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Factors Associated with Ewe Death and Casting in an Extensively Farmed Sheep Flock in New Zealand

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Citation: Capdevila-Ospina, K.; Corner-Thomas, R.A.; Flay, K.J.; Kenyon, P.R.; Ridler, A.L. Factors Associated with Ewe Death and Casting in an Extensively Farmed Sheep Flock in New Zealand. *Ruminants* **2021**, *1*, 87–99. https://doi.org/10.3390/ruminants1020007

Academic Editor: Irina Garcia Ispierto

Received: 30 June 2021
Accepted: 15 September 2021
Published: 6 October 2021

Abstract: Ewe deaths affect the productivity and profitability in sheep farming systems and have potential animal welfare and market perception implications. Internationally, there is scant data on the timing and causes of ewe deaths in extensive grazing systems. There is no published literature on the incidence and risk factors associated with casting (ewe in late gestation accidentally immobilised, often in dorsal recumbency). This study, undertaken using a cohort of 1789 ewes on a New Zealand farm, reports on the timing and risk factors associated with production parameters for ewe deaths through an almost two-year period, along with causes of death during both peripartum periods. Ewe deaths occurred throughout both years but were most frequent during the peripartum (pre-lambing to mid-lactation) period. Casting was the most commonly identified cause of death in both years, responsible for approximately a quarter to a third of potential annual mortality. Few risk factors for death or casting were identified. In conclusion, the peripartum period is a high-risk time period for ewe deaths (and, by extension, will also contribute to lamb perinatal mortality). In extensively grazed flocks where casting events occur, it is recommended that all ewes are monitored daily during the peripartum period.

Keywords: ovine; mortality; wastage; longevity; survival; peripartum; lambing; dystocia; vaginal prolapse; shepherding

1. Introduction

Ewe deaths affect the productivity and profitability in sheep farming systems [1,2] and are an important issue in terms of potential animal welfare implications and market (consumer) perceptions [3,4]. Reported ewe mortality rates in extensive outdoor grazing systems, such as in New Zealand, Australia and UK, are reported to be in the range of 2.8–27% [5–11]. Two recent New Zealand studies have reported average ewe mortality rates of around 7–13% per annum but with considerable variation between flocks, age-groups, and years [8,9].

Studies investigating ewe mortality rates and timing in extensive outdoor pastoral farming systems have largely focused on data collection at key production times (i.e., weaning, pre-mating, mid-pregnancy, and pre-lambing) with the estimation of mortality rates based on sheep missing at these times [8,12–14]. A large New Zealand study identified that the majority of ewes that went missing and were presumed to have died, or were reported as dead, did so over the mid-pregnancy to weaning period, but the causes of death were not investigated [8]. Few studies have reported on the relationship between productive parameters such as live weight, body condition score (BCS), litter size, and ewe mortality in outdoor grazing systems worldwide [8,12,14,15]. Therefore, the timing of ewe mortality, as well as the causes and the relationship with productive parameters in outdoor grazing systems, require further investigation.

Commonly reported causes of ewe deaths during the peripartum period include metabolic disorders, vaginal prolapse, dystocia, and ewes becoming cast (ewe in late gestation accidentally immobilized, often in dorsal recumbency) [16,17]. However, with the exception of vaginal prolapse [18], there is scant data on the incidence and risk factors associated with these conditions in New Zealand flocks. In New Zealand, over the past 90 years, a process of culling and natural selection for dystocia and other undesirable traits have led to the development of sheep that are able to rear at least one lamb outdoors without assistance [19,20]. Therefore, on many farms, ewes receive limited or no shepherding over the lambing period. Internationally, a low level of shepherding (assistance) during the lambing period also occurs in other extensive pastoral-based sheep systems such as Australia and parts of the UK [21]. Limited shepherding in extensive systems has the major advantage of reduced labor input and, in New Zealand systems, generally results in similar perinatal lamb mortality rates compared with higher-intervention systems [22]. However, the potential impact of low intervention systems on ewe mortality has not been reported.

Ewe mortality can be used as an indicator of the animal welfare and health status of individual farms [4,12]. Given that welfare and survival are linked, it is important to take measures to decrease ewe mortality, and to identify the associated factors which will likely improve animal welfare. Further, looking ahead, ewe mortality may affect consumer purchasing decisions due to increasing demand from consumers for products perceived as ethical [3].

