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Declaration

I hereby declare that this thesis is the results of my own investigations, except where otherwise stated. All other sources are acknowledged by bibliographic references. This work has not previously been accepted in substance for any degree and is not being concurrently submitted in candidature for any degree unless, as agreed by the University, for approved dual awards.

Contents

Abstract

Exposure is one of the greatest contributors to neonatal lamb mortality on outdoor lambing systems in the UK. Effective shelter has been predicted to reduce neonatal lamb mortality rates by up to half during periods of inclement weather. However, it is unclear how shelter provision influences the prevalence of other shepherding problems such as dystocia, ewe mismothering behaviour and poor lamb vigour. Periods of high wind speed and rainfall have been shown to influence shelter usage, however, it is not yet known how ewe factors such as breed, age and body condition score influence shelter-seeking behaviour. This study conducted on a working upland farm in the UK, was the first trial to quantify these variables. Firstly, it assessed the impact of shelter provision on the prevalence of shepherding problems. Secondly, it examined the and biological factors that influence individual ewe behaviour around natural and artificial shelter. Lambing ewes (n=147) were allocated on the basis of breed then age between two adjacent fields (total 6.3 hectares/stocking density 23 sheep/hectare); one field had existing natural shelter that was reinforced with three artificial shelters; the other exposed field was used as a control. Individual ewes were observed every 2 hours between 0800-1600 for 14 continuous days to monitor their location relative to shelter. Ewe breed (Aberfield and Highlander), age (2 to 8 years) and body condition score were considered as explanatory variables to explain flock and individual variance in shelter-seeking behaviour and the prevalence of shepherding problems. Any ewe observed with dystocia, a dead or poor vigour lamb or who exhibited mismothering behaviour was recorded as a shepherding problem. Mood's median and Kruskal-Wallis tests were used to see how variables such as field allocation, the presence of a lamb and ewe breed, age and BCS influenced a ewe's preference for shelter. Chi-square tests were used to see how the prevalence of shepherding problems varied between fields, breeds, age categories and ewe BCS. Windspeed (P=0.007) and the presence of a lamb (P=0.003) were highly significant in influencing ewe behaviour. Overall, ewes across both breeds that were given access to shelter experienced fewer shepherding problems than those without (P=0.048). This was reflected in a breed effect, with Highlander ewes significantly more likely to seek shelter than Aberfield ewes (P=0.001), and presenting significantly fewer shepherding problems (P=0.035).

This was a relatively low power study with a narrow range of climatic variables, therefore, for shelter to still have a significant influence in reducing the prevalence of shepherding problems is an important finding. A proven reduction in shepherding workload through the provision of shelter provides an industry incentive to adopt similar shelter interventions on upland farms in the UK.

Keywords: exposure, lamb survival, production, welfare, wind chill

Implications

The impact that shelter has on the prevalence of neonatal problems and shepherding workload is an important factor to consider in terms of the health, welfare and productivity of UK sheep (*Ovis aries*) flocks. The factors that influence ewe usage of both artificial and natural shelter on a typical working upland farm are crucial to inform the strategic placing of shelter and maximise the effectiveness of shelter provision for industry.

Acknowledgements

This study was funded by Innovis Ltd. and KESS 2. KESS 2 is a pan-Wales higher level skills initiative led by Bangor University on behalf of the Higher Education sector in Wales. It is part-funded by the Welsh Government's European Social Fund convergence programme for West Wales and the Valleys. The authors would personally like to thank the shepherding staff at the study farm for enabling this trial to be conducted on their breeding flock; without their collaboration this project would not have been possible.

1. Introduction

UK lamb mortality between mid-pregnancy and sale is quoted as ranging from 10 to 25% (Mellor and Stafford, 2004) and has been reported anecdotally as being as high as 30–40% on individual farms (Gascoigne *et al.*, 2017). Furthermore, there has been no documented reduction in lamb mortality since the 1970s (Gascoigne *et al.*, 2017). The majority of lamb losses occur in the neonatal period (first 7 days of life), with the first 48 hours being the highest risk period (Mellor and Stafford, 2004). Exposure-related mortality is a major contributor to neonatal deaths on outdoor-lambing systems (Dwyer, 2008; Gascoigne *et al.*, 2017). In addition to the economic costs that neonatal mortality causes the industry, exposure is recognised as an important welfare issue for UK flocks (Mellor and Stafford, 2004; Dwyer, 2008).

Cold-exposure impacts upon the lambs' cognitive functions and their ability to stand and suckle at birth, resulting in poor lamb vigour and death due to hypothermia and starvation (Dwyer, 2008). Cold-starvation syndrome has been cited as accounting for 30% of neonatal mortality cases (Olsen *et al.*, 1987), though this could notably increase in periods of extreme cold weather during lambing. Indeed, Huffman *et al.,* (1985) examined the predictors of neonatal mortality and found 58% of lamb deaths were due to starvation. Interestingly, there may be a delay between cold-exposure and lamb death. Horton *et al.* (2019) found that deaths on the day of birth were not strongly associated with a high chill index, but deaths in the following 3 days were significantly increased by a high chill index during that period. This could be important for deciding on an appropriate time-frame when looking for correlations.Cold-exposure has also been seen to result in a 20% lower average daily weight gain (**ADG**) of lambs under experimental conditions (De *et al*., 2018).

