sheep necropsy have been described by Griffiths (2005) and Roberts (2012). Although necropsy may not provide a final diagnosis in all cases, it can suggest the most likely cause of death. Within 24 hours of death, however, changes that occur due to autolysis can negatively affect the post-mortem examination and exclude decisive findings (Otter and Davies, 2015). As a result, a delay between death and post-mortem examination can limit the effectiveness of necropsy in ewes in field conditions. Although autolysis occurs rapidly in warmer conditions, in animals with dense wool or high fat cover it can occur quickly even during cold conditions (Bush et al., 2006a; Ghazali, 2007; Otter and Davies, 2015). A summary of the post-mortem diagnostic technique used in this study, and recommended samples to take are summarised in Appendix Table A1.

2.1.9. Summary and purpose of the investigation

Ewe mortality has an economic impact on the New Zealand sheep industry. It has been estimated that a 1% reduction in ewe mortality could save the New Zealand sheep industry up to NZ$17.7 million per annum (Griffiths et al., 2017), and this value could be further increased if the value of their future lambs is also included (Young et al., 2014). To date, ewe mortality has received little attention in New Zealand, with most of the available literature being more than 30 years old. Although some recent research has identified the prevalence of some specific causes of ewe mortality, the data are limited (Gautam et al., 2018; Ghazali, 2007). Another point to consider is the tendency for ewe mortality to increase during the lambing period. Further studies are required to evaluate ewe mortality rates, timing and causes in New Zealand sheep farms and therefore, to develop strategies to decrease ewe mortality on New Zealand sheep farms.

Few studies have reported the relationship between ewe mortality and productive parameters such as live weight, body condition score (BCS), litter size, worm egg count (Doughty et al., 2019; Ghazali, 2007; Griffiths, 2020; Kelly et al., 2014; Morgan-Davies et al., 2008). Some associations between productive parameters and ewe mortality have been described in the available literature for example low body weight and BCS (<35 kg, <2.5, respectively), the incidence of fly strike, parasite status and cold conditions have been reported as a risk factor in Merino ewes in Australia (Doughty et al., 2019; Horton et al., 2018a; Horton et al., 2016; Kelly et al., 2014). However, there is a lack of information about risk factors for ewe death in New Zealand. Investigations into the risk factors and associations between productive parameters would be beneficial to allow strategic approaches to increase ewe survival rates on New Zealand sheep farms.

Simple tools need to be developed to help farmers to identify the causes of ewe death among their flocks (Ghazali, 2007). Further research in ewe mortality will allow us to propose management, nutritional and health strategies that farmers can use to reduce their ewe mortality rates, thereby increasing their lambing percentage and financial returns. Moreover, a reduction in ewe mortality will increase the animal welfare status of sheep on New Zealand farms and improve consumer trust in the sheep industry.

Considering the above, the general objective of this thesis was to investigate the ewe mortality on a commercial sheep farm in New Zealand. The specific objectives were: i) to quantify the ewe mortality rate and determine the time of death from pre-mating to weaning, ii) to establish causes of ewe mortality during the lambing period and iii) to investigate the association between productive parameters (live weight, body condition score, litter size) and ewe mortality.

2.2. Lamb mortality

2.2.1. Introduction

The national lambing percentage in New Zealand has increased from 97% in 1990 to 139% in 2019 (Stats NZ, 2019). This increase has contributed to higher returns to the New Zealand sheep industry, however, it has resulted in an greater proportion of multiple-born lambs which in turn have higher mortality rates than single-born lambs (Everett-Hincks et al., 2005; Kerslake et al., 2005). Lamb mortality around the time of birth is an unresolved issue that impacts sheep farmers' revenue and limits the opportunity for farm growth and development (Everett-Hincks and Duncan, 2008; Kerslake et al., 2010).

2.2.2. Rates of lamb mortality in New Zealand and its impact

Lamb losses have financial, productive and animal welfare implications (Gascoigne et al., 2017). Lamb mortality results fewer lambs being available for sale and hence a reduction in the kilograms of lamb produced per hectare per year. Moreover, the selection of replacement stock is affected due to the reduced number of ewe lambs available to select from (Hinch and Brien, 2014). In addition to the reduced profits due to lost lambs, additional economic impacts include the costs of feeding the dam during pregnancy, management and veterinary expenses, vaccination, drenching, and pregnancy scanning. It has been calculated that a decrease of 1% of pre-weaning lamb losses could correspond to at least $10 gross margin per hectare (Morel and Kenyon, 2006).

From a welfare perspective, lamb mortality is considered an indicator of animal well-being, as prior to death, lambs may experience sickness, hypothermia, hunger, trauma and/or pain (Dwyer, 2008; Mellor and Stafford, 2004). Further, the impact on the ewe has received little attention, but should also be considered due to the distress experienced in losing their lamb and an unemptied udder (Dwyer, 2008).

In New Zealand, overall lamb mortality rates have been reported to be between 5% to 30% from birth to weaning (Kerslake et al., 2005; Stevens, 2010). Up to 50% of these deaths have been reported to occur during the perinatal period (around birth) thus indicating the first day of life is the most critical period for lamb survival (Dwyer, 2008; Everett-Hincks and Duncan, 2008; Kerslake et al., 2010).

2.2.3. Risk factors of lamb mortality

Lamb birth weight is an important contributor to lamb mortality (Fogarty et al., 2000). Lamb birth weight has a U-shaped relationship with lamb survival meaning that both light and heavy lambs have a greater risk of death than intermediate-weight lambs (Dwyer, 2008). It is commonly reported that lambs with a high birth weight have a greater risk of death due to dystocia, while light lambs, particularly in twins and triplets, have a greater risk of death due to the starvation/exposure complex. However, some reports have also reported a high incidence of dystocia in multiple born lambs that are both above and lower than the mean birth weight (Horton et al., 2018b; Kerslake et al., 2005; Pettigrew et al., 2020; Stevens, 2010). The optimal birth weight for lamb survival varies according to their birth rank and dam age, for example, Pettigrew et al. (2018, 2020) based on recent studies and prediction modelling from New Zealand sheep suggested that optimal birth weight for single lambs born to ewe lambs would be between 3.9 and 5.5 kg, while the optimal birth weight for single lambs born to mature ewes has been reported to be between 4.3 to 7.4 kg to reach survival rates above 80%. Lambs with a birth weight of ≤ 2.5 kg have a higher risk of mortality, with survival rates around 40%, regardless of birth rank.

The age of the dam has also been found to impact lamb mortality. Some studies have reported among lambs born to ewe lambs mortality rates to docking were up to double those of lambs born to mature ewes (Corner et al., 2013; Everett-Hincks et al., 2014; Morel et al., 2010; Mulvaney, 2011; Pettigrew et al., 2018). Morel et al. (2010) reported mortality rate to docking of 19.4% for lambs born from ewes that were 1 year of age in comparison to 9.7% among lambs born to older ewes. Similarly, Corner et al., (2013) reported 69% lamb survival to weaning for lambs born to ewe lambs, in contrast to 83.3% for those born to mature ewes. Likewise, in another study, lamb survival to weaning was reported to be lower for lambs born to ewe lambs (47.3%) than those born to mature ewes (83.1%) (Pettigrew et al., 2018). It has been suggested that lambs born to ewe lambs are more susceptible to environmental conditions (Morel et al., 2010) and have a greater risk of mortality due to lower birth weights and reduced vigour compared to lambs born to mature ewes (Corner et al., 2013; Pettigrew et al., 2018; Pettigrew et al., 2020).

Undernourishment during pregnancy is associated with increased lamb losses. Maternal undernutrition can lead to foetal growth restriction (Kenyon, 2008), low lamb birth weight (Morris and Kenyon, 2004), less vigorous lambs (Dwyer et al., 2003), and hence an increased in lamb mortality . Further, dams with low BCS have been shown to have poorer maternal behaviour at birth than better conditioned ewes which can affect lamb survival (Dwyer et al., 2003). A recent study, however, has shown that the behaviour of twin- and triplet-bearing ewes and their lambs at 12 to 24 hours of age is not a reliable indicator of lamb survival (Gronqvist et al., 2019). Milk production is a key determinant of lamb growth and survival (McGovern et al., 2015b). Maternal undernutrition in late pregnancy has been associated with poor mammary gland development, sub-optimum production of colostrum (Kenyon et al., 2005) and reduced milk production over the lactation period. Overall, maternal nutrition from day 100 of pregnancy to term has the greatest impact on lamb birth weight and lamb mortality.

Other factors that can influence lamb mortality rates include the udder status of the dam, sex of the lambs and birth rank. The udder status of the ewe can impact on lamb mortality, with hardness or lumps in the udder being associated with an increase in lamb mortality (Griffiths et al., 2019). In addition, lamb sex is a risk factor for lamb losses, with studies reporting that male lambs have a higher risk of death than females across different breeds such as Romney (Pettigrew et al., 2018), Decanni (Bangar, 2016), Scottish Blackface (Sawalha et al., 2007), and crosses

(Southey et al., 2001). Several authors have also reported that lamb mortality increased as litter size increased, therefore, multiple-born lambs, particularly triplets, have greater mortality rates than singles (Kerslake et al., 2005; Pettigrew et al., 2018).

2.2.4. Causes of lamb mortality

Causes of lamb mortality vary between flocks, according to management practices, farm location, and weather. Some of the common causes of lamb death are dystocia, starvation/mismothering/exposure complex, organ rupture, suffocation (amnion over nose), disease, abnormalities and unknown (Everett-Hincks and Duncan, 2008; Kerslake et al., 2005; Refshauge et al., 2016). Of those, dystocia and starvation/exposure account for up to 74% of perinatal lamb deaths on New Zealand sheep farms (Kerslake et al., 2005; Stevens, 2010; Young et al., 2010). Causes of lamb death are not necessarily independent, for example, lambs that have a difficult birth can show poor suckling behaviour and low heat production and thus are at increased risk of death from starvation/exposure (Everett-Hincks and Duncan, 2008; Kenyon et al., 2019). Similarly, Kerslake et al. (2005) reported that lambs initially classified as dead due to starvation/exposure had signs of birth stress suggesting dystocia was the main cause of death. The distribution of lamb mortality according to each cause of death is summarised in Table 2.5.

Dystocia has been reported to be a cause of lamb mortality in all litter sizes (Everett-Hincks and Dodds, 2008; Horton et al., 2018b; Jacobson et al., 2020; Kerslake et al., 2005; Refshauge et al., 2016). Traditionally lamb deaths due to dystocia have been reported to be more common among single-born lambs with high birth weights, however, lamb losses in twin and triplet-born lambs have also been reported (Brown et al., 2014; Everett-Hincks and Dodds, 2008; Horton et al., 2018b; Jacobson et al., 2020; Kerslake et al., 2005). For instance, Horton et al. (2018b) reported that dystocia increased with litter size for low birth weight lambs whereas dystocia was unaffected by litter size for lambs with high birth weights. Dystocia is considered a multi-factorial issue (Kenyon et al., 2019), therefore, some factors that are involved including foetal pelvic disproportion, lamb conformation (Brown et al., 2014), a long birth process (Everett-Hincks et al., 2007) and ewe nutrition (Kenyon et al., 2019). Several authors have reported a high percentage of lamb death from dystocia occurring within three days of the lamb being born (Table 2.5).

The starvation/exposure complex is another important cause of lamb death, particularly among multiple-born lambs (Dwyer, 2008; Refshauge et al., 2016). Higher rates have been reported in twin and triplets lambs than singletons resulting in higher mortality rates (Everett-Hincks and Dodds, 2008; Refshauge et al., 2016). For example, a study of 20 New Zealand flocks by Kerslake et al. (2005) reported lamb losses of total lamb deaths due to starvation/exposure among singles, twins and triplet lambs were 20%, 29% and 27%, respectively. Lambs with low birth weights have a greater surface area to body mass ratio resulting in a greater heat loss to the environment which is further exacerbated by having lower body reserves (Hinch and Brien, 2014). In support of this Everett-Hincks and Dodds (2008) reported that the risk of death due to starvation/exposure was the highest for lambs born two kg lower than the mean birth weight (4.8 kg), while lambs born one kilogram above the mean had the lowest risk. In the same study the risk of starvation increased for twin lambs as the heat loss increased. This is supported by Kerslake et al. (2010) who reported that the lightest triplet-born lamb produced less heat and lost more heat during cold stress than heavier multiple-born lambs, due to its lower birth weight.

Combined, dystocia and starvation/exposure are the two main causes of lamb mortality in New Zealand, with either other or unknown causes accounting for the rest, however, the main causes of lamb losses should be evaluated for each farm. Determining the causes of lamb mortality on individual farms is essential for making decisions that will minimise future lamb losses, hence, post-mortem examination of dead lambs is recommended for determining mortality and can be undertaken with only a small amount of training (Gascoigne et al., 2017).

2.2.5. Conclusions

Although lamb mortality has been widely studied in New Zealand, with the majority of fatalities occurring in the first 3 days after birth, determining the causes of lamb mortality on each farm is recommended. Post-mortem examinations enable the determination of the main causes of lamb losses and allows for implementation of strategies to minimize lamb mortality according to each farm case. Those strategies may include increased ewe pregnancy nutrition, conducting pregnancy diagnoses, mid-pregnancy shearing, pre-mating udder palpation, shelter provision, and in the long-term, genetic selection.

Although the objective of this thesis was to investigate ewe mortality, this study methodology allowed a brief investigation of lamb mortality. Given this, a specific objective of this study was to determine the causes of lamb mortality around the lambing period on a commercial farm sheep farm in New Zealand

Table 2.5 Summary of studies conducted in New Zealand and overseas reporting the causes (%) of lamb mortality within the first days of age according to litter size (single, twins, triplets). Causes identified by necropsy or farmers observations. Adapted from Kenyon et al. (2019)

Author[1]	Dystocia			Starvation/ exposure			Dystocia /starvation exposure			Stillborn			Other or unknown			Country
	S	Tw	Tp	S	Tw	Tp	S	Tw	Tp	S	Tw	Tp	S	Tw	Tp	
Holst et al. (2002) [A]	33	14	24	10	23	22	49	49	44				8	14	10	Australia
Kerslake et al. (2005) [A]	61	49	50	20	29	27	7	9	9				12	13	14	New Zealand
Stevens (2010) [B]	53	12		10	41								37	47	100	New Zealand
Refshauge et al. (2016) [A]		27			30						21			22		Australia
Holmoy et al. (2017) [A]	48	30	29	5	5	7							47	65	64	Norway

[1] [A] Identified by post-mortem examination [B] by farmers observation

[S] Single [TW] Twins [TP] Triplets

3. Materials and methods

3.1 Farm and animals

The study utilised a cohort of 1789 two-tooth ewes (16 to 19 months of age at breeding) that were part of a commercial sheep flock located in the Waikato region of the North Island of New Zealand (latitude 37°47'65.18"S, longitude 174°75'76.72"E). The ewes were a Coopworth x Composite based breed. The physical features making up the topography of the farm used in the study were flat to rolling (46%), with easy hills (42%) and steep faces (12%) (Murray and Yule, 2007), with intervening gullies and streams. Figure 3.1 shows the predominant topography of the farm.

Figure 3.1 Topography of the sheep grazing land

Ewes were individually identified using both an electronic identification tag (Layout2, Shearwell, Minehead, United Kingdom) and a plastic numbered tag (Lazatag, Allflex, Palmerston North, New Zealand). Ewes were managed under commercial grazing conditions on pasture containing mostly perennial ryegrass (*Lolium perenne*) and white clover (*Trifolium repens*), and under routine commercial management on the farm for the duration of the study. All the procedures undertaken in the present study were approved by the Massey University Animal Ethics Committee (MUAEC 19/48).