The aims of this study were to: (i) quantify the ewe mortality rate and determine the time of death over a 624-day time period; (ii) establish causes of ewe mortality during the lambing period; and (iii) investigate the association between productive parameters including live weight, body condition score, and litter size on both ewe mortality and becoming cast, during two years on a commercial farm in New Zealand.

2. Materials and Methods

2.1. Farm and Animals

The study was undertaken over a 624-day period encompassing two consecutive breeding and lambing periods. It utilized a cohort of 1789 ewes that were 16 to 19 months of age (two-tooths) at the beginning of the study. All ewes had given birth the previous year as ewe lambs. The ewes 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) and were a Coopworth × Composite breed. 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). Throughout the study, ewes were managed entirely outdoors (no housing) under commercial grazing conditions on pasture containing mostly perennial ryegrass (*Lolium perenne*) and white clover (*Trifolium repens*). No supplements were provided at any time. The ewes were under routine commercial management for sheep farms in the area (more details below). All the procedures undertaken in the present study were approved by the Massey University Animal Ethics Committee (MUAEC 19/48).

2.2. Climate Data

The study farm has a temperate oceanic climate (Cfb) based on the Köppen climate classification. The physical features making up the topography of the study farm were flat to rolling (46%), with easy hills (42%), and steep faces (12%) [23], with intervening gullies and streams. The altitude range is from 0 to 160 masl. The average annual rainfall is 1212 mm and the mean daily temperature ranges from 14 to 23.7 °C in summer and 7 to 15.5 °C in winter.

Daily rainfall, minimum temperature, and solar radiation data were obtained for the lambing monitoring periods in 2019 and 2020 (details below) by downloading data from the NIWA Virtual Climate Station Network for coordinates −37.475, 174.775 (www.data.niwa.co.nz; accessed 24 May 2021). These data were plotted along with casting events (details below).

2.3. Period of Study and Management

The study was undertaken from 25 March 2019 to 8 December 2020. Data were collected at eleven key management times when the ewes were yarded for commercial management events (ram introduction, ram removal, pregnancy diagnosis (PD), pre-lambing, mid-lactation, and weaning) and additionally when the ewes were monitored for a period of time over lambing (Table 1).

Table 1. Management events and data collection time points for a study investigating ewe mortality in a New Zealand sheep flock over two years.

Event	2019	2020
Ram introduction	25 March [1]	25 March [2]
Ram removal	8 May [1]	8 May
Pregnancy diagnosis (PD)	19 June [1,3]	4 June [1,3]
Pre-lambing	6 August [1]	4 August [1]
Lambing monitoring	12 August to 4 September [4]	16 August to 4 September [4]
Start of lambing	19 August	19 August
End of lambing	2 October	2 October
Mid-lactation	8 and 9 October [1]	8 October [1]
Weaning	12 December [1]	8 December [1]

[1] Weight and BCS data collected; [2] Weight data only collected; [3] Pregnancy diagnosis (litter size) data collected; [4] Researcher present on-farm for daily inspection of ewes and to collect death data.

From weaning to pre-lambing in each year, the ewes were managed in one or two large groups and moved to a new paddock every 2–5 days. During this time, observations of the ewes were largely limited to when they were moved (i.e., every 2–5 days) and during gathering for management events (Table 1). In each year, ewes were bred with entire rams for 44 days using mature rams at a ram to ewe ratio of 1:80. Pregnancy diagnosis (PD) was conducted in mid-pregnancy using trans-abdominal ultrasound approximately 45 days after ram removal. 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. Ewes that were non-pregnant were culled as standard management practice of the farm. From PD until pre-lambing, twin- and triplet-bearing ewes were managed in one mob, while single-bearing ewes and those in an earlier stage of gestation (i.e., later-lambing ewes) were managed in another mob with the intention of providing greater nutritional allowances for the twin- and triplet-bearing ewes as per normal farm practice. However, pasture allowances were not measured. Thirteen to fifteen days before the expected start of lambing, ewes were allocated to individual lambing paddocks at a rate of 4–10 per hectare based on litter size, pasture cover, and whether they were expected to be early- or late-lambing. In 2019, they were allocated to 12 lambing paddocks covering 260 ha, while in 2020 they were allocated to 15 paddocks covering 219 ha. The topography in each paddock comprised varying amounts of flat to rolling, easier hills, and steeper faces, as well as variable amounts of scrub, swamp, and other un-grazeable area. The ewes remained in these paddocks until weaning, and minimal observations were undertaken except during the lambing monitoring period (details below) and during gathering in mid-lactation (Table 1). Ewes were shorn twice-yearly, once in December and once just prior to PD in June.