The impact of wind speed and evaporation, of rain or amniotic fluid, are additive as the lamb rapidly loses heat through radiation and conduction (Pollard, 2006). Lamb mortality rates can exceed 70% in wet conditions where wind speed exceeds 5 ms^{-1} (Obst and Ellis, 1977). Donnelly (1984) created a model with various climatic parameters that predicted effective shelter could reduce lamb mortality rates up to 50% during inclement weather. Shelter modifies the microclimate by funnelling the wind over the top and around the edges of a structure, creating a shelter zone underneath.

The shelter zone is predominantly on the leeward side and encompasses a distance of approximately 14 times the height (**H**) of the shelter. Some shelter (about 2 H) is also provided on the windward side (Gregory, 1995). Location, height, and wind porosity are stated as the most important factors to consider when looking at the role of shelters in reducing wind speed (Gregory, 1995).

Ewe utilisation of shelter is an important variable in terms of the efficacy of shelter on overall flock performance (Bird et al., 1984). Factors influencing the use of shelter by lambing ewes include accessibility, climate, time of day and the duration since the ewes were last shorn (Gregory, 1995; Pollard *et al*., 1999). Other factors that might influence behaviour could include stocking density, ewe social interactions and visibility to predators. Another discussion point is that as ewes have a tendency to separate away from the rest of the flock to lamb; which may result in them moving away from sheltered areas if the shelter zone is limited (Gregory, 1995). Alternatively, high-stocking densities around limited shelter might also result in mismothering behaviours. Lynch *et al*. (1980) demonstrated lamb mortality in sheltered paddocks was half that of unsheltered paddocks. The majority of ewes lambed down in the shelter zone and, as expected, the ewes made use of the shelter during the night and day at times of inclement weather. Interestingly, ewes used the shelter for an extended period of time beyond when the shelter provided a physiological benefit, based on published figures for ewe thermoneutral temperatures (Donnelly *et al*., 1974). It was postulated that the ewes had become accustomed to the shelter and were using it as a ‘camp-area’. The sheep from the unsheltered paddocks failed to make use of the shelters when given the opportunity. This finding suggests that ewes should be given time to acclimatise to the shelter prior to the start of lambing. In an earlier behavioural study (Alexander *et al*., 1979), it was observed that ewes with lambs are less likely to seek shelter if it is widely dispersed compared to if it is more clustered and accessible. However, in inclement weather, such behavioural differences were negated as ewes would migrate towards the available shelter. However, desertion of neonatal lambs is an observed risk factor when ewes are required to travel long distances to seek shelter (Bird *et al*., 1984).

The sheltering behaviour of ewes-with-lambs and ewes-without-lambs has also been shown to differ, with the ewes-with-lambs being more clustered and ewes-without-lambs being more evenly distributed across the paddock. Alexander *et al*. (1979) observed that ewes separated away from the rest of the flock and chose sheltered areas on the periphery of the field where other ewes had lambed down previously. Differing wind porosity provided by different species of foliage within shelter has also been shown to influence the degree to which ewes will use shelter (Alexander *et al*., 1979). The paper concludes that the strategic placement of shelters at preferred lambing sites could be beneficial to lamb survival.

Twins and triplets can be a risk factor for lamb mortality (Huffman *et al*., 1985). Alexander *et al*. (1980) studied shelter and lamb survival interactions to find a 27% increase in single lamb survival when shelter from wind was provided in wet conditions < 5 °C, although no advantage was seen for twin lambs. More recently, Pollard (2006) found that the provision of shelter reduced mortality amongst both singles and twins (3-13% and 14-37% respectively) in cold or wet weather conditions, whereas shelter had no impact in reducing the mortality rate of twins. In contrast, Robertson *et al*. (2011) examined lamb survival around shrub belts and found that there was a 10% increase in survival for twins with shelter, but no effect on singles. It is worth noting however that they were unable to replicate these results over subsequent lambing seasons.

While the aforementioned studies focused on behaviour at a flock level, a recent study by Broster *et al*. (2017) used global positioning system trackers to assess individual ewe movement in relation to shelter sites at the time of lambing. To determine whether a ewe would choose to spend more time in a sheltered area, a preference index (**PI**), first proposed by Heady (1964), was used where a value > 1 indicates a preference for that site. Their findings showed that although a higher than expected proportion of ewes lambed down within the shelter zone, they did not spend additional time in the shelter zone before or after lambing. This is contrary to the findings of Lynch *et al*. (1980) who observed extended use of the shelter for days post-partum.

In addition to shelter provision there are many lamb and ewe factors that influence lamb survivability and so any intervention must be assed in the context of these other variables. These include, but are not limited to, breed, ewe nutrition, litter size, lamb birthweight, colostrum intake and the ewe-lamb bond (Dwyer *et al*. 2015, Kenyon *et al.*, 2019). Breed, birth weight, and litter size are particularly important in terms of a lamb's thermoregulative ability (Dwyer and Morgan, 2006). Appropriate breed choice is crucial when considering lamb survivability in upland outdoor lambing systems (Dwyer and Lawrence, 2005, Dwyer and Bünger, 2012). The link between ewe behaviour and lamb survivability has been an area extensively researched by Dwyer and Lawrence and highlights the importance of good ewe selection (Dwyer and Lawrence, 1999, Dwyer and Lawrence, 2000, Dwyer, 2014). Although there is limited data on the heritability of genetic factors that influence lamb survival, there are observable benefits in directly selecting for lamb suvivability, including mothering behaviour and lambing ease (Brien *et al.*, 2014).