3.2 Period of study and management.

The present study was undertaken from March to December 2019. Data was collected at seven key management times when the ewes were yarded for commercial management events. The visit dates and events are shown in Figure 3.2.

Ewes were bred with crayon-harnessed entire rams for 44 days, from 25 March 2019. Mature rams were used at a ram to ewe ratio of 1:80. Ewes were shorn in mid-pregnancy (3 June 2019). In addition, pregnancy diagnosis (PD) was conducted on 19 June 2019 using trans-abdominal ultrasound conducted by an experienced commercial operator. Ewes were diagnosed as either, non-pregnant, single, twin, or triplet-bearing. Ewes that were in an earlier stage of gestation, and therefore expected to lamb later, were also identified. Twin and triplet-bearing ewes were managed in one mob, while single-bearing ewes and those in an earlier stage of gestation were managed in another mob until set-stocking. On 6th August 2019, ewes were drafted into lambing groups based on litter size (single, twin and triplet-bearing) and managed separately under commercial conditions, with the intention of providing greater nutritional allowances for triplets, followed by twins and then singles. However, pasture allowances were not measured. Ewes that were non-pregnant at pregnancy diagnosis were culled (n=83), as standard management practice of the farm.

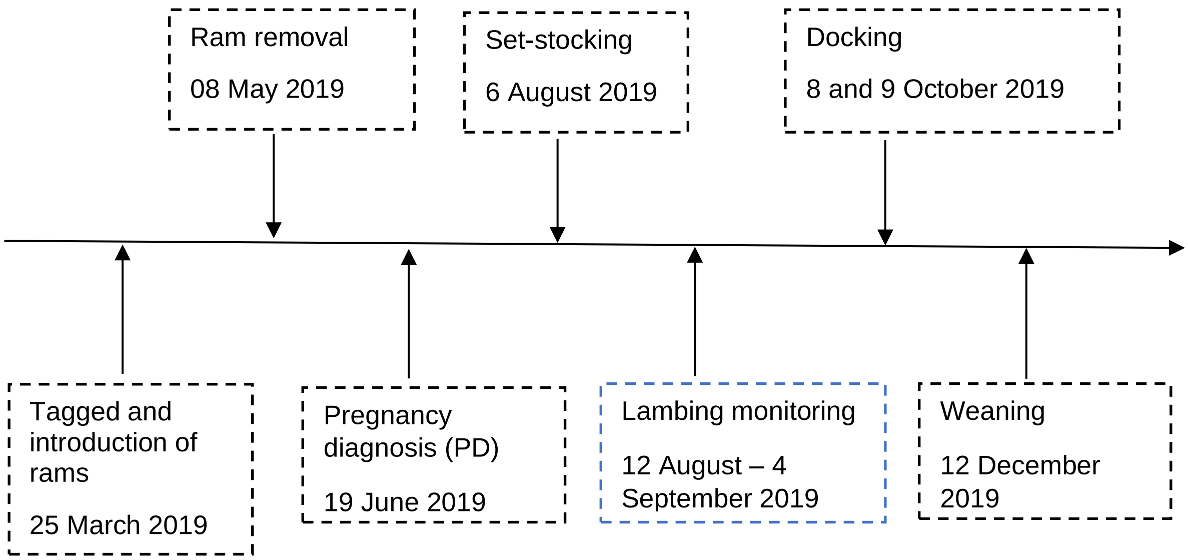


Figure 3.2. Visit dates and events for the ewe mortality study

Ewes were allocated to individual lambing paddocks (set-stocked) according to pregnancy rank 13 days before the expected start of lambing. The stocking rates were approximately 6.9, 5.7 and 6.1 ewes per hectare for single, twin and triplet-bearing ewes, respectively. Ewes diagnosed as late lambing were allocated to a single paddock regardless of pregnancy rank. Table 3.1 shows the paddock dimensions and stocking rates.

Table 3.1. Summary of lambing paddocks with the size (ha), the pregnancy rank of ewes (single, twin or triplet) in the paddock, the number of ewes allocated at set-stocking and the ewes per ha.

Paddock identifier	Paddock size (ha)	Pregnancy status	n ewes (approximately)	ewes/ha
1	14.38	Twin	84	5.8
2	21.06	Twin	188	8.9
3	16.19	Twin	127	7.8
4	24.07	Single	146	6.1
5	17.14	Twin	125	7.3
6	17.25	Single	140	8.1
7	13.54	Twin	101	7.5
8	32.4	Twin	146	4.5
9	51.24	Twin	178	3.5
10	10.57	Twin	66	6.2
11	27.15	Late[1]	277	10.2
12	15.29	Triplet	93	6.1

[1] The late lambing paddock included single, twin and triplet-bearing ewes.

Intensive monitoring was undertaken by researchers once per day from 10 days before the planned start of lambing, and during the first 16 days of the lambing (from 12th August to 4th September 2019), (see section 3.3 for details). Post-mortem examinations of all dead ewes and lambs were undertaken (see section 3.4 for a description of the post-mortem examination).

On 8th and 9th November 2019, ewes and their lambs were yarded to allow the lambs to be tail docked. At the same time, the udder of each ewe was palpated and ewes were identified as either non-lactating (dry) or lactating (wet). Lambs were weaned on either 12 or 13 December 2019, 115 days after the start of the lambing period. At weaning, the ewe lactational status (wet or dry) was determined.

3.3 Live body weight and body condition score measures

Live weight and body condition score (BCS) were recorded by researchers at six visits: 1) ram introduction 2) ram removal 3) pregnancy diagnosis (PD) 4) set-stocking 5) docking and 6) weaning (Figure 3.2). Ewes were weighed to the nearest 0.5 kg in a commercial weight crate (Racewell™, Te Pari, Oamaru, New Zealand). Ewe BCS was determined using a 5-point scale (in 0.5 intervals), indicating a score of 1 for being emaciated and 5 for being obese (Jefferies, 1961; Kenyon et al., 2014; Russel, 1984). The BCS measurements were undertaken by the same experienced technician at all six time points. Ewes with no weight or BCS recorded at two consecutive events were considered **missing ewes** unless their body was found.

3.4 Monitoring during lambing

For 26 days during the lambing period, all ewes were observed once a day by a researcher using a variety of techniques: visually using binoculars, driving or walking through the mob, and from aerial images collected using a drone. The drone (DJI Phantom 4, Da Jiang Innovations, Shenzhen, China) was flown over paddocks that had several gullies or where access was difficult. The maximum altitude of each drone flight was 100 meters above sea level, to comply with the Civil Aviation Authority of New Zealand (CAA) and the Ministry of Transport guidelines for flying unmanned craft (CAA, 2018). Observations began 10 days prior to the planned start of lambing to allow for ewes to acclimate to the presence of the researchers and the drone. During this adaptation period, researchers walked through the paddocks once per day and flew the drone when the weather permitted. Ewes identified as requiring intervention were restrained and assessed. This assessment considered the severity of any presenting conditions, and ewes were either treated if possible or euthanised on welfare grounds.

A scoring system was developed to record ewe interventions made during the lambing season. Interventions were classified as: (a) ewe would have survived without intervention; (b) ewe most likely would have died without intervention (Probably dead); or (c) ewe would have died without intervention (Dead). Scoring systems for ewes that successfully underwent an intervention according to each cause are described in Tables 3.2, 3.3, 3.4 and 3.5. These tables show the likely outcome for a ewe if no intervention had been undertaken to resolve a ewe being cast (accidental immobilisation in dorsal recumbency) (Table 3.2), experiencing dystocia (birthing difficulties) (Table 3.3), experiencing a vaginal prolapse (Table 3.4) or being identified as having mastitis (Table 3.5). The ewes that were classified as dead and probably dead in the scoring system were entered in the category of "assumed dead**"** for the statistical analysis.

Table 3.2. Scoring scale for ewes being cast, according to their vigour, manipulation needed to resolve the cast, time to walk, and the likely outcome without intervention.

Score	**Vigour[1]**	**Manipulation[2]**	**Time to walk**	**Likely outcome for ewe[3]**
0	Strong	Ewe righted herself, stands by itself	N/A	Alive
1	Strong	Required a light push	N/A	Alive
2	Medium	Required a light push	N/A	Alive
3	Weak	Required a Medium push. Reacted to human presence	Less than 3 minutes	Probably dead
4	Weak	Required a medium push. No reaction to human presence	More than 3 minutes	Dead
5	None	Required a hard push. No reaction to human presence	More than 3 minutes	Dead

[1] Effort made by ewe in her attempt to stand up. **Strong**: ewe with continuous movement. **Medium:** ewe spends 50% to 90% of the time moving. **Weak**: less than 50% of the time moving.
[2] Required in order to resolve the cast.
[3] In the absence of intervention

Table 3.3. Scoring scale for ewes that experienced dystocia, according to the traction and intervention required and the likely outcome without intervention.

Score[1,2]	Traction[3]	Intervention[3]	Description	Likely to have lambed? [4]	Likely outcome for ewe[4]
1	Unassisted	No	Delivery of long duration >30 min	Yes	Alive
2	Easy pull	Minor	N/A	Maybe	Alive
3	Moderate pull	Moderate	Accurate presentation	Probably not	Probably dead
4	Hard pull	Major	Malpresentation	No	Dead
5	Hard pull	Major	Difficult resolution (i.e. ring womb)	No	Dead

[1]Adapted from Horton et al. (2018b). LambEase (ease of lambing) score. [2]Adapted from Matheson et al. (2011). Birth assistance scores. [3] Required in order to resolve the dystocia. [4]In the absence of intervention.

Table 3.4. Scoring scale for ewes with vaginal prolapse, clinical grading scale, manipulation required, and the likely outcome for the ewe without intervention.

Score	Clinical Grading Scale [1]	Manipulation[2]	Likely to have lambed?	Likely outcome for ewe[3]
1	Intermittent prolapse of vagina, common when lying down	Minor. Light push to resolve	Maybe	Probably dead
2		Minor. Moderate push, no resolution	No	Dead
3	Continuous prolapse of vagina, urinary bladder retroflexed. Presence or not of trauma, infection or necrosis of the vaginal wall	No manipulation, euthanised	No	Dead

[1.] Reproduced from Miesner and Anderson (2009) [2] Required in order to resolve the vaginal prolapse [3] In the absence of intervention

Table 3.5. Scoring scale for ewes with mastitis, clinical grading scale, manipulation required, and the likely outcome for the ewe without intervention.

Score	Inspection (Udder symmetry and volume)	Palpation	Likely outcome for ewe[1]
1	Abnormal	Normal	Alive
2	Abnormal	Lumps or hard consistency. No inflammation or heat	Alive
3	Abnormal	Udder inflammation ±abnormal milk or purulent discharge	Probably dead
4	Abnormal	Abnormal. Black mastitis	Dead

[1] In the absence of intervention

3.5 Post mortem examination

During the lambing period, all dead ewes were examined and a necropsy was undertaken in the field to identify the most probable cause of death. The necropsy was based on the technique described by Griffiths (2005) and Roberts (2012). Biopsies and tissue samples were not collected for further pathology analysis, rather the cause of death was determined from the field autopsy and daily observations of the flock. All found bodies of ewes were classified as 'confirmed dead**'.** Lamb post-mortem examinations were also undertaken in the field. Information from live lambs was not recorded. The lamb necropsy and diagnosis of the primary cause of death was based on the protocol described by Everett-Hincks and Duncan (2008). Appendix Table A2 and Table A3 contain the ewe and lamb necropsy forms used in the study.

3.6 Data management and statistical analysis

All analyses were conducted using SAS software (Statistical Analysis System, version 9.4.01; SAS Institute Inc., Cary, NC, USA). In order to generate descriptive statistics and check normality, the UNIVARIATE procedure was used for each variable. The collected data suggested normal distribution and levels of skewness and kurtosis were minor. However, the tests for normality (Shapiro-Wilk, Kolmogorov-Smirnov, Cramervon Mises, and Anderson-Darling) indicated a departure from normality ($p<0.05$). Although several transformations (square, square root, cube root, logarithm) were used in trying to normalise the data, the goodness-of-fit tests showed non-normal distributions, greater skewness and kurtosis. Therefore, recorded data that were not transformed were used for the analysis, because they had the closest distribution for normality (Kolmogorov-Smirnov D=0.052).

Live weights greater than three standard deviations above or below the mean were considered outliers and were deleted. A total of thirty-nine live weight data points of the 9912 collected were deleted from the database (pre-mating n=5, ram removal n=8, pregnancy diagnosis n=5, set-stocking n=3, docking n=11 and weaning n=7). Moreover, the recorded data of ewes that were not-pregnant were excluded from most of the models, unless their inclusion is stated.

3.6.1 Missing ewes, assumed dead and confirmed dead.

The ewes were classified as alive or dead according to their presence or absence at each weighing event. The ewes were considered dead if entered in one of the following categories: i) 'missing ewes': no weight or BCS recorded at two consecutive weighing events, ii) 'assumed dead': ewes that would have died without intervention (section 3.4), or iii) 'confirmed dead': known to have died because the body was found. Therefore, the mortality rate was based on the number of missing ewes, assumed dead and confirmed dead.

The percentage of missing ewes were calculated using the following equation:

$$Ewes\ missing\ \% = \frac{number\ of\ missing\ ewes\ from\ time\ 1\ to\ time\ 2}{number\ of\ ewes\ at\ time\ 1} * 100.$$

The ewe mortality rate across the whole study period, and the mortality rate between timer periods were calculated with the following equations:

$$Ewe\ mortality\ study\ \% = \frac{number\ of\ missing\ ewes + assumed\ dead + actual\ dead\ \ during\ the\ study}{number\ of\ ewes\ at\ the\ start\ of\ the\ study} * 100$$

$$Ewe\ mortality\ between\ time\ 1\ and\ 2\ \% = \frac{number\ of\ dead\ ewes\ (missing + assumed\ dead + actual\ dead)\ from\ time\ 1\ to\ 2}{number\ of\ ewes\ at\ time\ 1} * 100\ .$$

The percentage of ewe mortality and percentage of missing ewes after pregnancy diagnosis was calculated from the number of ewes that were diagnosed pregnant, as non-pregnant ewes were culled. Culling was not included as ewe mortality.

3.6.2 Ewe live weight

Ewe live weight differences between alive and dead ewes were assessed using the MIXED procedure for repeated measure analysis of SAS. Only live weight recordings from pre-mating to docking were included, and non-pregnant ewes were excluded. The status (alive or dead), weighing events (pre-mating, ram removal, pregnancy diagnosis, set-stocking and docking), litter size (1,2,3) and mating cycle (early or late) were included as fixed effects. Ewe identification was included as a random effect. All possible two-way interactions between the fixed effects were tested. Several models were tested, and selection of the final model was based on their AIC with only interactions of interest included in the model. Three-way interactions were not included in the final model.