2.4. Live Body Weight and Body Condition Score Measures

Live weight and body condition score (BCS) were recorded by researchers at eleven visits: ram introduction (weight only in 2020), ram removal (2019 only), pregnancy diagnosis, pre-lambing, mid-lactation, and weaning (Table 1). Ewes were weighed to the nearest 0.5 kg in a commercial weigh crate (Racewell™, Te Pari, Oamaru, New Zealand). Ewe live weight gain (g/day) between each weighing event was calculated using the following equation.

$$Live\ weight\ gain = \frac{end\ live\ weight\ (kg) - start\ live\ weight\ (kg)}{number\ of\ days\ between\ weighing\ events} \times 1000$$

Ewe BCS was determined using a 5-point scale (1.0–5.0, in 0.5 intervals), indicating a score of 1.0 as emaciated and 5.0 as obese [24,25]. The BCS measurements were undertaken by a single experienced technician at all time points. As there were few ewes at BCS <2.0 or >4.0, for analysis the BCS categories were condensed to $\leq$2.0, 2.5, 3.0, 3.5, and $\geq$4.0.

Ewes with no liveweight or BCS recorded at two consecutive events were considered as missing ewes unless their body was found, in which case they were classified as confirmed dead.

2.5. Monitoring during Lambing

For 24 days in 2019 and 20 days in 2020, starting 2–6 days prior to the start of lambing, all ewes were observed once a day by a researcher using a variety of techniques: visually using binoculars, driving or walking through the paddocks, and from real-time 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 to all parts of the paddock was difficult. The maximum altitude of each drone flight was 100 m above sea level, to comply with the Civil Aviation Authority of New Zealand (CAA) and the Ministry of Transport guidelines for flying unmanned craft [26], and it was only used when the weather permitted.

During these observations, dead or compromised ewes were identified. Compromised ewes that required intervention were restrained and assessed based on the severity of presenting conditions and either treated if possible or euthanized on welfare grounds. Scoring systems were developed to record interventions for compromised ewes and these were classified as: alive—a ewe that would have survived without intervention; probably dead—a ewe that most likely would have died without intervention; or dead—a ewe that would have died without intervention being provided. Scoring scales for cast (recumbent on back), dystocia, vaginal prolapse, and mastitis are described in Tables 2–5. 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 2. Scoring scale for ewes being cast (recumbent on back), according to their vigor, manipulation needed to resolve the cast, time to walk after assistance given, and the likely outcome without intervention.

Score	Vigor [1]	Manipulation [2]	Time to Walk after Assistance Given	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 min	Probably dead
4	Weak	Required a medium push. No reaction to human presence	More than 3 min	Dead
5	None	Required a hard push. No reaction to human presence	More than 3 min	Dead

[1] Effort made by ewe in attempting to stand up prior to assistance being given. Strong: ewe with continuous movement. Medium: ewe spends 50% to 90% of the time moving. Weak: less than 50% of the time moving; [2] Manipulation required in order to resolve the cast; [3] In the absence of intervention.

Table 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 [1,3]	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 [27]. LambEase (ease of lambing) score; [2] Adapted from [28]. Birth assistance scores; [3] Intervention required in order to resolve the dystocia; [4] In the absence of intervention.

Table 4. Scoring scale for ewes with vaginal prolapse, clinical grading scale, manipulation required to resolve prolapse, and the likely outcome for the ewe without intervention.

Score	Clinical Grading Scale [1]	Manipulation [2]	Likely to Have Lambed without Assistance?	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, euthanized	No	Dead

[1] Adapted from [29]; [2] Manipulation required in order to resolve the vaginal prolapse; [3] In the absence of intervention.

Table 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 of Udder	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.