The two objectives of the study were to:

- Assess the impact of shelter provision on the prevalence of shepherding problems including lamb mortality, lambs of poor vigour, dystocia and/or mismothering behaviour
- Examine the climatic and biological factors that influence individual ewe behaviour around natural and artificial shelter including windspeed, field allocation, the presence of a lamb and ewe breed, age and BCS

2. Material and methods

2.1 Study site

An independent randomised control trial was conducted at Ceredigion (52˚ 27' 26.298" N, 3˚57' 55.195" W) during April 2019. The trial fields were situated between 180 and 230 metres above sea level. Natural shelter was provided on the Northern periphery provided by a shallow ditch planted with gorse (*Ulex europaeus*). The quality of natural shelter in one field, provided by a continuous band of thick gorse and a deep ditch, was much greater compared to the natural shelter in the neighbouring field that had only a shallow ditch and isolated areas of limited gorse growth. The field with the greatest degree of natural shelter was chosen as the 'sheltered' field (3.3 hectares, 74 ewes, stocking density 22 ewes/hectare) and the adjacent ‘exposed’ field (3.0 hectares, 73 ewes, stocking density 24 ewes/hectare) was used as a control. The proportional area of land included in the ‘sheltered’ and ‘exposed’ quadrants was very similar between both fields.

2.2 Experimental design

Lambing ewes had historically been observed to lamb down at the top of the hill amongst the gorse cover. Two elongated s-shelters (*Shelter 1* 0.7m x 16.5m x 5.5m, visual porosity 0.05 and *Shelter 3* 0.7m x 26.5m x 8.5m, visual porosity 0.05) and one cross shelter (*Shelter 2* 0.7m x 8.0m x 7.5m, visual porosity 0.05) were built with tyres approximately 8 metres below the start of the gorse cover in the sheltered field (Figure 1). The linear artificial shelters were placed parallel to the natural shelter and were perpendicular to the prevailing wind (Southerly). The aim of these shelters was to the replicate the wind break effect provided by the natural shelter.

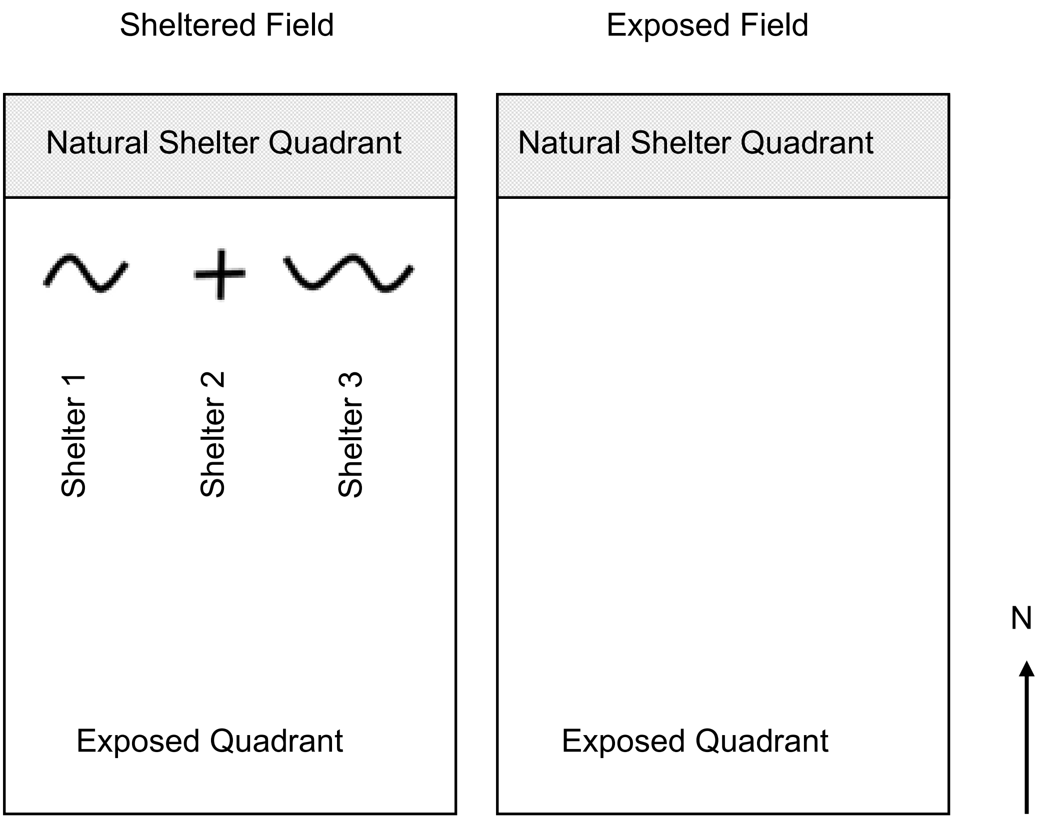

Figure 1 Schematic diagram of quadrants for *Sheltered* and *Exposed* trial fields