3.6.3 Conceptus adjusted ewe live weight

Ewe conceptus adjusted live weight (CALW), also known as conceptus free live weight, was calculated to remove the influence of the weight of the conceptus on ewe live weight during pregnancy. Conceptus weight for each ewe at post-mating, pregnancy diagnosis and set-stocking was estimated using an equation based on the estimation of Freer et al. (1997) as follows:

$$Conceptus\ weight\ = lamb\ birth\ weight\ x\ \ 1.43^{13.38}\ \left(1^{-0.91}\left(1 - \frac{days\ pregnant}{146}\right)\right).$$

Based on existing New Zealand research, lamb birth weight was assumed to be 5.8 kg, 4.7 kg and 4.1 kg for single, twin and triplets-bearing ewes, respectively (Schreurs et al., 2012). Days of pregnancy were calculated based on the mid-point of the mating cycle (first oestrous cycle = first 17 days of the breeding period or second cycle = 18 to 34 days). Change in CALW (g/day) during mating, from ram removal to PD, and from ram removal to set-stocking were calculated using the following equation:

$$Change\ in\ CALW\ (\frac{g}{day}) = \frac{(CALW\ time\ 2 - CALW\ time\ 1)}{number\ of\ days\ between\ time\ 1\ and\ 2} * 1000.$$

Mixed models for repeated measures were implemented to compare CALW and changes in CALW between alive and dead ewes using the MIXED procedure of SAS. The fixed effect, random effect and interactions were the same as the live weight model (section 2.5.4), but only those which were significant were retained in the final model.

3.6.4 Body condition score

Ewe BCS was analysed using the GEMOD procedure in SAS using a poisson distribution. The model included the fixed effects of ewe status (alive or dead), and events when BCS was measured (pre-mating, ram removal, pregnancy diagnosis, set-stocking and docking) The model was run with two-way interactions. The identification of the ewe was included as a random effect in the model.

3.6.5 Associations between productive parameters and ewe mortality

Associations and risk of death were assessed using the LOGISTIC procedure. The outcome variable was the status of the ewe at the end of the study (alive or dead), and the odd ratios were modelled based on the risk of the ewe being dead. Firstly, univariate analysis was implemented for several variables (live weight, CALW, BCS from each weighing time, change in CALW, litter size, mating cycle) to inspect their association and odd ratio (OR) with the outcome variable.

Variables that were associated in the univariate analysis ($p < 0.2$) were used to build the preliminary multivariable models. The models were explored using the stepwise, forward and backward options, with variables retained if p values were $p<0.1$ in the Wald test. The selection and fit of the models were assessed using the Hosmer and Lemeshow goodness of fit test, and the Akaike Information Criterion (AIC).

3.6.6 Ewes that were cast

The data from ewes that were cast and those that were alive were included in the models that are described in this section. Non-pregnant ewes, missing ewes and those that died from other causes were excluded from the analysis. Only ewe live weight and BCS recorded from pre-mating to set-stocking were included.

A mixed model was assessed using the MIXED procedure, to evaluate the ewe's live weight and the CALW differences between ewes that were cast and ewes which were alive. The fixed effects included were as follows: ewe being cast (yes or no), weighing events (pre-mating, ram removal, pregnancy diagnosis, and set-stocking), litter size (1, 2, and 3), and mating cycle (first, second). Two-way interactions were included. The final model was chosen based on the AIC result. Differences in the BCS were inspected using the GEMOD procedure in SAS using a poisson distribution. The fixed effects were ewes being cast (yes or no) and weighing events. The ID of the ewes was included as a random effect and the two-way interaction was included. Associations between productive parameters and the risk of being cast were analysed using univariate analysis.

3.6.7 Lamb mortality

Lamb mortality data were collected from 126 dead lambs. Information from the live lambs was not recorded. Information from two lambs was not included in the analysis, due to partial predation. However, it was included in the calculation of the mortality rate. The estimated lamb mortality rate was calculated using the following equations, that were adapted from Thrusfield and Christley (2018) :

$$\begin{aligned} &\textit{Number of lambs lost between PD and docking} \\ &\qquad = \textit{number of lambs at PD} - \textit{number of lambs at docking} \end{aligned}$$

$$Lamb\ mortality\ rate\ from\ PD\ \ to\ docking = \frac{Number\ of\ lambs\ lost\ from\ PD\ to\ docking}{number\ of\ lambs\ at\ PD} * 100$$

$$Lamb\ mortality\ during\ the\ lambing\ monitoring\ (LM)\ = \frac{(number\ of\ \ dead\ lambs\ recorded\ during\ LM)}{number\ of\ lambs\ at\ PD} * 100\ .$$

The relationship between the birth rank and the cause was assessed using Chi-square analysis and likelihood ratio chi-squares. Differences in the weight of dead lambs were assessed using the GLM procedure for factorial fixed effects in SAS. The birth rank (twin or triplet), cause and sex (male or female), were included as fixed effects. Two-way interactions between the fixed effects were tested but only interaction between birth rank and cause was included in the model due to its significance. Differences in the weight of dead lambs caused by dystocia among birth rank was evaluated using GLM in SAS for completely randomized design.

Associations between weight and the risk of the dead lambs falling into dystocia or starvation/exposure category were evaluated using the LOGISTIC procedure. Two different univariate analyses were done, one for lambs' death for dystocia and the other for starvation/exposure. The outcome variable was the cause of lamb's death (dystocia or all others; starvation/exposure or all others) and the explanatory variable was weight. Multivariable models were not built due to small sample size in the litter size group that could affect the power of the model.

3.6.8. Weather analysis

A descriptive analysis of the weather data in the farm is shown in the results section, including daily rainfall, daily maximum temperature, daily minimum temperature and daily mean wind speed at 10 metres. The data were downloaded from the Virtual Climate Station Network (VCSN) of the New Zealand's National Climate Database (NIWA) which was calculated from measurements of nearby monitoring stations.

4. Results

4.1 Alive and dead ewes

A total of 1789 ewes were enrolled in the study with 1603 remaining eight and a half months later, at weaning. A total of 103 ewes were considered to have died during the study. Ewes considered to be dead were classified as either missing (n=51), assumed dead (n=26) or confirmed dead (n=51) (Table 4.1). It is important to note that the number of ewes that were weighed and condition scored at each time point may differ from the number of ewes considered alive, due to missing data at each weighing event (see Appendix Table A4 for more detail).

The calculated ewe mortality rate during the study was 5.7% (103/1789), with 52.4% (54/103) of deaths occurring between set-stocking and docking. The period between ram removal and PD accounted for the second-highest rate of ewe mortality (19.4%, 20/103). Ewes were culled if they were non-pregnant at pregnancy diagnosis (n= 83). Ewe mortality rate ranged from 0.2% to 3.2% between each weighing event (pre-mating, ram removal, PD, set-stocking, docking and weaning) (Table 4.2).

Overall, ewe survival declined markedly after set-stocking (Figure 4.1A). When culling as a result of PD result was included (which occurred post PD) in the analysis, there was a sharp decrease in the number of ewes after pregnancy diagnosis (Figure 4.1B). Of ewes that were recorded as having died during the study, missing ewes (missing at two consecutive weighing events) accounted for 49.5% (51/103) of the overall ewe mortality.

Table 4.1. Number of ewes classified as alive and dead, for those classified as dead whether they were classified as missing, assumed dead or confirmed dead at each weighing event (pre-mating, ram removal, PD, set-stocking, docking and weaning)

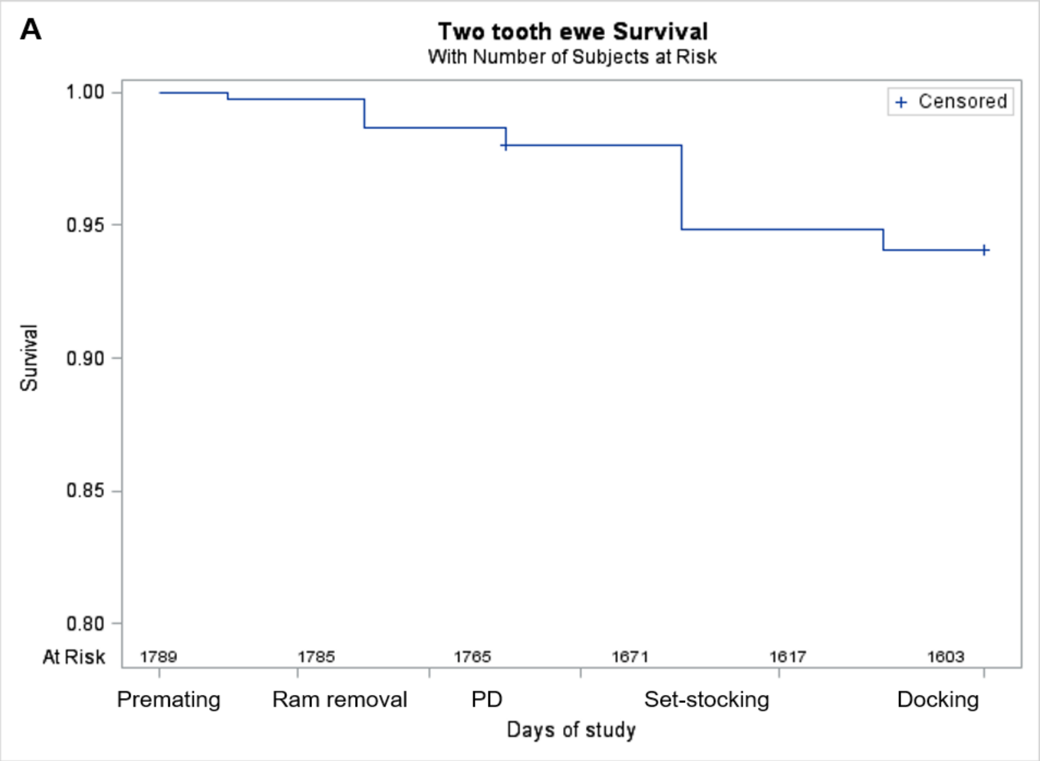
Ewe status	Pre-mating	Ram removal	PD	Set-stocking	Docking	Weaning	Total
Alive	1789	1785	1765	1671	1617	1603	N/A*
Dead	N/A	4	20	11	54	14	103
Missing		4	18	10	7	12	51
Assumed dead		0	0	0	26	0	26
Confirmed dead		0	2	1	21	2	26

*N/A not applicable

Table 4.2 Ewe mortality between weighing events and the distribution of the dead ewes during the study

	Pre-mating to ram removal	Ram removal to PD	PD to set-stocking	Set-stocking to docking	Docking to weaning	Total
Ewe mortality	0.2% (4/1789)	1.1% (20/1785)	0.6%* (11/1765)	3.2%* (54/1671)	0.9%* (14/1617)	5.7% (103/1789)
Percentage of ewe deaths	3.9% (4/103)	19.4% (20/103)	10.7% (11/103)	52.4% (54/103)	13.6% (14/103)	100% (103/103)

* Culled ewes were not included in the calculation of ewe mortality rate.



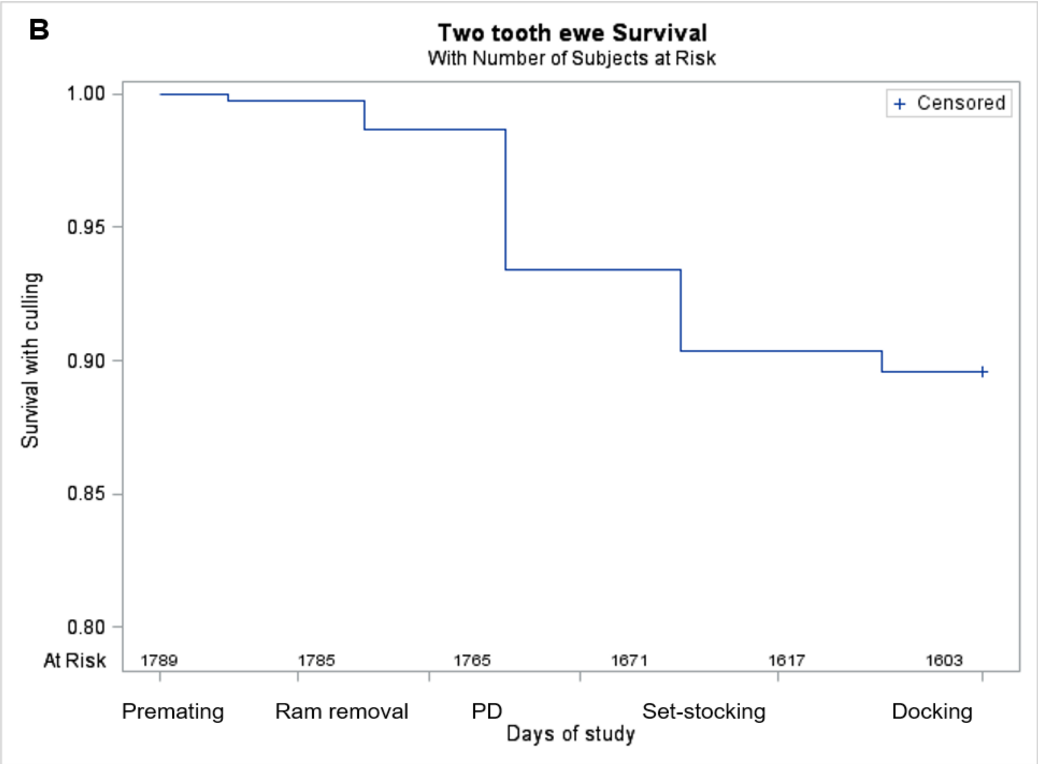


Figure 4.1 Survival curves showing the number of ewes present at each weighing event. (A) Survival, with no culling. (B) Survival with culling for non-pregnant ewes at PD.

4.2 Cause of death of ewes between set-stocking and docking

A total of 54 ewes were considered to have died between set-stocking and docking. Of those ewes, 7 were classified as missing, 26 assumed dead and 21 confirmed dead. Cause of death was identified for 47 ewes that were assumed or confirmed dead (Table 4.3). Evaluation of the causes of death, therefore, was possible for 87 % (47/54) of the ewes that were classified as having died between set-stocking and docking.

The main cause of ewe death during the monitored lambing period was due to the ewe becoming cast (66%, 31/47). Of the cast ewes, 26 were rescued due to intervention (assumed dead) while 5 were found dead (confirmed dead). Vaginal prolapse, commonly known as a bearing, was the next most common cause of death (17.1%, 9/47) while dystocia was the third most common (Table 4.3).

Table 4.3. Causes of ewe death for 47 ewes assumed or confirmed dead, during the period of monitored lambing through to docking.

Causes of death	Frequency of ewes (n)	Percentage
Cast *	31	66.0%
Vaginal prolapse	9	19.1%
Vaginal prolapse/Dystocia[#]	2	4.3%
Dystocia	3	6.4%
Thorax haemorrhage	1	2.1%
Unknown	1	2.1%
Total	47	100%

***** 4 ewes were twice found to be cast. They were only included once in the frequency

[#] It could not be determined if dystocia contributed to the vaginal prolapse, or vice-versa

4.3 Weight and Body condition score (BCS)

4.3.1 Ewe liveweight and BCS

At the cohort level, the ewe live weight and BCS distribution changed over time ($P < 0.05$). Mean ewe live weight was lower ($P<0.05$) at pregnancy diagnosis than at other weighing events and it was greatest at set-stocking ($P<0.05$). Mean ewe body condition score was lower ($P<0.05$) at docking than at other weighing events and greater ($P<0.05$) at ram-removal and weaning, with no differences between the last two (Table 4.4). The number of ewes weighed, and the number of ewes at each BCS category are shown in Appendix Table A4, Table A5 and Figure A1.

Table 4.4. Live-weight (kg; mean ± standard error) and body condition score (mean ± lower and upper mean) at each weighing and measurement events (Pre-mating, ram removal, PD, set-stocking, docking and weaning).