Outside of the lambing monitoring periods (i.e., the remaining 580 days of the study), farm staff were encouraged, but not obliged, to record the identification number of any dead ewes and report these to the researchers.

2.6. Post Mortem Examination

During the lambing monitoring period, all identified dead ewes had a field necropsy undertaken to identify the most probable cause of death [30,31]. Biopsies, tissue, and blood samples were not collected for further pathology analysis due to the remote location of the farm and, therefore, the cause of death was based solely on the gross field autopsy and daily observations of the flock.

2.7. Data Management and Statistical Analyses

All analyses were conducted using SAS software (Statistical Analysis System, version 9.4.01; SAS Institute Inc., Cary, NC, USA).

2.7.1. Missing Ewes, Assumed Dead and Confirmed Dead

Ewes were classified as alive or dead according to their presence or absence at each weighing event. 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; or (iii) "confirmed dead"—known to have died because their body was found. Therefore, the mortality rate was based on the combination of 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 specific periods were calculated with the following equations:

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

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

Data analysis for 2019 and 2020 only included those ewes that were pregnant in those years, respectively, as all non-pregnant ewes in each year were culled from the flock (n = 83 and 17, respectively).

2.7.2. Statistical Analyses

Descriptive statistics, including the frequency and percentage of ewes, were computed for ewes that died between each weighing event (ram introduction, ram removal, pregnancy diagnosis, pre-lambing, mid-lactation, and weaning), those that died between each year (2019 and 2020), or those that were found cast during lambing.

The associations of the risk of death or being found cast during lambing with ewe live weight and BCS at each weighing event, live weight gain between each weighing event (g/day), and litter size identified at pregnancy diagnosis were investigated using the logistic procedure. Initially, the fixed effects of ewe live weight and BCS at each weighing event, live weight gain between each weighing event, and litter size was tested. Any fixed effect with an overall *p*-value of <0.2 was selected for inclusion in a multivariate analysis. Ewe live weight and live weight gain were not included in the same multivariate analysis. A backwards stepwise selection method was used to identify variables with a Wald test *p*-value of <0.1.

3. Results

3.1. Ewe Mortality

3.1.1. Descriptive Analysis

Over the 624-day study period, in the absence of intervention, it was assumed that 222 of the 1789 ewes would have died (12.4%). However, due to intervention during the lambing monitoring period, 180 ewes died (10.1%), indicating that intervention saved 42 ewes, 6 of whom were saved in both years (Table 6). In both years of the study, the largest number of deaths occurred between pre-lambing and mid-lactation (Table 6).

Table 6. Number of ewes alive at each management event, number that went missing or died in the intervening period, and mortality rate in a New Zealand sheep flock over two years both with and without invention during a 20–24 day monitoring period during lambing.

Year	Event	Alive without Intervention [1] (n)	Alive with Intervention (n) [2]	Missing (n) [3]	Assumed Dead (n) [4]	Confirmed Dead (n) [5]	Assumed Mortality Rate without Intervention (%) [6]	Mortality Rate with Intervention [7] (%)
2019	Ram introduction	1789	1789	-	-	-	-	-
	Ram removal	1785	1785	4	n/a	0	0.2	0.2
	Pregnancy diagnosis	1767	1767	17	n/a	1	1.0	1.0
	Pre-lambing	1760	1760	6	n/a	1	0.4	0.4
	Mid-lactation [8]	1710	1732	3	22	25	2.8	1.6
	Weaning	1697	1719	11	n/a	2	0.8	0.8
2020	Ram introduction	1682	1704	12	n/a	3	0.9	0.9
	Pregnancy diagnosis	1673	1695	9	n/a	0	0.5	0.5
	Pre-lambing	1645	1667	28	n/a	0	1.7	1.7
	Mid-lactation [8]	1590	1632	21	26 [9]	14	3.3	2.1
	Weaning	1567	1609	23	n/a	0	1.4	1.4
	TOTAL	-	-	134	48 (42) [9]	46	12.4	10.1

[1] Ewes present at each event if those that were assumed dead, had died; [2] Ewes that were actually present at each event (i.e., ewes that were assumed dead actually survived); [3] Ewes that were missing at that event and the subsequent event; [4] Ewes that would have died without intervention during the lambing monitoring period, but survived due to intervention; [5] Ewes that were found dead by either researchers or farm staff; [6] Calculated as (n missing + n assumed dead + n confirmed dead at event)/n alive without intervention at previous event × 100; [7] Calculated as (n missing + n confirmed dead at event)/n alive with intervention at previous event × 100; [8] 3–6 weeks after lambing. The period between pre-lambing and mid-lactation included a 20–24 day period when ewes were monitored daily by researchers; [9] Six ewes that were assumed dead during the lambing monitoring period of 2019 were also assumed dead during the lambing monitoring period of 2020.