2.3 Climatic and spatial parameters

To measure the exposed weather conditions, an automatic weather station (**AWS**; Vantage Pro 2, Davis Instruments, USA) was set up in an exposed area on the periphery between the two fields. The AWS recorded rainfall, relative humidity, air temperature, wind direction and wind speed. The shelter zone was quantified by placing three 2D WindSonic anemometers (Gill Instruments, Hampshire, UK) connected to a CR1000 data logger (Campbell Scientific Inc, USA) at 0.5H and 5H on the leeward side and 5H on the windward side of one of the elongated s-shelters. Data was recorded at 30-minute intervals and downloaded from the anemometers and AWS approximately every 24 hours. Each field was then divided into quadrants and ewes were recorded as either being situated in the *Exposed*, *Natural Shelter*, or *Artificial Sheltered* quadrants (Figure 1). If the ewes were observed within the 5H (3.5 m) perimeter of any of the artificial shelters, they were recorded as using that specific shelter. If the ewes were observed amongst the gorse or in the ditch at the top of the field, they were recorded as using the natural shelter.

2.4 Ewe selection and identification

Two maternal lines, the Aberfield (n=81) and Highlander (n=66), were used. Only ewes scanned for twins were included in the trial. Parity was not a factor in ewe selection. Body condition score (**BCS**) is a five-point system used to describe the condition of a sheep based on palpation of the lumbar region (Russel, 1984). Any ewes under BCS 3.0 or whose health was otherwise compromised were excluded from the trial. The ewes were allocated on the basis of' breed, thenage (< 2 years, 2-5 years, and > 5 years) between the two fields to ensure an equal distribution of breeds and age categories. These age categories were chosen as gimmers (first-time lambing ewes) and older ewes (> 5 years) are at higher risk for shepherding problems (Olsen *et al.*, 1987).

In order to be able to identify individuals from a distance, the trial ewes were marked on their back and sides with a unique visual identifier (**ID**) that correlated to their electronic identifier number (**EID**).

2.5 Behavioural and biological parameters

The flock was observed for 14 continuous days. Observations were carried out at fixed time intervals (0800 h, 1000 h, 1200 h, 1400 h and 1600 h) for both the *Sheltered* and *Exposed* fields. On foot entry in to the fields was required for observation - the *Exposed* field was observed first followed by the *Sheltered* field. The ewe visual ID, litter size and quadrant were recorded for all individual ewes. Mismothering behaviour and lamb vigour were also recorded for ewes after they had lambed. Mismothering was categorised as the rejection of the lamb by the ewe, which included abandonment of the lamb or failure to allow the lamb to suckle. Lamb vigour was categorised as 'good' if the lamb was standing, suckling and keeping up with the ewe, and 'poor' if the lamb was unable to stand and suckle. A record was made of any human intervention that was required during the lambing period (including assistance at lambing, and housing). Dead lambs were collected off the field for post-mortem examination (**PME**). The location (field and quadrant), ewe visual ID and litter size were all recorded. Post-mortem examination was carried out to determine the time and cause of death (methodology adapted from Gascoigne *et al.*, 2017).

2.6 Statistical analysis

Shepherding problems were classed as any human intervention a ewe received during the neonatal period. This was a binary outcome for each ewe and included the presence of lamb mortality, lambs of poor vigour, dystocia and/or mismothering behaviour. Ewes with a litter size of one or ewes that did not lamb down during the trial period were excluded from the shepherding problem dataset (n=70). Chi-square tests were used to see how the prevalence of shepherding problems varied between fields, breeds, age categories and ewe BCS.

In order to quantify ewe shelter seeking behaviour, a PI (Broster *et al.,* 2017) was calculated for each ewe using the following equation (a value > 1 indicates a preference for that site):

$$PI = \frac{\text{proportion of time spent in area of interest}}{\text{proportion of area relative to entire area available}}$$

This calculation corrected for the variation in quadrant size. All ewes that started the trial were included in the PI data set (n=147). Box and whisker plots were used to describe the variation in PI between quadrants for the *Exposed* and *Sheltered* fields and to describe the variations in PI between the three artificial shelters. Mood's median tests were used to see how variables such as field allocation and the presence of a lamb influenced post-lambing PI. Mood's median and Kruskal-Wallis tests were also used to look at how ewe breed, age and BCS influenced PI. For significant results, the data was plotted using a box and whisker chart to determine the variance between and within groups. Non-parametric statistics were used throughout the analysis as it would have been inaccurate to assume a normal distribution. The data set was based on a small sample size, contained many nominal and ordinal observations and had significant outliers.

3. Results

3.1 Climatic summary and wind break effect

Mean rainfall over the trial period was 0.22 ± 0.05 mm/hr (mean ± SEM). Mean temperature was 6.18 ± 0.11 °C. Minimum mean temperature was 5.96 ± 0.11 °C. Wind direction was predominantly SE and ESE (62% of total measurements). The mean wind speeds for each distance (H) from Shelter 3 are shown in Table 1.