Time	n	Weight [1]	n	BCS[1]
Pre-mating	1612	56.0^{b} ± 0.14	1552	2.70^{b} (2.65-2.75)
Ram removal	1740	57.4^{c} ± 0.13	1672	2.97^{e} (2.92-3.02)
Pregnancy diagnosis	1739	55.0^{a} ± 0.13	1663	2.83^{d} (2.78-2.88)
Set-stocking	1638	65.5^{e} ± 0.14	1657	2.80^{c} (2.75-2.85)
Docking	1551	57.9^{d} ± 0.14	1562	2.34^{a} (2.30-2.38)
Weaning	1593	61.4^{f} ± 0.14	1602	2.97^{e} (2.92-3.03)

[1] Values with different superscripts within a column indicate significant differences ($p<0.05$) between time.

4.3.2 Conceptus adjusted ewe live weights (CALW)

CALW differed ($P<0.05$) across weighing events. The CALW was lower ($P<0.05$) at PD than at all other points (Table 4.5).

Table 4.5. Live-weight (kg; mean ± standard error) at pre-mating, docking and weaning and CALW (kg; mean ± standard error) at ram removal, PD and set-stocking)

Time	n	CALW[1] /Live weight
Pre-mating	1612	56.0^{b} ± 0.14
Ram removal	1740	57.0^{c} ± 0.13
Pregnancy diagnosis	1739	53.1^{a} ± 0.13
Set-stocking	1638	57.9^{d} ± 0.14
Docking	1551	57.9^{d} ± 0.14
Weaning	1593	61.4^{e} ± 0.14

[1] Live weight at pre-mating, docking and weaning, and CALW at ram removal, PD and set-stocking. [ab] Values with different superscripts indicate significant differences (P<0.05).

4.3.3 Ewe live weight and BCS of alive and dead ewes

Ewes that died at any time point during the study had lower (P >0.05) mean live weight at ram removal than alive ewes (Table 4.6), although the interaction between the status and the weighing events was not significant (P >0.05). The body condition score of alive and dead ewes did not differ at any time (P >0.05) (Table 4.6). In addition, the live weight of ewes did not differ with mating cycle (P >0.05) but differed according to litter size (P<0.05).

4.3.4 Conceptus adjusted live weights (CALW) of alive and dead ewes

The CALW differed between alive and dead ewes at ram removal, and docking (P >0.05) (Table 4.6). The CALW differed between weighing times (P<0.05) and litter size (P<0.05). However, the fixed effect of mating cycle (first or second) was not significant (P >0.05). The two-way interaction between the status and weighing events on the CALW was not significant (P >0.05).

Table 4.6. Live-weight (kg; mean ± standard error), conceptus adjusted live weight (kg; mean ± standard error), and BCS (mean ± lower mean, upper mean), of alive and dead ewes at each weighing event (Pre-mating, ram removal, PD, set-stocking, docking).

	Weighing event									
	n	Pre-mating	n	Ram removal	n	Pregnancy Diagnosis	n	Set-stocking	n	Docking
					Live weight					
Alive ewes	1445	56.8 ± 0.21 ^{c}	1564	58.3 ± 0.21 ^{d}	1579	56.1 ± 0.21 ^{ab}	1570	66.4 ± 0.21 ^{f}	1537	58.8 ± 0.21 ^{e}
Dead ewes	95	55.2 ± 0.93 ^{abc}	95	56.0 ± 0.93 ^{bc}	78	54.4 ± 0.92 ^{a}	68	65.5 ± 0.94 ^{f}	14	55.8 ± 1.37 ^{abc}
					Conceptus adjusted live weight					
Alive ewes	1445	57.0 ± 0.21 ^{cd}	1564	58.1 ± 0.21 ^{e}	1579	54.2 ± 0.21 ^{ab}	1570	58.9 ± 0.21 ^{fg}	1537	58.9 ± 0.21 ^{g}
Dead ewes	95	55.5 ± 0.93 ^{bc}	95	55.9 ± 0.93 ^{bc}	78	52.6 ± 0.93 ^{a}	68	57.8 ± 0.94 ^{defg}	14	56.2 ± 1.36 ^{bvdef}
					Body Condition Score					
Alive ewes	1457	2.71^{b} (2.68-2.73)	1577	2.97^{gh} (2.95-2.99)	1584	2.83^{df} (2.81-2.86)	1589	2.80^{bcdef} (2.78-2.83)	1548	2.34^{a} (2.32-2.36)
Dead ewes	95	2.71^{bcf} (2.59-2.84)	95	2.98^{h} (2.87-3.08)	79	2.85^{egf} (2.73-2.97)	68	2.75^{ce} (2.65-2.86)	14	2.28^{a} (2.12-2.45)

^{abcdefgh} Values with different superscripts within subheadings indicate significant differences e for each group of ewes.

4.3.7 Change in conceptus adjusted live weight

The change of CALW was greater ($P < 0.05$) for alive ewes than dead ewes at mating and tended to differ (p 0.065) at ram removal (Table 4.7 and Figure 4.2).

Table 4.7. Change in CALW (g/day; mean± standard error) of alive and dead ewes at different periods (mating, ram removal to PD, PD to set-stocking and set-stocking to docking)

	Change in CALW (g/day)			
Period	N	Alive	n	Dead ewes
Mating	1459	23.9^{b} ±1.6	81	3.4^{a} ±6.4
Ram removal to PD	1594	-89.9 ±1.5	74	-76.5 ± 6.9
PD to set-stocking	1529	9.8±1.5	68	10.6 ±7.2
Set stocking to docking	1486	-0.01±1.5	14	-0.9 ±16.0

^{ab} Values with different superscripts across rows indicate significant differences ($P < 0.05$) between alive and dead ewes within time.

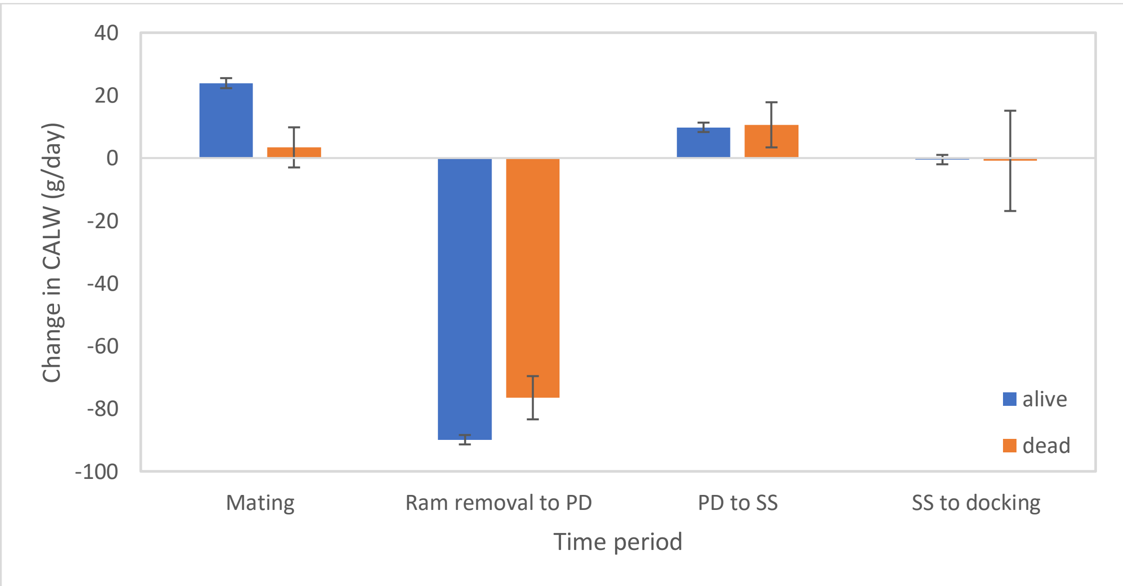


Figure 4.2. Change in CALW (g/day; mean± standard error) of alive (blue) and dead (orange) ewes at different weighing events (mating, ram removal to PD, PD to set-stocking and set-stocking to docking)

4.4 Associations between productive parameters and ewe mortality

4.4.1 Risk of death

4.1.1.1 Weight and CALW

There was no association (P >0.05) between ewe live weight or CALW at pre-mating, pregnancy diagnosis or set-stocking and the risk of death during the study. Ewe live weight and CALW at ram removal tended (p=0.06, p=0.07, respectively) to be negatively associated with the risk of death. This finding suggests that the odds of death during the study was 4% lower (OR=0.96 (95% CI=0.928-1.004); p=0.07)) for each unit increase of CALW at the time of ram removal. A similar result was found for each unit increase of ewe live weight (OR= 0.96 (95% CI=0.926-1.002); p=0.06) (Figure 4.3).

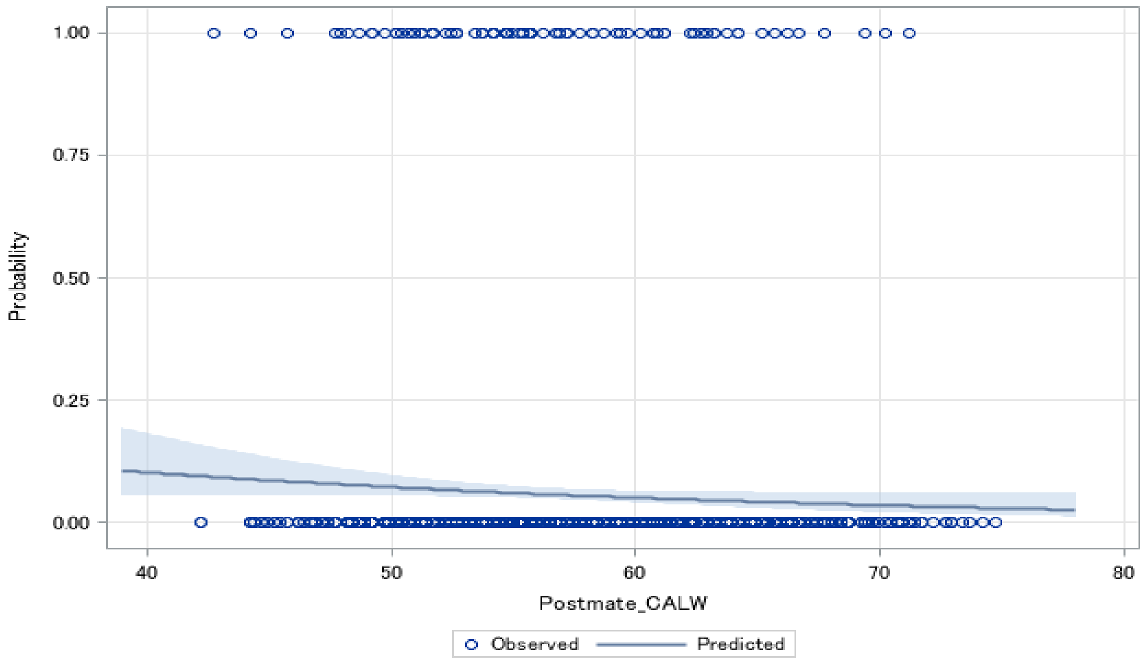


Figure 4.3. Association between ewe CALW at ram removal and the probability of death during the end of the study. The solid line shows the predicted risk with the light blue shading indicationg the 95% CI.

4.4.1.2 Change in CALW

The risk of death during the study period decreased with increasing changes in CALW between pre-mating and ram removal (OR=0.997 (95% CI=0.94-1.0): P < 0.05)

(Figure 4.4). There was, however, no influence (P >0.05) in change in CALW from ram removal to PD, PD to set-stocking or set-stocking to docking on the risk of death.

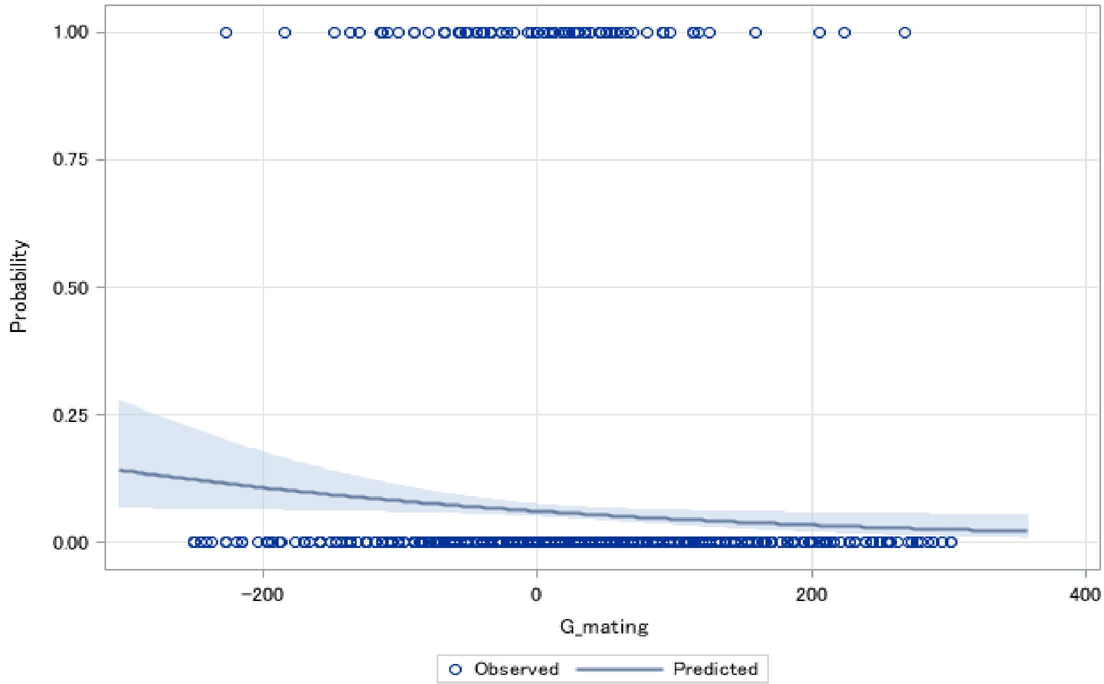


Figure 4.4. The association between CALW during mating and the probability of death during the study. The solid line indicates the predicted risk and the light blue shading the 95% CI.

4.4.1.3 BCS

There was no association between BCS at pre-mating, PD, set-stocking, or docking and the risk of death during the study (P >0.05). There was a tendency (p=0.08), however, for an association of BCS at ram removal and ewe death. The odds of death were lower (p<0.05) for ewes with a BCS > 2.0 compared with those with BCS ≤ 2.0 (Table 4.8).

Table 4.8. The odds (95%CI) of death for ewes in each body condition score group at pre-mating, ram removal, pregnancy diagnosis and set-stocking.

BCS group	Pre-mating	Ram removal	Pregnancy diagnosis	Set-stocking
≤ 2	ref	ref	ref	ref
2.5	0.96 (0.53-1.74)	0.38 (0.15-0.98) *	1.00 (0.43-2.30)	0.79 (0.35-1.77)
3	0.98 (0.50-1.90)	0.27 (0.10-0.70) *	0.76 (0.31-1.83)	0.66 (0.28-1.54)
3.5	0.50 (0.19-1.31)	0.36 (0.13-0.98) *	0.95 (0.36-2.53)	1.03 (0.41-2.59)
≥4	1.86 (0.73-4.74)	0.25 (0.06-0.94) *	1.49 (0.50-4.40)	N/A

* Odds ratio is significantly different to the reference group (BCS ≤ 2 ($p<0.05$) N/A not applicable, CS ≥4 was included in category 3.5 at set-stocking due to low numbers.