During the two lambing monitoring periods, a total of 93 ewes died or were considered to have died. The most common cause of death in both years was cast, which was responsible for 57% and 79% of the deaths during the lambing monitoring period in 2019 and 2020, respectively (Table 7).

Table 7. Causes of ewe death (confirmed and assumed) during a 20–24 day period prior to, and during the early stages of, the lambing period on a New Zealand sheep farm over two years.

	2019			2020		
Cause of Death	**n**	**% Deaths [1]**	**Mortality Rate (%) [2,3]**	**n**	**% Deaths [1]**	**Mortality Rate (%) [2,4]**
Cast	31	57	1.8	31	79	1.9
Vaginal prolapse	11	20	0.6	3	8	0.2
Dystocia	3	6	0.2	2	5	0.1
Other	2	4	0.1	1	3	0.1
Unknown	7	13	0.4	2	5	0.1
TOTAL	54	100	3.1	39	100	2.3

[1] Calculated as a percentage of deaths during the lambing monitoring period; [2] Calculated as number of deaths (confirmed and assumed)/number of ewes present at pre-lambing ×100; [3] 1760 ewes present at pre-lambing; [4] 1667 ewes present at pre-lambing.

3.1.2. Risk Factors for Ewe Mortality

In 2019, the odds of death were influenced by liveweight gain between ram introduction and ram removal, whereby for every 10 g/day increase in liveweight the odds of death decreased by 0.975 (95% CI 0.925–0.998; $p = 0.03$). BCS had no effect on the odds of death. The odds of death were also associated with PD result (litter size), such that triplet-bearing ewes were more likely to die compared with single-bearing ewes. Using single-bearing ewes as a reference, the odds of death (95% CI) for twin-bearing ewes was 2.1 (95% CI 1.0–4.2; $p = 0.18$) and for triplet-bearing ewes was 4.5 (95% CI 1.9–11.0; $p = 0.004$). However, in a multivariate analysis, there were no significant variables when the cutoff was $p = 0.1$.

In 2020, the odds of death decreased with greater ewe liveweight at PD and pre-lambing, such that for every 1 kg of additional liveweight, the odds of death decreased by 0.960 (95% CI 0.929–0.993; $p = 0.01$) and 0.954 (95% CI 0.919–0.989; $p = 0.02$), respectively. In contrast, there was an increase in the odds of death with increasing ewe liveweight at mid-lactation, such that for every 1 kg of additional liveweight, the odds of death increased by 1.065 (95% CI 1.023–1.109; $p = 0.002$). For every 10 g/day increase in liveweight between ram introduction to PD, the odds of death increased by 1.018 (95% CI 1.004–1.033; $p = 0.038$). Considering BCS at PD, the odds of death decreased for ewes that were greater than BCS 2.0 (Table 8). However, in a multivariate analysis, there were no significant variables when the cutoff was $p = 0.1$.

Table 8. Odds of death (and 95% CI) for ewes at different body condition scores (BCS) at pregnancy diagnosis (mid-pregnancy) on a New Zealand sheep farm in 2020.