Table 1 *Mean and maximum wind speed measurements from Shelter 3*

	Position of anemometer			
	Exposed	Distance from shelter		
Wind speed[1]		0.5H North[2]	5H North	5H South
Mean (m/s)	3.73 (0.09)[a]	1.62 (0.03)	2.19 (0.02)	2.41 (0.03)
Maximum (m/s)	6.85 (0.13)	3.57 (0.05)	4.30 (0.04)	4.56 (0.05)

[1] Mean of half-hourly mean and maximum wind speed readings over the 14-day trial period

[2] Where H = height of shelter

[a] ± SEM included in brackets

3.2 Ewe location and climate

A Pearson's r correlation was used to see if wind speed, rainfall and temperature influenced the percentage of ewes observed in the *Exposed* quadrant in the *sheltered* field. Wind speeds were significant (*P*=0.007) in influencing ewe shelter-seeking behaviour, whereas rainfall (*P*=0.488) and air temperature (*P*=0.068) were not significant in altering shelter-seeking behaviour. *Figure 2* looks at wind speed and ewe location data collected at the same time-points for the *Sheltered* field. R^2 values were interpreted at >0.04 for the correlation to be deemed statistically significant and at >0.25 for a strong correlation to be stated (Ferguson, 2009). A weak negative correlation exists between the number of ewes observed in the *Exposed* quadrant and increasing wind speed ($r^2 = 0.057$). Although increased wind speeds did not appear to influence the use of *Artificial Shelter* ($r^2 = 0.000$); increased wind speeds did lead to an increase in the number of ewes seeking out *Natural Shelter* ($r^2 = 0.068$). The *Exposed* field, where the quality of shelter in the *Natural Shelter* quadrant was very limited, showed no correlation between ewe location and wind speed for the *Exposed* quadrant ($r^2 = 0.002$) or the *Natural Shelter* quadrant ($r^2 = 0.001$).

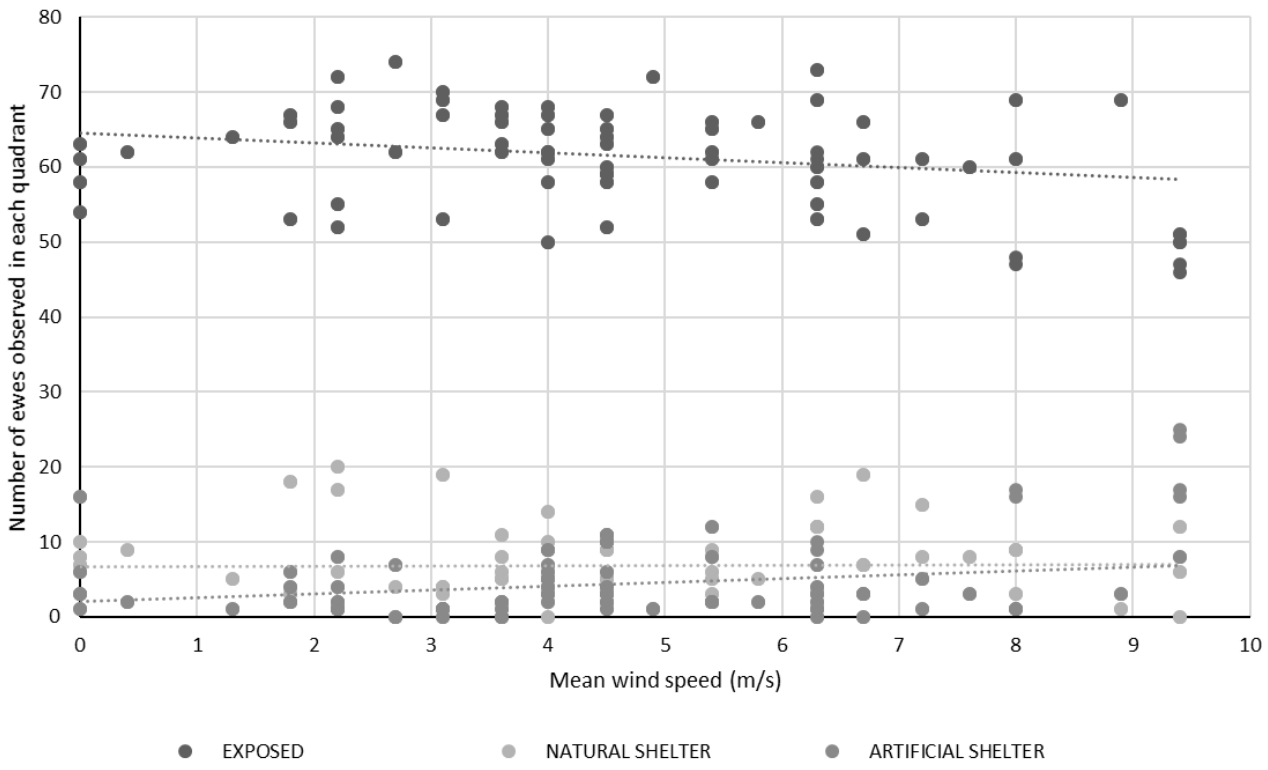

Figure 2 Scatter graph plotting wind speed and the number of ewes observed in each quadrant over 140 observations for *Sheltered Field* (with linear trend lines)

3.3 Shepherding problems in Exposed *versus* Sheltered *fields*

A Chi-square test for independence showed that field allocation was significant (*P*= 0.048) in influencing the prevalence of shepherding problems. Approximately, four times more ewes in the *Exposed* field (n=11) experienced shepherding problems than in the *Sheltered* field (n=3). The provision of shelter was therefore a significant variable in reducing the prevalence of shepherding problems; even when the ewes were given free choice to utilise it.