4.4.1.4 Litter size and mating cycle

There was an association between the litter size identified at pregnancy diagnosis and the odds of ewe mortality during the study ($P<0.01$). The odds of death were greater ($P<0.05$) for multiple than single-bearing ewes. Twin-bearing ewes had more than twice the odds of death compared with single-bearing ewes. Similarly, triplet-bearing ewes had more than three times the odds of death than. single-bearing ewes (Table 4.9). There was no association between the mating cycle and the odds of ewe mortality ($P>0.05$).

Table 4.9. The odds (95% CI) of death of ewes diagnosed with single, twin or triplet fetuses at pregnancy diagnosis.

Litter size at PD	Odds ratios – Singles as reference group	Odds ratios - triplets as reference group
Single	ref	0.22 (0.09-0.54) **
Twins	2.05 (1.01-4.19) *	0.45 (0.23-0.87) *
Triplets	4.49 (1.89-10.96) **	Ref

* Odds ratio is significantly different to reference group ($p<0.05$) ** ($p<0.01$)

4.4.1.5 Multivariable models

The association of ewe mortality over the entire study period with ewe live weight and CALW were assessed using two models. The first included the ewe live weight at ram removal and litter size. The second included CALW at ram removal and litter size. There was a tendency (p=0.1) for an association between both live weight at ram removal (OR=0.96 (95% CI=0.922-1.0) p=0.1) and CALW at ram removal (OR=0.96 (95% CI=0.923-1.0) p=0.1) with ewe death during the study (Figure 4.5)

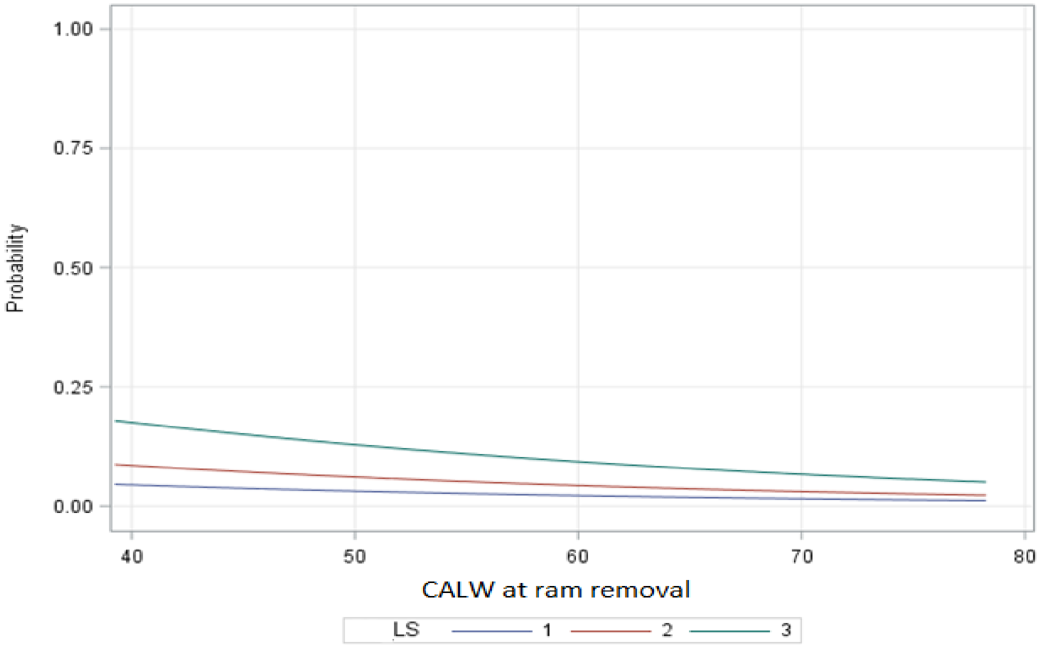


Figure 4.5. Association between CALW at ram removal for each litter size (single, twin and triplet) and the risk of dying over the entire study period.

A model that included the change in CALW and litter size showed no association (P>0.05) between changes in CALW during the mating period and the risk of death. Further, models that investigated BCS at ram removal could not be built, as the inclusion of this variable did not fit any model. Therefore, there was no association found between BCS at ram removal and the risk of ewe mortality during the study.

4.5 Ewes that were cast

4.5.1 Ewe live weight, CALW and body condition score of alive ewes and those found cast

Ewe live weight and CALW both changed over time ($P<0.001$) but there were no significant differences ($P >0.05$) between mating cycle groups, litter sizes or their two-way interactions. At set-stocking, the mean live weight was less ($P<0.05$) than at other times (Table 4.10).

Cast ewe live weight and CALW did not differ from those that did not become cast ($P >0.05$) at any weighing event (Table 4.10). Similarly, the mean body condition score of ewes that were found cast did not differ ($P > 0.05$) from ewes that did not become cast at any of the weighing events (Table 4.10).

Table 4.10. Live weight (kg; mean ± standard error), conceptus adjusted live weight (kg; mean ± standard error), and BCS (mean ± lower mean, upper mean), at each weighing event (pre-mating, ram removal, PD, set-stocking, docking) of alive ewes and those that were cast

	Weighing event							
	n	Pre-mating	n	Ram removal	n	Pregnancy Diagnosis	n	Set-stocking
				Live weight				
Alive ewes	1445	56.7 ± 0.21 ^{bd}	1564	58.2 ± 0.21 ^{e}	1579	56.0 ± 0.21 ^{ac}	1570	66.3 ± 0.21 ^{f}
Cast ewes	30	55.0 ± 1.9 ^{abcde}	31	56.4 ± 1.9 ^{cde}	31	54.4 ± 1.9 ^{ab}	30	65.4 ± 1.9 ^{f}
				Conceptus adjusted live weight				
Alive ewes	1445	56.9 ± 0.21 ^{ce}	1564	58.0 ± 0.21 ^{abfh}	1579	54.2 ± 0.21 ^{a}	1570	58.9 ± 0.21 ^{fg}
Cast ewes	30	55.4 ± 1.9 ^{cdegi}	31	56.3 ± 1.9 ^{bcdefghi}	31	52.8 ± 1.9 ^{abd}	30	57.8 ± 1.9 ^{hi}
				Body Condition Score				
Alive ewes	1457	2.71 ^{begh} (2.68-2.73)	1577	2.97 ^{abde} (2.95-2.99)	1584	2.83 ^{abcg} (2.81-2.86)	1589	2.80 ^{defh} (2.78-2.83)
Cast ewes	30	2.65 ^{cfgh} (2.45-2.86)	30	2.93 ^{acdf} (2.78-3.08)	31	2.74 ^{gh} (2.56-2.92)	31	2.70 ^{gh} (2.54-2.88)

^{abcdefgh} Values with different superscripts across rows indicate significant differences within-group time (P < 0.05).

4.5.2 Change in conceptus adjusted live weight

Change of CALW during mating, from ram removal to PD, and from PD to set-stocking did not differ (P > 0.05) between alive ewes and those found cast (Table 4.11).

Table 4.11. Change in CALW (g/day; mean± standard error) at different periods (mating, ram removal to PD, PD to set-stocking) of alive ewes and those that were cast

Period	N	Alive	n	Ewes found cast
Mating	1459	24.3 ±1.8	30	21.3 ±12.0
Ram removal to PD	1594	-91.1 ±1.7	31	-83.4 ± 12.5
PD to set-stocking	1529	9.8 ±1.7	30	10.3 ±12.3

4.5.3 Associations between productive parameters and ewes found cast

4.5.3.1 Risk of being cast

4.5.3.1 Weight, CALW and change in CALW

No associations (P > 0.05) were found between ewe live weight or CALW at each weighing event (pre-mating, ram removal, PD and set-stocking) and the risk of being found cast. Further, the risk of being cast was not associated (P > 0.05) with the change in CALW during mating, from ram removal to PD and PD to set-stocking (Table 4.12).

Table 4.12. The odds (95% CI) of a ewe becoming cast by ewe live weight, CALW, and change in CALW at each weighing event.

Time	OR (95% CI)	p-value
	Live weight	
Pre-mating	0.97 (0.91-1.04)	0.43
Ram removal	0.97 (0.913-1.04)	0.50
Pregnancy diagnosis	0.98 (0.912-1.05)	0.60
Set-stocking	1.00 (0.949-1.06)	0.84
	CALW	
Ram removal	0.97 (0.91-1.04)	0.49
Pregnancy diagnosis	0.97 (0.90-1.05)	0.51
Set-stocking	0.99 (0.93-1.05)	0.82
	Change in CALW	
Mating	1.00 (0.99 -1.00)	0.86
Ram removal to PD	1.00 (0.99 -1.00)	0.69
PD to set-stocking	1.01 (0.96 -1.06)	0.69

4.5.3.2 BCS

There were no associations between condition score at pre-mating, ram removal, PD, set-stocking and the risk of a ewe becoming cast ($p > 0.05$) (Table 4.13).

Table 4.13. Body condition score and association with risk of being cast at pre-mating, ram removal, pregnancy diagnosis and set-stocking. Odd ratios (95%CI)

Score	Pre-mating	Ram removal	Pregnancy diagnosis	Set-stocking
≤ 2	2.04 (0.64-6.52)	N/A[1]	1.87 (0.46-7.6)	2.98 (0.89-9.92)
2.5	1.46 (0.52-4.11)	1.47(0.65-3.31)	2.19 (0.85-5.6)	1.83(0.69-4.79)
3	ref	ref	ref	ref
3.5	0.39 (0.04-3.39)	1.26 (0.46-3.44)	1.14 (0.28-4.61)	1.90 (0.60-5.96)
≥4	3.73 (0.86-16.05)	0.68 (0.08-5.35)	1.86 (0.37-9.40)	N/A[2]

N/A[1] not applicable, CS≤ 2 included in category≤ 2.5 at ram removal.
N/A[2] CS ≥4 included in category≥ 3.5 at set-stocking

4.5.3.3 Litter size and mating cycle

The association between litter size and the risk of becoming cast tended to be significant with the Wald test ($p=0.06$). Similarly, the results of likelihood ratio and chi-square were significant ($p < 0.05$). The odds of a ewe becoming cast differed between single and multiple-bearing ewes (Table 4.14). Twin or triplet-bearing ewes were at greater risk of being found cast than single-bearing ewes, however, the risk of becoming cast between twin and triplet-bearing ewes did not differ ($p > 0.05$). There was no association between the mating cycle and the risk of being found cast ($p > 0.05$).

Table 4.14. Association of litter size at pregnancy scanning and risk of being cast. Odd ratios (95%CI)

	Odds ratios (95%CI)	
Litter size at PD	Singles as reference group	Triplets as reference group
Single	ref	0.074(0.008-0.67) *****
Twins	8.3 (1.23-61.42) *****	0.61 (0.21-1.79)
Triplets	13.49 (1.49-122.02) *	ref

* Odd ratio is significantly different to the reference group (p<0.05)

4.5.3.4 Distribution of cast ewes according to lambing paddock

Of the ewes that were found cast the greatest percentage were in paddock 11 (8/31) and paddock 8 (5/31). Paddock 11, however, had a greater number of ewes and therefore higher relative density than the other lambing paddocks (277 ewes and 10.2 ewes/ha, respectively). The percentage of ewes that were found cast per paddock was greater in paddock 10, accounting for 4.5% of the ewes allocated at set-stocking. A similar percentage was shown in paddock 12 where 4.3% of allocated ewes were found cast (Table 4.15). The number of cast ewes per hectare was highest in paddock 11 (0.29 ewes per hectare), paddock 10 (0.28 ewes per hectare) and paddock 12 (0.26 ewes per hectare).

Table 4.15. The number of ewes at set-stocking allocated to each paddock, including the pregnancy status of the ewes, number (%) of cast ewes that were found during the lambing monitoring and cast ewes per hectare.

Paddock (ID)	n ewes at set-stocking	Pregnancy status	Number (%) of ewes that were cast per paddock	Cast/ha
11	277	Late[1]	8 (2.9%)	0.29
10	66	Twin	3 (4.5%)	0.28
12	93	Triplet	4 (4.3%)	0.26
7	101	Twin	3 (3.0%)	0.22
2	188	Twin	4 (2.1%)	0.19
8	146	Twin	5 (3.4%)	0.15
1	84	Twin	1 (1.2%)	0.07
5	125	Twin	1 (0.8%)	0.06
9	178	Twin	2 (1.1%)	0.04
3	127	Twin	0 (0.0%)	0.00
4	146	Single	0 (0.0%)	0.00
6	140	Single	0 (0.0%)	0.00

[1] The late lambing paddock included single, twin and triplet-bearing ewes

4.6 Lamb mortality

The calculated lamb mortality rate between pregnancy diagnosis and docking was 15.8% (493/3112). During the period of monitored lambing, lamb mortality was calculated from the number of lambs subjected to post-mortem examination (126/3112, 4%), which accounted for 25.6% (126/493) of the lambs that died between PD and docking. Lamb mortality rates of singles, twins and triplets was (7%, 13% and 30%, respectively). The majority of dead lambs examined were twins with 58.1% (72/124), and triplets with 29.0% (36/124), while singles accounted for 7.3% of deaths (9/124). Deaths of lambs of unknown birth rank accounted for 5.6% (7/124).

Starvation/exposure was the main cause of lamb mortality during the period of monitored lambing, followed by dystocia, then unknown causes (Table 4.16). Other causes of death accounted for 21% (25/124) (Table 4.16). A summary of the percentage and number of lamb deaths according to each cause for singles, twins and triplets is shown in Table 4.16. Detailed numbers and causes of lamb deaths are shown in Appendix Table A.6. Of the dead lambs collected during the monitored lambing period 57.5% (69/120) were male with the remaining 42.5% (51/120) being female.

Table 4.16. Cause of death (n and %) of the lambs examined during the monitored lambing period according to litter size (single, twins, triplets, or not recorded).

Causes of lamb deaths	**Single**		**Twins**		**Triplets**		**NR***		**Total**	
	n	%	n	%	n	%	n	%	n	%
Starvation/exposure	1	11	34	47	17	47	5	71	57	46
Dystocia	5	56	15	21	3	8	1	14	24	19
Unknown	1	11	12	17	5	14	0	0	18	15
Stillborn	0	0	4	6	3	8	1	14	8	6
Others#	2	22	7	10	8	22	0	0	17	14
Total	9	100	72	100	36	100	7	100	124	100

* NR litter size not recorded

\# Include infection, diarrhoea, trauma and constipation.

The association between lamb birth rank and cause of death was assessed using Chi-square and likelihood ratio chi-squares, was not significant (p=0.06). The mean live weight of the dead lambs differed between the sex of the lamb (P <0.05) and their birth rank (P <0.01) (Table 4.17). There was an interaction of birth rank by cause of death for weight of the dead lambs (P <0.01) in the model where only twins and triplets were included. Among twin lambs those that died of dystocia or that were stillborn were heavier than lambs that died of any other cause (Table 4.18). Among triplet lambs, however, lambs that died of other causes were heavier than lambs that died of all other causes.

The odds of the cause of lamb death being dystocia increased with lamb weight (OR=2.22 (95% CI=1.39-3.56): P <0.001) (Figure 4.6). The odds of lamb death due to dystocia increased 1-2 fold for each unit (kg) increase in weight. The odds death due to starvation/exposure was not associated (p=0.06) with the weight of the lamb.