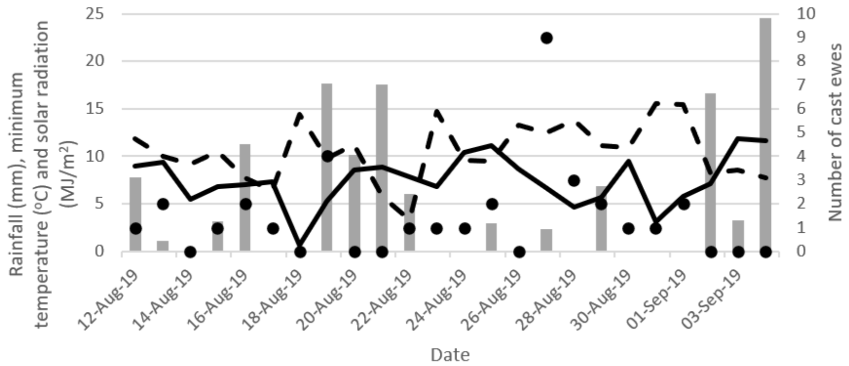
BCS	n	Odds of Death (95% CI)
≤2	47	ref
2.5	369	0.26 (0.13–0.55)
3	711	0.22 (0.11–0.45)
3.5	337	0.30 (0.15–0.62)
≥4	129	0.24 (0.10–0.59)
		$p = 0.001$

3.2. Cast Ewes

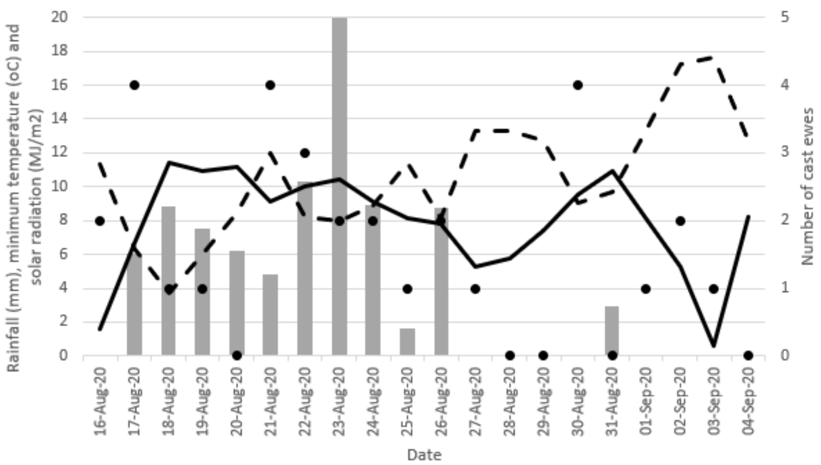
3.2.1. Descriptive Analysis

In total, 67 casting events involving 56 individual ewes occurred over the two lambing monitoring periods. In 2019, there were 35 casting events involving 31 ewes; 4 ewes were cast twice in that year. In 2020, there were 32 casting events involving 31 ewes; 1 ewe was cast twice in that year. Six ewes were cast in both 2019 and 2020. In all casting events, the ewe was either found dead (n = 9) or it was considered the ewe would have likely died without intervention (n = 58; score 3, 4 or 5; Table 2).

In both years, casting events occurred throughout the lambing monitoring period and there was no apparent relationship between weather conditions (minimum temperature, rainfall or solar radiation) and casting events (Figure 1a,b). Cast ewes were identified in 9/12 lambing paddocks in 2019 and 12/15 lambing paddocks in 2020. In both years, two of the three paddocks, in which no ewes became cast, contained single-bearing ewes only.



(**a**)



(**b**)

Figure 1. Rainfall (mm; grey bars), minimum temperature (°C; solid line), solar radiation (MJ/m^2; dashed line) and casting events (black circles) for ewes on a commercial farm in New Zealand monitored during a 16-day period prior to, and in the early stages of, the lambing period in (**a**) 2019 and (**b**) 2020.

3.2.2. Risk Factors for Cast Ewes

In 2019, the only factor associated with increased odds of becoming cast was litter size, such that triplet-bearing ewes were more likely to become cast than single-bearing ewes (OR 13.53, 95% CI 1.50–122.36; p = 0.03). There was no difference in the odds between single- and twin-bearing ewes or twin- and triplet-bearing ewes. In 2020, no factors (i.e., liveweight, BCS, or litter size) were significantly associated with the risk of becoming cast.