3.4 Shepherding problems and ewe breed, age and BCS

A Chi-square test for independence showed that breed was significant (*P*=0.035) in influencing the prevalence of shepherding problems. Highlander ewes experienced fewer shepherding problems than Aberfield ewes. Age was significant (*P*= 0.003) in contributing to an increased prevalence of shepherding problems in ewes over five years old. BCS was not significant (*P*=0.662) in influencing the prevalence of shepherding problems.

3.5 Lamb PME results

The cause of death for each lamb from the trial fields that received PME during the 2-week trial period (n = 18) was compared to a convenience sample of PMEs performed on lambs that had died from the rest of the 761 head lambing flock over the month of April (n = 54). The MG flock PMEs included commercial breed lambs, terminal breed lambs and singles. The actual number of lambs over the expected number of lambs was 73% for the *Exposed* field and 78% for the *Sheltered* field. A Chi-square of PME outcomes between the two treatments was not significant (*P*=0.743). The actual number of lambs over the expected number of lambs for the rest of the MG flock was 74%. The Chi-square between the two trial fields and the rest of the MG flock was not significant (*P*=0.847). Therefore, the mortality rate for the trial fields was representative of the rest of the flock. The causes of death identified at PME are shown in *Figure 2*. The causes of mortality observed in the trial field also appear representative of the rest of the MG flock.

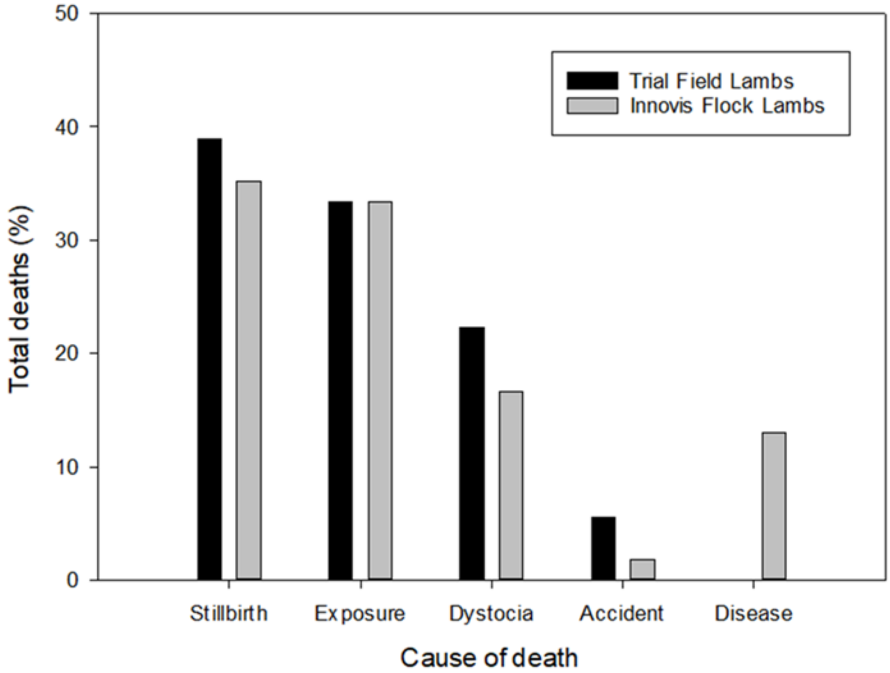

Figure3 Cause of lamb death identified on PME for trial and MG flock lambs

3.6 Ewe PI for Exposed, Natural Shelter *and* Artificial Shelter

There appeared to be some notable variation in flock PI between the *Sheltered* and *Exposed* quadrants *(Figures 4 and 5).* In the *Exposed* field the mean PI for the *Natural Shelter* quadrant (3.27) was 3.8 times greater than the mean PI for the *Exposed* quadrant (0.86). Likewise, in the *Sheltered* field with the mean PI for the *Natural Shelter* quadrant (4.81) being 5.5 times greater than the mean PI for the *Exposed* quadrant (0.87). Mean PI for the *Artificial Shelter (1.82)* was 2.1 times greater than for the mean PI for the *Exposed* quadrant. For both fields, the median PI values are also higher for the *Natural Shelter* than the *Artificial Shelter* quadrants. This shows that, at a flock level, there is a greater preference for spending time in areas with natural and artificial shelter post-lambing. However, it is worth noting the degree of individual variation in ewe PIs demonstrated in the *Figures*.

The PI for each of the artificial shelters is shown in *Figure 6*. There was a clear preference for *Shelter 1*, with a mean PI value of 4.2, while *Shelter 2* and *3* were not as popular (mean PI of 0.9 and 0.0 respectively).