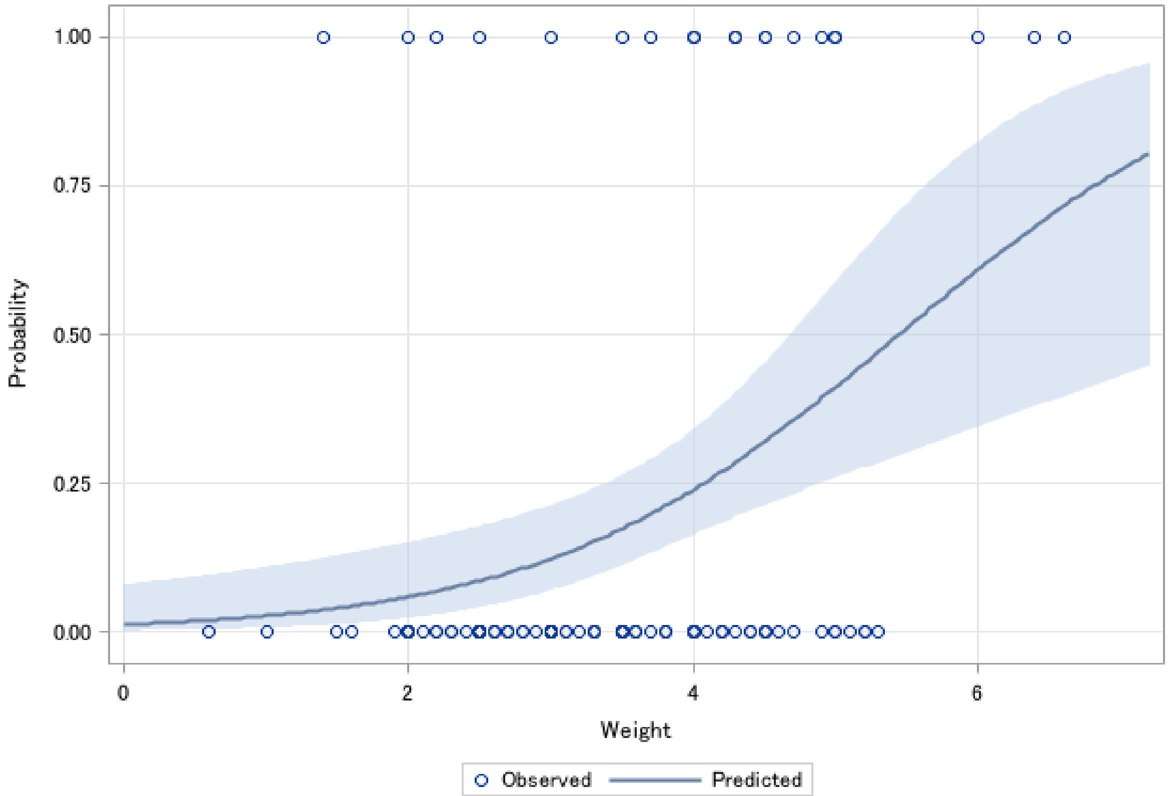


Figure 4.6. The predicted risk (95% CI) of a lamb death due to dystocia associated with lamb live weight. The solid line shows the predicted risk with light blue shading indicating the 95% CI.

Table 4.17. Weight (kg; mean ± standard error) of the dead lambs according to birth rank, dystocia (for single, twins and triplets), sex, and cause (for twins and triplets)

		Lamb live weight (kg)		
Birth Rank	**n**	**All lambs**	**n**	**Dystocia deaths**
Singles	8	4.89 ± 0.35 [c]	5	5.5± 0.45 [c]
Twins	71	3.59 ± 0.13 [b]	15	4.0± 0.51 [b]
Triplets	34	2.91 ± 0.17 [a]	3	2.5± 0.51 [a]
Sex of the lamb				
Female	49	3.16 ± 0.18 [a]		
Male	64	3.63 ± 0.16 [b]		

[abcd] Values with different superscripts indicate significant differences within group-category (P < 0.05).

Table 4.18. Lamb live weight (kg; mean ± standard error) of twin and triplet lambs that died of starvation/exposure, dystocia, stillborn, other causes and unknown causes

				Lamb weight by cause of death						
Birth Rank	**n**	**Starvation / exposure**	**n**	**Dystocia**	**n**	**Stillborn**	**n**	**Others**	**n**	**Unknown**
Twins	34	3.4 ± 0.15 ^{c}	15	4.0± 0.51 ^{d}	4	4.4± 0.45 ^{d}	7	2.7± 0.3 ^{ac}	12	3.2± 0.26 ^{ac}
Triplets	17	2.7± 0.21 ^{ab}	3	2.5± 0.51 ^{ac}	3	2.5± 0.51 ^{ac}	8	3.5± 0.3 ^{cd}	5	2.1± 0.5 ^{ab}

^{abcd} Values with different superscripts indicate significant differences within group- category ($P < 0.05$).

4.7 Weather data

During the 24-day of the period of monitored lambing the maximum precipitation was 25.7 mm with an average of 5.5 mm. There were two periods of intense precipitation, concentrated from day 8 to 11 and during the last 3 days of the monitoring. The maximum temperature ranged between 10.7 and 18.3^{o}C with an average of 14.7^{o}C. Temperatures did not fluctuate dramatically during the study period. The minimum temperature ranged between 0.7 and 11.8^{o}C with an average of 7.5^{o}C. There was a fluctuation in the minimum temperature over the period of monitoring from 5.3 to 11.8^{o}C, reaching a minimum on day 7. The mean wind speed at 10 meters above the ground ranged from 1.2 to 6.8 m/s with an average of 4.0 m/s (Figure 4.7).

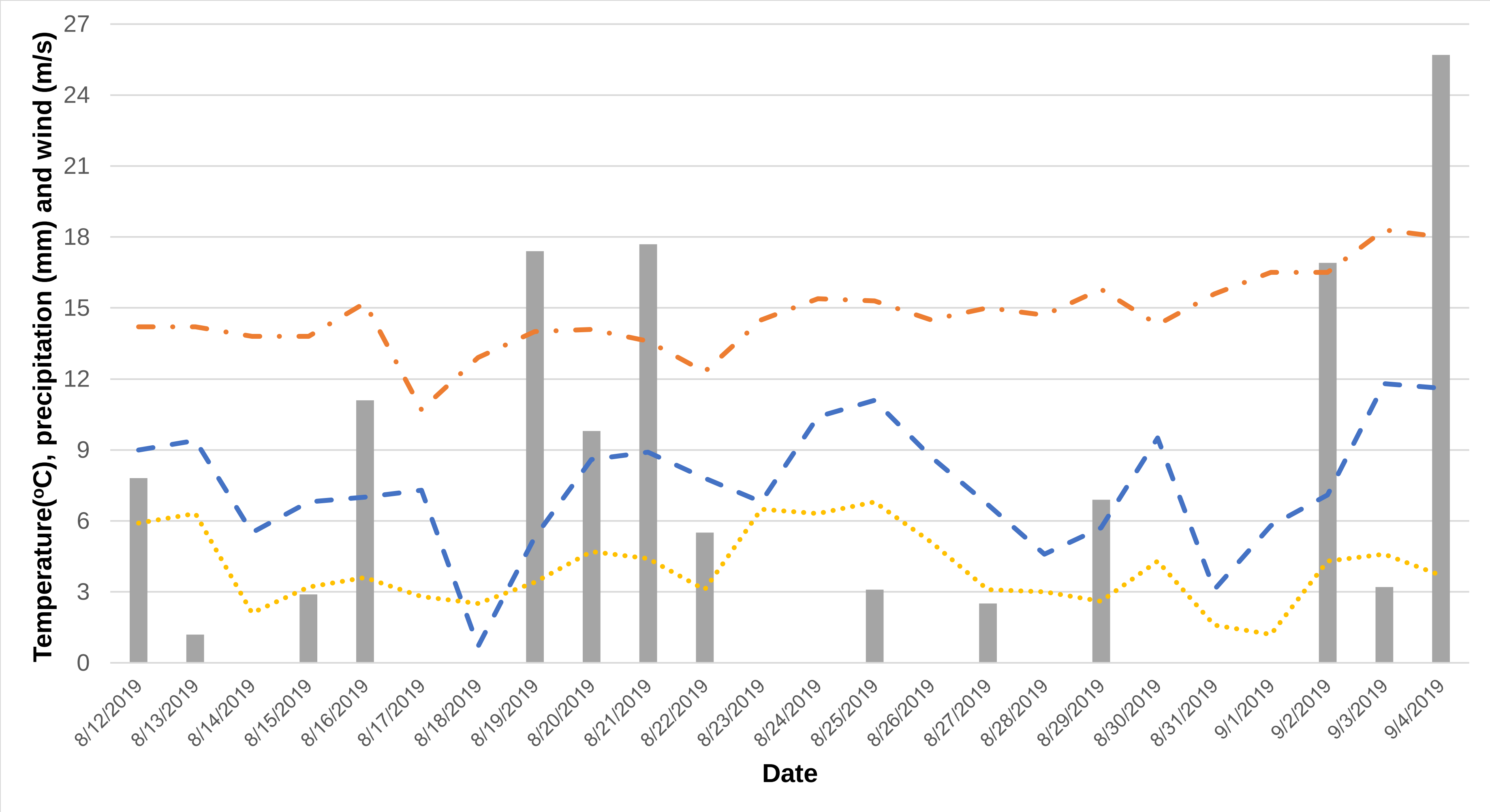


Figure 4.7. Daily maximum temperature ^{O}C(- . - .), minimum temperature ^{O}C (- - -), mean wind speed at 10 meters (m/s) (. . .) and precipitation (mm (bar chart) calculated by the Virtual Climate Station Network (VCSN)

5. Discussion

The discussion is presented in two parts. Ewe mortality is discussed in 5.1 and lamb mortality is discussed in 5.2.

5.1 Ewe Mortality

On-farm ewe mortality is an important issue in the New Zealand sheep industry that has become increasingly recognised in recent years (Farrell et al., 2019). Ewe mortality is important due to both the financial impact on farmers and the potential welfare implications for the animals. While some recent reports have described ewe mortality in New Zealand (Anderson and Heuer, 2016; Ghazali, 2007; Griffiths, 2020) most of the previous reports are from more than 20 years old (Hickey, 1960; Pyke, 1974; Quinlivan and Martin, 1971; Tarbotton and Webby, 1999). Before proposing strategies that farmers can utilise to reduce on-farm ewe mortality, it is necessary to determine the associated rates, timing, causes, risk factors, and productive parameters. This study therefore, aimed to examine ewe mortality rates, timing during the production calendar and association with productive parameters (live weight, body condition score, litter size) on a commercial farm in New Zealand between pre-mating and weaning. The causes of ewe mortality during the peripartum period were also determined.

The ewe mortality rate in the present study was 5.7% (from pre-mating to weaning), which is within the range reported previously in New Zealand from surveys and on-farm studies of between 2.0 and 20.8% per annum (Anderson and Heuer, 2016; Davis, 1979; Gautam et al., 2018; Ghazali, 2007; Griffiths, 2020; Hickey, 1960; Quinlivan and Martin, 1971). Similar mortality rates have been reported in Australia 2.7 to 19.1% per annum (Bush et al., 2006a; Bush et al., 2006b; Dever, 2017; Doughty et al., 2019; Kelly et al., 2014) and Ireland, United Kingdom and the United States of America of 3.0 to 10.1% (Annett et al., 2011; Gunn, 1967; Morgan-Davies et al., 2008; Nass, 1977). The on-farm mortality rate in the current study was lower than previous years on this commercial farm which ranged from 8 - 12% for cohorts of ewes between two- and four-years of age, and 4 - 9% for the five-year-old cohort and from 7 - 25% for the 6 year-old cohort (Griffiths, 2020). This lower on-farm mortality rate in the present study might be explained by normal variability between cohorts, the age of the ewes or changes in farm practice as the farm manager had changed in the intervening years.

In the present study, the ewes considered dead were classified into one of three categories: missing, assumed dead, or confirmed dead. The missing ewes accounted for 49.5% of the total ewes considered dead with the remainder in the other categories. Previous studies have often included dead and missing ewes in one category (Dever, 2017; Doughty et al., 2019; Gautam et al., 2018; Ghazali, 2007; Griffiths, 2020; Kelly et al., 2014). In an on-farm study reported by Ghazali (2007) missing ewes made up 68% of those in the dead/missing category. It is important to acknowledge that while the missing ewes were likely to be dead, some may have also strayed into other paddocks and mobs on the farm or in gullies that are hard to identify individuals in. From set-stocking to docking ewes in the missing category accounted for only 12.9% (7/54) of the ewes considered dead. The majority of the ewes considered dead (81.4%) during this study period were identified during the intensive monitoring in the peripartum period, which allowed the identification of a high number of ewes that were assumed dead or confirmed dead. However, a few ewes were not found which might have died in gullies or areas that are difficult to access by walking or driving or areas that drone use was limited (i.e. deep gullies with thick bush). Actively searching for dead ewes using binoculars, driving though the mobs, and using the drone helped to reduce the missing percentage during the peripartum period and also enabled the identification of the causes of ewe mortality.

Over half (52.4%) of ewe mortalities occurred in the period between set-stocking and docking and most of these (81.4%) were found within the 21-day monitored periparturient period. This finding is comparable with previous studies in Australasia and elsewhere which reported there was an increase in ewe mortality during the periparturient and lambing period (Annett et al., 2011; Dever, 2017; Ghazali, 2007; Griffiths, 2020). Given the increase in physiological stressors of ewes during the lambing period, and the findings from previous studies as well as the present study, it is likely that the period between set-stocking and docking has the greatest risk of ewe mortalities on commercial farms in New Zealand in the absence of a disease outbreak. Therefore, it is recommended that if farmers wish to reduce their ewe mortality rate they focus on this period.

In the current study, the cause of ewe mortality, including confirmed dead and assumed dead, was recorded only for a 21-day period during lambing. During this period the majority (66%) of ewe mortalities were due to ewes becoming cast (immobilised in dorsal recumbency), while vaginal prolapse (19.1%) and dystocia (6.4%) were the other two predominant causes. Vaginal prolapse and dystocia have previously been reported to be the main causes of death during the lambing period in New Zealand and internationally (Anderson and Heuer, 2016; Bush et al., 2006a; Davis, 1979; Ghazali, 2007; Harris and Nowara, 1995). Ewes becoming cast has previously only been reported to be a minor cause with rates of less than 7% if reported at all (Anderson and Heuer, 2016; Davis, 1979; Ghazali, 2007). The difference in methodology used in the current study may explain the difference in findings. In the studies of Ghazali (2007) and Bush et al. (2006a) based on daily monitoring by a researcher (during 21 days and 5 days per season, respectively) any ewes found cast and alive were not recorded in the dead category. Anderson and Heuer (2016); Davis (1979); Harris and Nowara (1995) used farmer-reported death which may have in fluenced the accuracy of the data collected. In addition, farmers may have likely returned cast ewes to their feet and thus not considered them as dead ewes.