4. Discussion

In the absence of intervention, the mortality rate in this almost 2-year study would have been 12.4% or approximately 5.1–7.7% of ewes per year. This is below the average ewe mortality rates previously reported in other recent New Zealand studies under extensively grazed conditions [8,9]. Previous studies have identified that the pre-lambing to weaning period is the period in which the greatest proportion of ewes die on-farm; this was also found in the present study. In both years of the present study, casting events were the most common cause of ewe mortality (resulting in both confirmed death and assumed death) identified during the lambing monitoring period. Indeed, becoming cast during the 20–24 day monitored peripartum period was responsible for approximately a quarter to a third of the actual and potential annual ewe mortality in this study. Hence, while this study was only from a single farm, and is therefore limited in its scope, it does suggest that, on farms where casting events occur, daily monitoring of ewes over the peripartum period has the potential to result in a substantial reduction in annual ewe mortality. From a welfare perspective, ewe mortality is an indicator of animal well-being [4,32]. The identification of this period with the greatest proportion of ewe death will help to identify management conditions and preventive practices to improve animal welfare through reducing ewe mortality. It must also be recognized that ewe death during the peripartum period also results in lamb death so any reduction in ewe deaths will result in more lambs being born and reared successfully. It suggests that ewe death is an important contributor to lamb wastage; this aspect should be included in future studies investigating factors affecting perinatal lamb survival.

There were limited associations between liveweight, BCS, and the risk of death. Mid-pregnancy BCS of ≤2.0 was associated with an increase in the odds of death for ewes in 2020 which is consistent with [8]. This is the first New Zealand study to report on associations between liveweight and odds of death, and, in general, ewes at lower liveweight or with poorer liveweight gain had higher odds of death. Refs. [12,14] found a similar result in Australian Merino ewes. Ref. [14] reported that the risk of ewe death increased for each kilogram decrease in ewe live liveweight regardless of when was it measured. Ref. [12] found a higher risk of ewe death for ewes under 40 kg than those between 40 and 45 kg. Therefore, to reduce ewe losses, farmers need to consider management strategies, such as ensuring replacement ewes reach target weights. Regular whole-flock body condition scoring would allow identification of poor BCS ewes (≤2.5/5) and enable differential feeding to ensure all are in suitable condition for optimal production and, particularly at mid-pregnancy, to reduce mortality [8,25,33]. Due to the extensive nature of the production system, it was not possible to accurately record feeding levels.

This appears to be the first published study to have reported on the incidence and risk factors associated with casting events. Ewes became cast almost daily during the lambing monitoring (peripartum) period, casting events occurred in most paddocks, and there was no apparent association with climatic conditions. Litter size in 2019 was the only measured parameter that was associated with ewes becoming cast, although it is possible that the relatively small number of cast ewes limited the ability to identify other associations. However, these results suggest that there is no justification for prioritizing the monitoring of certain types of ewe, specific paddocks, or only during or after specific climatic conditions, in order to reduce casting events. Thus, if the primary objective of monitoring over the peripartum period is to identify and resolve cast ewes, then monitoring of all ewes should occur daily. One author has stated that winter shearing (in mid-gestation) is likely to reduce the incidence of cast [17]; however, in both years of this study, the ewes had been shorn in winter. It is unknown how wool length might affect the incidence of cast ewes. Eleven out of the fifty-six ewes that became cast were cast on more than one occasion and so farmers who monitor for cast ewes may wish to permanently identify these ewes and factor this into culling decisions.

A range of other causes of ewe death in the peripartum period have been reported, including vaginal prolapse, dystocia, and metabolic disorders [16,17]. The reported mean incidence of vaginal prolapse in New Zealand is 1% per annum but with large variation between farms and between years (range 0–5.9%) [18]. In the present study, only 0.6% and 0.2% of ewes had vaginal prolapse in 2019 and 2020, respectively, although the causes of death of the 24 ewes that went missing between pre-lambing and mid-lactation in 2019 and 2020 were unknown. Rates of dystocia in commercially farmed New Zealand sheep flocks have not been reported, but in this study only 0.1–0.2% of the ewes present pre-lambing died from dystocia. However, as with vaginal prolapse, it is possible that some of the missing ewes may have died from dystocia. In 2019 and 2020, 0.4% and 0.1%, respectively, of ewes that were found dead had died of unknown causes; it is possible that metabolic disorders may have been involved in some of these. However, laboratory testing was not undertaken as part of this study so it was not possible to investigate the potential role of metabolic disorders. It should be recognized that the ewes in this study were from a single age cohort (two-tooth in 2019; four-tooth in 2020, hence an age range from 16 to 39 months of age during the study), and so the reported causes of death may differ from what might be expected in younger or older ewes. For example, dystocia is reported to be more prevalent in first parity ewes, particularly ewe hoggets, compared with multiparous ewes [34].