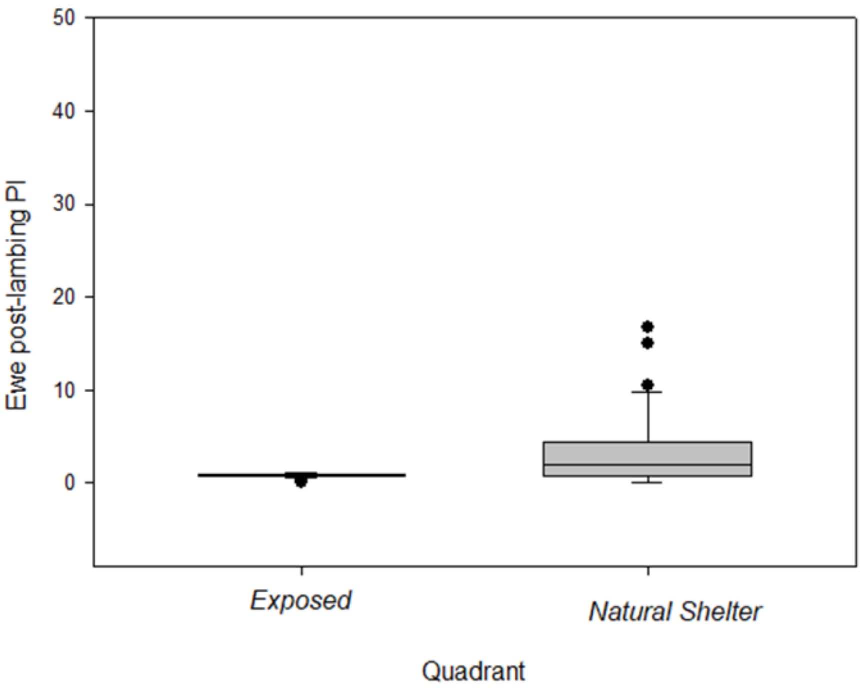

Figure 4 Ewe post-lambing PI for the *Exposed* and *Natural* Shelter quadrants in the *Exposed* field (boxplot with median bar, quartiles and SE)

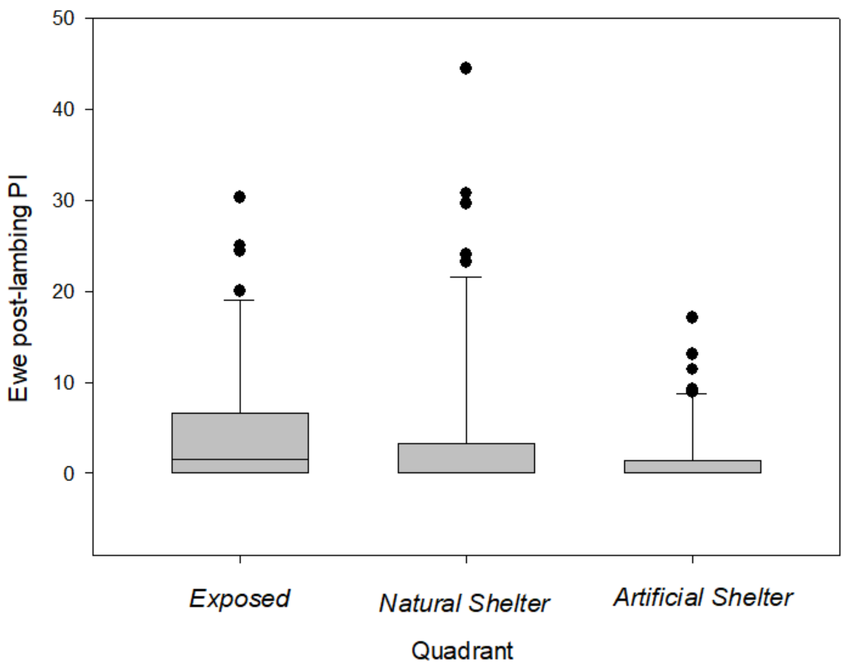

Figure 5 Ewe post-lambing PI for the *Exposed*, *Natural Shelter* and *Artificial Shelter* quadrants in the *Sheltered* field (boxplot with median bar, quartiles and SE)

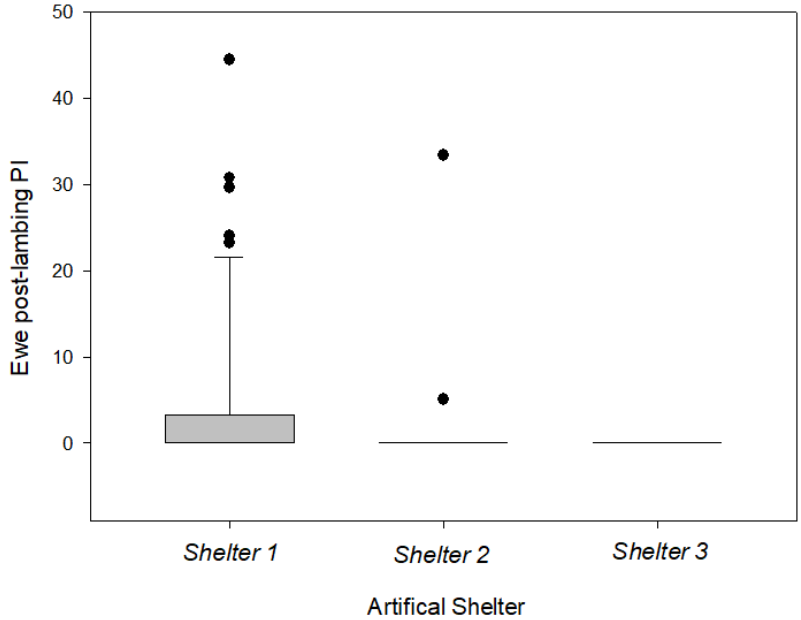

Figure 6 Ewe post-lambing PI for *Artificial Shelter* (boxplot with median bar, quartiles and SE)

3.7 Ewe PI pre-lambing versus post-lambing

A Mood's median showed that the presence of a lamb was highly significant (*P*=0.003) in influencing ewe post-lambing PI for the *Exposed* quadrant. Ewes demonstrated increased shelter-seeking behaviour after they had lambed down *(Figure 7)*. The pre-lambing mean PI for the *Exposed* quadrant was 1.01 before lambing compared to 0.95 after lambing.