To this author’s knowledge, the high incidence of ewes becoming cast as in the current study has not been previously reported during the periparturient period in New Zealand. It is likely ewes have been lifted but this has not been recorded. A small number of authors have reported a low incidence of cast (Anderson and Heuer, 2016; Davis, 1979; Ghazali, 2007). There is some suggestion, however, from farmer´s communications and manuals that suggest “lifting cast ewes” around lambing may decrease ewe deaths (Geenty, 1997). On commercial New Zealand farms, the level of monitoring of ewes during the period from set-stocking to docking varies between farms, ranging from once or twice daily to infrequent shepherding (Fisher, 2003; Fisher and Mellor, 2002). Minimal or less intensive monitoring would limit the identification of ewes with health issues and that have become cast, which may contribute to higher ewe death rates. The results from the present study suggest that ewes becoming cast should be considered as an important cause of ewe mortality around lambing; however, further investigation is required into causes of ewe death and frequency of cast ewes on other commercial farms and variation according to the age, year, breed, body conformation and paddock topography.

The identification of productive parameters and risk factors associated with ewe mortality is key to developing strategies to reduce ewe losses. Ewe live weight, conceptus adjusted live weight (CALW) and change in CALW were found to be important risk factors for ewe death. At ram removal and docking, the cohort of ewes that died had 4% lower live weight and CALW than ewes that survived. In addition, at ram removal live weight and CALW tended to be associated with the risk of death, with the odds of ewe mortality being 4% lower for each kilogram increase in live weight. During the mating period each kilogram increase in ewe live weight or CALW reduced the odds of ewe mortality by 0.3%. These findings are in agreement with the Australian study of Kelly et al. (2014) who reported that risk of ewe mortality increased by 1-fold for each kilogram decrease in Merino ewe live weight regardless of when it was recorded. Similarly, Doughty et al. (2019) reported that the relative risk of ewe death was 4.5 for ewes under 40 kg compared with those between 40 and 45 kg. The present study suggests that ensuring that ewes gain weight during mating and achieve greater ewe live weight and CALW at ram removal can decrease the risk of ewe death. It should be noted, however, that the strength of this association was weak and further investigation is required.

Ewe BCS was not associated with the risk of mortality during the present study, however, there was a tendency for an association at ram removal with greater odds of ewe mortality among ewes with a BCS of 2.0 or less compared with those greater > 2.0. However, the number of ewes with low BCS at some weighing events was relatively low, which may have reduced the statistical power. This finding is comparable with that of Griffiths (2020) in New Zealand flocks where the odds of mortality decreased with a greater BCS at pre-mating. Similarly studies from Australia (Doughty et al., 2019; Horton et al., 2018a; Kelly et al., 2014) and the United Kingdom (Morgan-Davies et al., 2008) have reported the risk of ewe mortality was increased as BCS decreased. Combined, the studies indicate farmers should ensure ewes are at adequate BCS (≥ 2.5) before and during mating. In the current study BCS at recorded pre-mating and in mid-pregnancy was not associated with ewe mortality, however, Griffiths (2020) and Morgan-Davies et al., (2008) reported BCS at these times were a better predictor than BCS at mating. Furth-er investigation on more farms would be beneficial to identify the importance of greater BCS on ewe survival over the entire production year.

Multiple-bearing ewes had higher odds of mortality compared with single-bearing ewes while triplets-bearing ewes were at greater risk than twin-bearing ewes. Multiple-bearing ewes have greater nutritional demands than singles and in particular triplets are under high metabolic pressure (Kenyon and Cranston, 2017; Kenyon et al., 2019; McGovern et al., 2015a; McGovern et al., 2015b). The greater odds of mortality of multiple bearing ewes in the current study is contrary to Ghazali (2007) which reported a higher risk for single- than twin-bearing ewes. Similarly, in the United Kingdom Morgan-Davies et al. (2008) reported no association of ewe pregnancy rank with mortality. These contradictory results may reflect differences in the main cause of death and the number of single and multiple-bearing ewes in each study. In the present study, the farm had a high scanning percent and therefore most ewes were carrying multiples. The main cause of death was cast and for which multiple-bearing ewes was a risk factor. In other studies, the main cause of death was dystocia with higher risk for ewes carrying singles (Ghazali, 2007).

Ewes becoming cast was the main cause of death (assumed dead) identified during the interval between set-stocking to docking in the current study. Relationships between LW, CALW, change in CALW, BCS and the risk of a ewe becoming cast were investigated, although no significant relationships were observed. There was a tendency for a positive association between pregnancy rank and the risk of being cast, however, further investigation is required due to the relatively small number of cast ewes. No other published studies have investigated associations or risk factors for ewes becoming cast.

In the present study, cast ewes were found in most of the lambing paddocks. Although some paddocks had a greater number of cast ewes, this could be explained by a larger number of ewes in those paddocks. However, the paddock topography might be a contributing factor for the risk of cast ewes. From personal observation in the present study, most of the ewes were found cast in flat areas, however, in rolling areas (with greater slope) ewes might become cast if they get caught in shrubs, ditches or holes that impede their ability to mobilise. Wool length is probably a factor that increases the incidence of cast. Stafford (2013), described that although the number of ewes that die from cast is unknown, winter shearing is likely to reduce the incidence. In the present study, however, ewes were shorn in mid-pregnancy. Further investigation is required in New Zealand into risk factors, including productive factors and topography of the land, associated with ewes becoming cast.

5.1.1 Limitations of the research approach

The present study assumed that missing ewes were likely to have died and were considered dead. This is a common assumption in previous mortality studies in New Zealand (Anderson and Heuer, 2016; Ghazali, 2007; Griffiths, 2020; Tarbotton and Webby, 1999) and internationally (Annett et al., 2011; Bush et al., 2006a; Bush et al., 2006b; Dever, 2017; Gunn, 1967; Kelly et al., 2014; Nass, 1977). This assumption, however, might result in the rate of ewe mortality being overestimated as the apparent death of the missing ewes remained unconfirmed in most cases. Unfortunately, this is a limitation with undertaking such research in commercial environments with extensive management.

A major limitation of this study was that it only took place on one farm during a limited period between premating to weaning (10 months). Therefore, ewe mortality in the post-weaning period could not be determined. The age and breed of the cohort of ewes were limited to two-tooth ewes (16 to 19 months of age at breeding) and Coopworth x Composite breed. Therefore, further investigations are required to determine the influence of age and breed on ewe mortality with such investigations ideally conducted on more than one farm. Finally, the inclusion of topographic variables that would allow analysis of paddock terrain where the ewes were cast would have been beneficial.

5.1.2 Implications

This study confirmed that during the period from set-stocking to docking, especially in the peripartum period, is a time of increased risk of ewe mortality on commercial farms. In addition, being cast was the main cause of ewe mortality during the peripartum period, which is an issue that can be resolved if it is detected early. A quarter (26/103) of potential ewe mortality identified during the study period could have been prevented by righting cast ewes during the monitoring period which is a promising outcome. The potential repeatability of ewes becoming cast should be further evaluated. Moreover, the risk of ewe mortality was increased among twin- and triplet-bearing ewes compared with single-bearing. Advantages of the easy-care lambing management system commonly employed in New Zealand are widely reported in terms of practicality, lower lamb mortality, and low labour cost, however, there is concern about the welfare of individual ewes that may require assistance during lambing and the financial impact of losing the ewe (Fisher, 2001, 2003; Kilgour et al., 2008). The present study suggests that farmers might reduce ewe deaths and subsequent lamb death by undertaking monitoring around the peripartum period, especially of twin and triplet-bearing ewes.

In the present study, there was a tendency for an association between the increase in ewe mortality and a low change of CALW, low weight and BCS ≤ 2.0 at ram removal. Hence, it is recommended that farmers improve the live weight and BCS in this period to reduce ewe losses.

5.1.3 Further research

This research forms the basis of future on-farm ewe mortality studies on commercial farms in New Zealand to determine the causes of ewe mortality and associations with productive parameters. The outcome of the present study was from a cohort of two-tooth ewes during a single year, hence, further studies of other flocks (farms) should include cohorts of different ages, and breeds to allow comparison to be made with these findings. In addition, the incidence of ewes being cast and its associated risk factors such as topography and other paddock terrain variables in other flocks and farms should be further investigated. Future research might enable scientists and farmers to determine in which paddocks areas or terrain types ewes are more likely to become cast; therefore, farmers could select which group of ewes to set-stock in each paddock and target monitoring of specific areas. Finally, the use of technologies such as drones that can allow the detection of individual ewes that require assistance, would benefit farm management, potentially reducing the time spent on monitoring, facilitating monitoring of areas with difficult access and reducing the disturbance of the ewes.

Undertaking similar monitoring on other farms is a feasible and realistic option. However, limiting the monitoring to up to the first two weeks of lambing would provide accurate data about the causes of ewe mortality. In the present study, a researcher could feasibly monitor approximately 260 hectares per day, including identifying and undertaking post-mortem examination of dead ewes and lambs, taking around seven hours of work, at ewe stocking rates 6 to 9 ewes/hectare. If necessary the frequency of monitoring could be reduced to every second day; although fewer ewes are likely to be saved at that frequency the causes of death are likely to be determined.

5.1.4 Conclusions

Combined, the result of the current study showed that ewes have a higher risk of death in the interval from set-stocking to docking than other periods of the year and that most of deaths were concentrated during the peripartum period. Causes of ewe death were associated with problems during lambing such as vaginal prolapse and dystocia, however, ewes becoming cast must also be considered as an important cause of ewe death during this period. Therefore, further investigations of associated parameters and risk factors are required. Of the productive parameters associated with ewe mortality in this study, change of CALW at mating, and the productive parameters of liveweight, CALW, and BCS at ram removal, tended to be lower in ewes that died than those that survived. This suggests that the risk of ewe death decreases with increased live weight gain during mating and achieving high live weight at ram removal. There was a tendency for decreased mortality for ewes with a BCS > 2.0 at ram removal. In addition, greater litter size was associated with increased ewe mortality. This suggests that monitoring of ewes, especially multiple-bearing ewes, during the peripartum period, might actively decrease ewe mortality. The above suggests that farmers should focus on increasing live weight and BCS of their ewes before and during mating to reduce ewe mortality, likewise, monitoring multiple-bearing ewes during the peripartum period might actively decrease ewe mortality. It should also be noted that if a ewe dies pre-lambing, their lambs would not be born, therefore, lamb mortality is also affected. This study gave an approach to investigating the causes and associated parameters of on-farm ewe mortality in New Zealand. Further investigation is required in regard to the causes, timing and association of ewe mortality in New Zealand flocks.

5.2 Lamb Mortality

Lamb mortality around lambing is an important issue that has a financial impact on sheep farmers, limiting farm productivity in terms of kilograms of lamb produced as well as having animal welfare implications for the sheep industry (Dwyer, 2008; Gascoigne et al., 2017; Kerslake et al., 2010). The increase in the national lambing percentage over the last two decades has resulted in increased litter sizes and consequently lamb mortality rates in New Zealand sheep systems (Kerslake et al., 2005). Lamb mortality around the time of birth and causes of death have been widely studied in New Zealand (Everett-Hincks and Duncan, 2008; Kerslake et al., 2005; McCoard, 2017; Pettigrew et al., 2020), however, the cause of death should be determined on a farm-by-farm basis. Therefore, a secondary objective of the current study was to determine the main causes of lamb mortality around lambing on a commercial farm, through post-mortem examination during the monitored lambing period.

In the present study the lamb mortality rate was calculated to be 15.8% (from pregnancy diagnosis to docking) and of these 4% were inspected by post mortem examination. This mortality rate was within the range reported in previous studies of between 5-30% from birth to weaning (Kerslake et al., 2005; Stevens, 2010). Foetal loss was not evaluated, therefore, the lamb mortality around the time of birth may have been over-estimated.

Lamb mortality rate was greater as litter size increased, accounting for 7%, 13% and 30% for single, twin and triplet lambs, respectively. These findings are in agreement to previous studies in which multiple-born lambs, particularly triplet lambs, had higher mortality rates than singles (Kerslake et al., 2005; Pettigrew et al., 2018). Among the lambs that had post-mortem examinations the majority were twins and triplets (58.1% and 29.0%, respectively) with a smaller proportion singles (7.3%) and those of unknown birth rank (5.6%). These percentages were similar to the proportion of autopsied lambs reported by Refshauge et al. (2016).

In this study, starvation/exposure and dystocia were the two main causes of death of the post-mortem examined lambs (46% and 19%, respectively). These two causes have been reported previously in New Zealand studies, although, the percentage of dead lambs classified as dead because of starvation/exposure was higher than in other reports. Stevens (2010) reported that 26% and 30% of lamb deaths were due to starvation/exposure and dystocia, respectively. Similarly, Kerslake et al. (2005) found that 28% and 56% of lambs died due to these causes, respectively. In Australia, Refshauge et al. (2016) reported that 30% of the lambs died because of starvation/exposure and 27% due to dystocia. Some authors have reported that the proportion of dead lambs considered have died due to dystocia were incorrectly categorized in the starvation/ exposure category (Kerslake et al., 2005). In the present study, the decision on cause of death was made based on the protocol described by Everett-Hincks and Duncan (2008) reducing the risk of classifying the dead lamb in the wrong category. However, some causes of lamb mortality are inter-related, potentially acting as a preliminary gateway to the other, more impactful factors which lead to an increased risk of death.

There was no statistically significant difference between the proportion of dead lambs among litter size and the causes of lamb death. However, the strength of this test was likely affected by the low frequency of lambs in some categories so this association level change if more data were included in the analysis. More than half of the single lambs deaths were due to dystocia (57%), while for twins and triplets it was 21% and 8%, respectively. This finding was comparable with Refshauge et al. (2016) in Australian flocks where a single lamb had a greater risk of dying from dystocia or being stillborn than from other causes. Holst et al. (2002) also reported that a higher percentage of single lambs died from dystocia than lambs from multiple births. Similar results were also reported across New Zealand farms by Stevens (2010) where farmers reported that 53% of single lambs died due to dystocia compared with 12% of twin born lambs. In contrast, other studies have reported a high proportion of lamb losses as a consequence of dystocia in twin and triplet-born lambs, accounting for up to 50% of the lamb mortality (Kerslake et al., 2005). Everett-Hincks and Dodds (2008) also found a higher risk of dystocia in triplet-born compared with twin-born lambs.

Starvation/exposure was established as the main cause of death for 11% of single lambs, and 47% of twin and triplet lambs. These findings are in agreement with Refshauge et al. (2016) where multiple-born lambs were more likely to have died of starvation/exposure than singletons. A study in Australian flocks described greater percentages of multiple-born lambs (23%) being found dead due to starvation/exposure than singles (10%) (Holst et al., 2002). In New Zealand studies, similar findings were found based on farmers observation, with 10% of single and 41% of twin-born lamb deaths being attributed to starvation/exposure (Stevens, 2010). Kerslake et al. (2005), based on post-mortem examination, reported a greater percentage of multiple-born lambs dead of starvation/exposure than singletons.

In the present study, the live weight of lambs that died differed according to birth type and between some causes of death. Twin born lambs that died due to dystocia were heavier than those that died of other causes, except for stillborn. However, triplet born lambs had similar weight for almost all the categories of cause of death, except those classified as died from ‘other’ causes. Further, single born lambs that died due to dystocia were heavier than multiple- born lambs in the same cause category. The odds of the cause of death being dystocia increased 1.2-fold for each kilogram increase its weight. These results are comparable to previous studies in New Zealand flocks. Kerslake et al. (2005) reported that in half of 20 flocks, birth weight of the dead twin lambs was higher than those that died due to other causes. In Australian Merino flocks, Horton et al. (2018b) also described that high birth weight dystocia was not influenced by litter size. The risk of dystocia, however, has been widely described in multiple-born lambs that are lighter than the mean (Brown et al., 2014; Everett-Hincks and Dodds, 2008; Horton et al., 2018b). The present study shows the influence of lamb birth weight on the risk of dying as the result of dystocia, specifically with lambs of high birth weight. Further research is required to evaluate risk factors of lamb losses due to dystocia.