In this study, 134 ewes were missing from at least two consecutive management events and were therefore assumed to have died. High rates of missing ewes on large, extensive New Zealand farms have been reported previously [8,9]. Of the 111 ewes that died or were assumed to have died between pre-lambing and mid-lactation in 2019 and 2020, during which the lambing monitoring periods occurred, a total of 24 ewes were missing but their bodies were not found. However the pre-lambing to mid-lactation period in 2019 and 2020, respectively, was 63 and 65 days whereas the lambing monitoring period was only 24 and 20 days, respectively, so it was not possible to determine how successful the researchers were at finding all dead ewes during the lambing monitoring period. Only 46 ewes were confirmed dead (bodies found) during the 624-day study and 39 of these were found by the researchers during the lambing monitoring periods. Outside of that period, the farm staff were encouraged, but not obliged, to identify and report dead ewes but only seven dead ewes were reported. It is unknown whether they found some of the missing ewes and did not report them, or whether they were never found. Nevertheless, this result is consistent with other studies undertaken on commercial farms where missing ewes were not found dead but were assumed to have died based on their absence at subsequent data collection events [8,9]. These studies and the present study emphasize the difficulty in physically identifying dead ewes on extensive commercial farms. There are no predators in New Zealand capable of killing adult ewes or consuming entire carcasses.

The major limitation of this study is that it took place on only one farm. However, it is well established that ewe mortality rates in New Zealand and other extensive pastoral sheep systems around the world are variable but can be relatively high, and the present study confirms that the majority of ewe deaths occur from late pregnancy to mid-lactation. It is likely that the causes of ewe mortality will vary between production systems and between individual farms with similar production systems, but this study emphasizes that if farmers wish to reduce ewe mortality rates then they should target this time period. To reduce ewe mortality rates and, by extension, perinatal lamb mortality, individual farms would ideally implement measures to gain an understanding of their causes of ewe death during this period in order to identify appropriate interventions.

5. Conclusions

Ewe deaths occurred throughout both years of the study but occurred most frequently during the pre-lambing to mid-lactation period. The main reason for actual and potential deaths during this period was ewes becoming cast. Casting events identified over a 20–24 day peripartum period each year were responsible for a quarter to a third of the potential annual ewe mortality on the farm. No risk factors were consistently associated with casting events; on farms where casting events occur, it is recommended that ewes are monitored daily during the peripartum period. Farmers might reduce ewe death and subsequent lamb death with daily monitoring during the peripartum period, thereby improving animal welfare. However, further analysis on labor cost and practicality of lambing monitoring in extensive rearing systems is essential. It is suggested that ensuring ewes are BCS > 2 at mid-pregnancy will decrease ewe mortality; therefore, it is recommended that farmers monitor individual ewes to maintain BCS of >2. Further research is required on more farms to investigate the causes of ewe death during the peripartum period and to identify interventions that could reduce mortality.

Author Contributions: Conceptualization: A.L.R., R.A.C.-T.; methodology: A.L.R., P.R.K., R.A.C.-T., K.J.F.; software: K.C.-O., R.A.C.-T.; formal analysis: R.A.C.-T.; investigation: K.C.-O., A.L.R., K.J.F.; data curation: K.C.-O., A.L.R., R.A.C.-T.; writing—original draft preparation: A.L.R., K.C.-O.; writing—review and editing: all authors; supervision: P.R.K., A.L.R., R.A.C.-T.; project administration: A.L.R.; funding acquisition: A.L.R., P.R.K., K.J.F. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by the C. Alma Baker Trust, New Zealand. No grant number is available.

Institutional Review Board Statement: The study was conducted according to the guidelines of the Declaration of Helsinki, and approved by the Ethics Committee of Massey University (protocol code MUAEC 19/48, 17 May 2019).

Data Availability Statement: The data utilised in this study are available on request from the corresponding author.

Acknowledgments: The authors wish to thank the farm manager and farm staff for their involvement in the study and Geoff Purchas for technical assistance.

Conflicts of Interest: The authors declare no conflict of interest.

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