There was no association between lamb weight and the probability of a lamb dying of starvation/exposure. This finding is in disagreement with Kerslake et al. (2010), who suggested that the lightest triplet-born lamb produced less heat and lost more heat in comparison to other multiple-born lambs, which was linked to low birth weight. The present results also disagrees with those of Everett-Hincks and Dodds (2008), who reported that lamb death risk to starvation/exposure increased with birth weights below the mean. The present result could be a reflection of a small sample size and other factors that were not evaluated that may also influence the risk of death for starvation/ exposure, such as lamb and dam behaviour, weight variation within the litter, surface area to body weight ratio and shelter in the lambing paddocks (Hinch and Brien, 2014; Morel et al., 2008). This is supported by Kerslake et al. (2010) who reported that the lightest triplet-born lamb produced less heat and would lose more heat during cold stress than heavier multiple-born lambs, which is a reflection of its low birth weight.

5.2.1 Limitations of the research approach

A limitation of the present study was the low number of single lambs that died. Therefore, weight differences in the interaction between litter sizes and causes of death could not be determined for all litter sizes. Moreover, the strength of the association between the litter sizes and causes may also have been affected. The weight of the lambs was collected at death, was also another limitation, as it may not have reflected the lamb's actual birth weight. This is particularly a problem for lambs that dies of starvation/exposure which may have died at up to a week of age. This study was done on one farm, in one year, in one cohort of two-tooth ewes, therefore, the repeatability of this result could not be evaluated. Although the analysis was limited to determining the causes of lamb mortality among the influences of litter size and the weight, the inclusion of other lamb and dam factors that are likely to influence lamb mortality would have allowed for a wider analysis.

5.2.2 Implications

The result of this study supports the finding that multiple-born lambs had higher lamb mortality rates on this farm. Starvation/exposure was the main cause of lamb death, with dystocia being the second most common cause. Therefore, measures to reduce lamb losses on this farm should be focused on reducing the risk factors resulting in starvation/exposure in multiple-born lambs, followed by those for dystocia.

Although lamb birth weight was not the only factor involved in the risk of starvation/ exposure, the low weight of the twin and triplet dead lamb was likely a factor. Further research on other risk factors exacerbating lamb losses due to starvation/exposure should be undertaken. The repeatability of the present results should be evaluated in further years on the same farm, as well as the variation in groups of ewes of different ages.

5.2.3 Further research

The results of the present study gave a brief approach to perinatal lamb mortality that complement the many other studies in this area. Further research is required to determine lamb and dam risk factors that influence lamb losses and predictors of lamb survival. The variables in terrain of lambing paddocks and their impact on lamb mortality should also be analysed. Besides the influence of birth weight, further research might also include the level of dam´s feeding on starvation/exposure.

5.2.4 Conclusions

Combined, lamb mortality around birth was influenced by litter size. The proportion of lamb losses in order of magnitude were triplet-born, twins-born followed by single-born. The main cause of lamb death across all litter sizes was starvation/exposure, with dystocia being a lesser but still significant cause. A significant statistical association was not found between litter sizes and causes, however, the low frequencies in some categories limited the strength of the analysis. Over half of the single dead lambs died due to dystocia, while almost half of multiple-born lamb's losses were because of starvation/exposure.

The odds of lambs dying due to dystocia increased by 1.2-fold for each one-kilogram increase in birth weight. Twin lambs that died of starvation/exposure were lighter than twin lambs that died due to other causes. Therefore, birth weight influenced the cause of lamb death.

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Appendix

Table A1. Summary of the main findings during necropsy, including the common finding, samples taken and preservatives used according to each cause of ewe mortality. Adapted from Ghazali (2007).

Causes of ewe mortality	Common finding during necropsy	Samples taken	Preservatives
Dystocia or birth complications	Found recumbent[1]. Foetus in the uterus, cervix without dilation. Some cases with vaginal prolapse	Uterus if findings are inconclusive	Formalin
Pregnancy toxaemia	Hepatic lipidosis [1] Liver yellow with fatty liver[2] Foetus in the uterus. Ewe in the last period of pregnancy [4]	Liver	Formalin
Mastitis	Udder: swollen, red, purple or black depends on severity. Oedematous udder. Watery or red secretion. Supramammary lymph nodes enlarged and haemorrhagic [3,4].		
Bloat	Abdominal or rumen distension with gas. Esophageal “bloat line”. In some cases diaphragm rupture.[4]		
Malnutrition	BCS ≤ 1.5. Depletion of fat reserves[1] Often with other causes. Reduced rumen content[1]		
Internal parasites	*Fasciola hepatica* present in bile ducts[1]. For *Trichostrongylus* soft fecal material, diarrhoea with mucous appearance. In “*Haemonchus contortus”*, large clusters of worms in the abomasum with anemia.[3]	Intestine, faecal sample or abomasal worm count 1	Formalin or refrigerate
Pneumonia/ post shearing stress	Lungs: Red-spotted, and/or attached to the thoracic wall.[2]	Lungs	Formalin [2]
Ovine Johne´s disease	Thickened corrugated intestine.[4]	Intestine (between large and small) ileocecal valve and lymph node. [5]	Formalin [2]
Clostridial diseases	Often sheep in prime condition [1] Intestinal congestion or with gas. Autolytic kidney[4] Foci areas of haemorrhage and necrosis[4]	Intestine smears [4]	Fresh,
Misadventure	Location in a fence or dam that suggest possible cause[1]		

Cutaneous myiasis	Necrotic wounds on the body or breech could have maggots.[1]		
Leptospirosis	Icteric carcass, kidneys red and swollen. Liver often yellow.[4]		
Septicemia	Petechia, splenomegaly, large swollen lymph nodes. Rapid reduction of body fluid[4]	Liver and lymph nodes	Formalin

[1] Bush et al. (2006a). [2] Ghazali (2007). [3] West et al. (2018). [4] Roberts (2012)). [5] Gautam et al. (2018)

Table A2 Ewe post-mortem examination form.

Date		**Paddock**	
Electronic tag		**Plastic Tag**	
Birth rank		**Autolysis**	

EXTERNAL FINDINGS	
Oral cavity and teeth	
Feet	
Udder	
Vulva	

INTERNAL FINDINGS	
ABDOMINAL CAVITY	
Intestine	
Liver and Pancreas	
Abomasum	
Rumen and forestomach	
Uterus	
Kidneys and urinary tract	
THORACIC CAVITY	
Lungs§ and respiratory tract	
Hearth	

Other findings	
PRESUMPTIVE DIAGNOSIS	

§ Reproduced from Goodwin et al. (2004) and Ghazali (2007).
Pneumonia scale: 0=Unaffected lung 1= Lung with <5% affected 2= for 5 to <10% affected
3= 10 to <20% affected 4= >20% affected.

Table A3 Lamb post-mortem examination form.

Date		**Paddock**	
Birth rank		**Autolysis**	
Weight		**Sex**	

EXTERNAL FINDINGS			
Cleaned	**Y/N**	**Walked**	**Y/N**
Physical abnormalities		**Other**	

INTERNAL FINDINGS		
Lungs	**Fully aerated / partial aerated/ not aerated**	
Oedema[2] **(No edema /minor/ moderate/severe)**	**Head** **Neck** **Sternum/ribcage**	**Limbs** **Generalised** **Others**
Haemorrhage	**Y/N**	
Liver	**Rupture**	**Y/N**
	Infection or lesions	**Y/N**
Heart **Brown fat metabolised?**	**No/partial/full**	
Kidneys **Brown fat metabolised?**	**No/partial/full**	
Stomach	**No milk cloth/ Presence of milk cloth**	
Intestine	**No milk absorption/ Presence milk absorption**	
Meconium	**Y/N**	
Navel Infection	**Y/N**	
Others		

Presumptive diagnosis[3]	**Dystocia**	**Starvation / exposure**	**Amnion over nose**	**Organ rupture**	**Disease**	**Unknown**	**Stillborn**

[1]Adapted from Refshauge et al. (2016) and Everett-Hincks and Duncan (2008).
[2]Reproduced from Everett-Hincks et al. (2008).**No oedema.** **Minor:** Visible but not measurable. **Moderate**: greater than 3 mm up to 1 cm in depth. **Severe:** greater than 1 cm depth.

Table A4. Summary of the number of ewes at each weighing event (pre-mating, ram removal, PD, set-stocking, docking and weaning) that were considered alive, that had a liveweight, BCS recorded and that were missing live weight or BCS.

Category	Pre-mating	Ram-removal	Pregnancy diagnosis	Set-stocking	Docking	Weaning
Considered alive	1789	1785	1765	1671	1617	1603
Weight recorded	1612	1740	1739	1638	1551	1593
BCS measurement	1624	1753	1746	1657	1562	1602
Missing weight values	177	45	26	33	66	10
Missing BCS values	165	32	19	14	55	1

Table A5. Number (%) of ewes in each BCS category at each weighing event (pre-mating, ram removal, PD, set-stocking, docking and weaning).

BCS scale	Premating	Ram-removal	Pregnancy diagnosis	Set-stocking	Docking	Weaning
1.5	19 **(1.2%)**	0 **(0.0%)**	13 **(0.7%)**	14 **(0.8%)**	187 **(12.0%)**	0 **(0.0%)**
2	246 **(15.1%)**	49 **(2.8%)**	141 **(8.1%)**	138 **(8.3%)**	579 **(37.1%)**	71 **(4.4%)**
2.5	720 **(44.3%)**	543 **(31.0%)**	707 **(40.5%)**	687 **(41.5%)**	508 **(32.5%)**	538 **(33.6%)**
3	380 **(23.4%)**	733 **(41.8%)**	540 **(30.9%)**	535 **(32.3%)**	185 **(11.8%)**	563 **(35.1%)**
3.5	193 **(11.9%)**	329 **(18.8%)**	240 **(13.7%)**	221 **(13.3%)**	67 **(4.3%)**	284 **(17.7%)**
4	52 **(3.2%)**	91 **(5.2%)**	85 **(4.9%)**	49 **(3.0%)**	23 **(1.5%)**	106 **(6.6%)**
4.5	14 **(0.9%)**	8 **(0.5%)**	20 **(1.1%)**	12 **(0.7%)**	11 **(0.7%)**	34 **(2.1%)**
5	0 **(0.0%)**	0 **(0.0%)**	0 **(0.0%)**	1 **(0.1%)**	2 **(0.1%)**	6 **(0.4%)**
Total	1624	1753	1746	1657	1562	1602

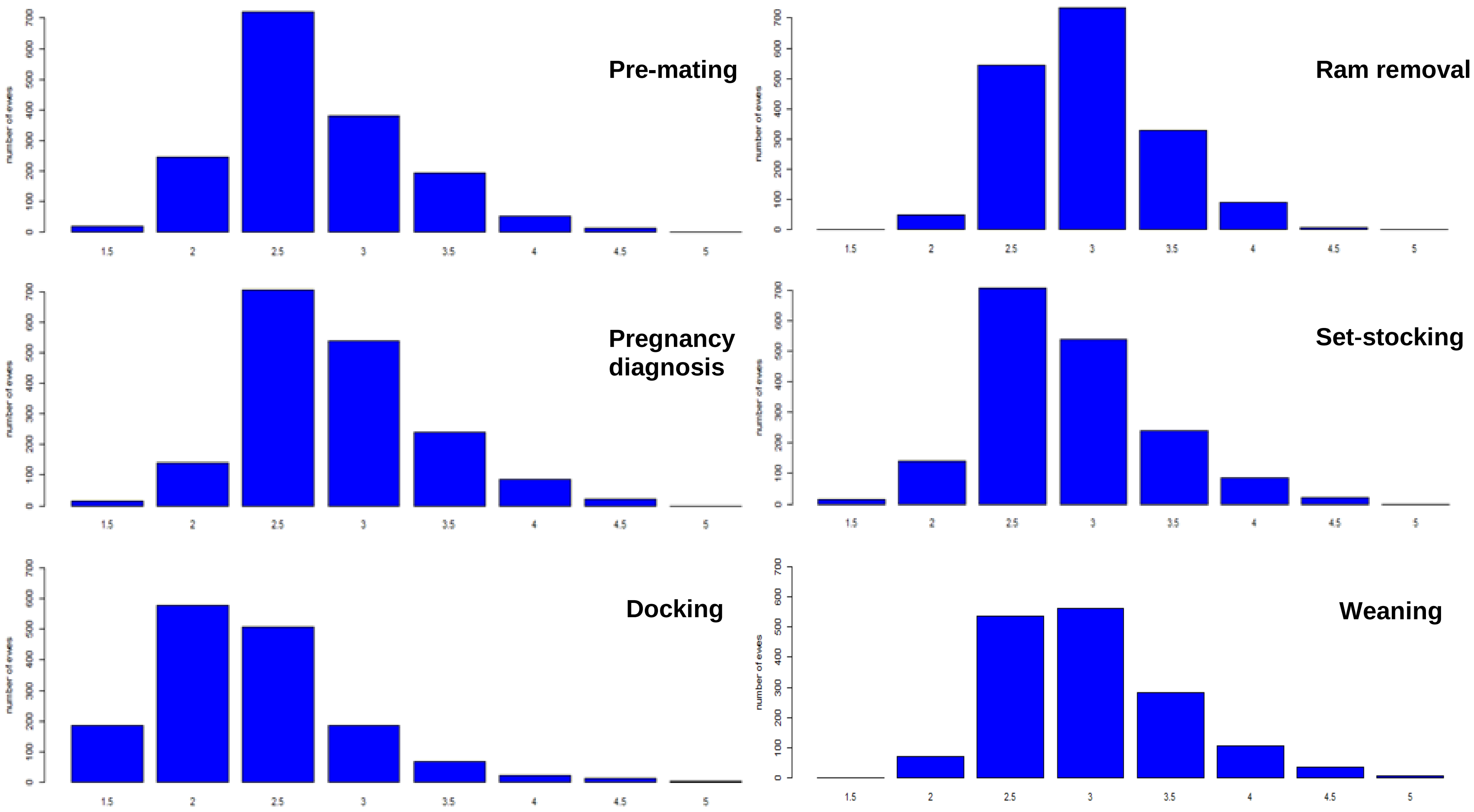

Figure A.1. Number of ewes in each scale of the BCS during the measurement times (pre-mating, ram removal, PD, set-stocking, docking and weaning)

Table A.6. Causes of lamb death (n and %) identified by post-mortem examination from 124 lambs during the lambing monitoring according to litter size (single, twins, triplet, or nor recorded).

Causes of lamb deaths	**Single**		**Twins**		**Triplets**		**NR***		**Total**	
	n	%	n	%	n	%	n	%	n	%
Starvation/exposure	1	11	34	47	17	47	5	71	57	46
Dystocia	5	56	15	21	3	8	1	14	24	19
Unknown	1	11	12	17	5	14		0	18	15
Stillborn	0	0	4	6	3	8	1	14	8	6
Infection	0	0	2	3	3	8	0	0	5	4
Diarrhoea	0	0	1	1	1	3	0	0	2	2
Trauma	0	0	1	1	1	3	0	0	2	2
Constipation	0	0	1	1	0	0	0	0	1	1
Total	9	100	72	1	36	1	7	1	124	100

* NR litter size not recorded