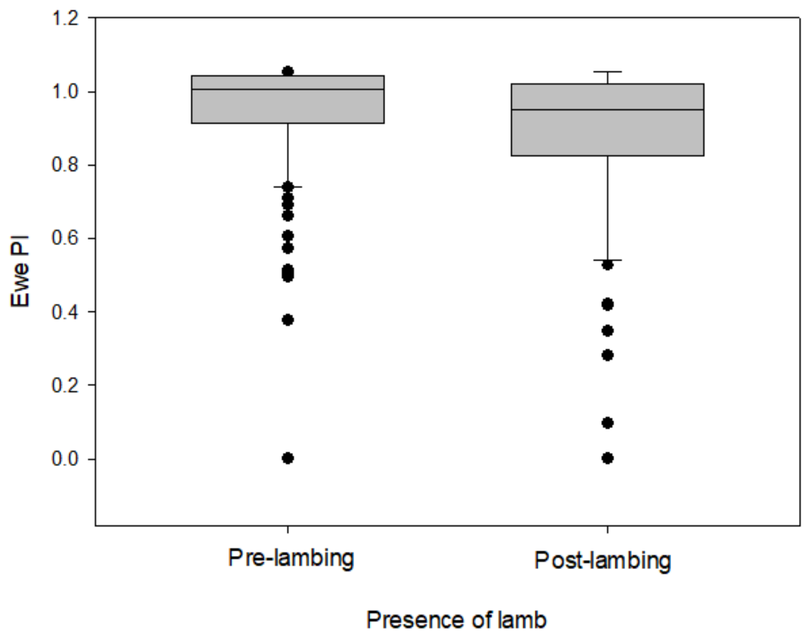

Figure 7 Ewe PI for the *Exposed* quadrant pre- and post- lambing (boxplot with median bar, quartiles and SE)

3.8 Ewe post-lambing PI for Sheltered *versus* Exposed *fields*

A Mood's median test showed that field allocation was not significant (*P*=0.913) in influencing ewe post-lambing PI for the *Exposed* quadrant and for the *Natural Shelter* quadrant (*P*=0.616). There was no significant difference in ewe shelter-seeking behaviour between the two fields.

3.9 Ewe post-lambing PI and ewe breed, age and BCS

A Mood's median test showed that ewe breed was highly significant (*P*=0.001) in influencing ewe post-lambing PI for the *Exposed* quadrant, with Highlander ewes demonstrating greater shelter-seeking behaviour than the Aberfield ewes *(Figure 8)*. The mean PI for the *Exposed* quadrant was 1.00 for Aberfields and 0.89 for Highlanders showing a relative indifference to shelter in the former breed but an obvious preference for shelter in the latter. BCS was not significant (*P*=0.733) in influencing ewe post-lambing PI for the *Exposed* quadrant. A Kruskal-Wallis test showed that age was not significant (P=0.334) in influencing ewe post-lambing PI for the *Exposed* quadrant.

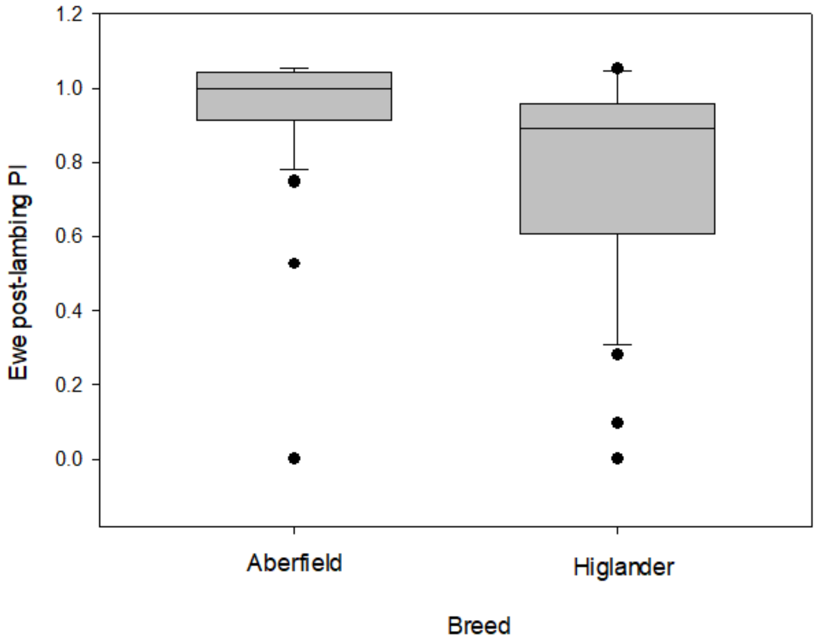

Figure 8 Breed and ewe post-lambing PI for the *Exposed* quadrant (boxplot with median bar, quartiles and SE)

4. Discussion

The majority of the literature that examines shelter interventions originates from Australasia and focuses primarily on the effect of natural shelter provision and climate on lamb mortality rates (Alexander *et al.* 1980; Bird *et al.*, 1984; Gregory, 1995; Pollard, 2006; Broster *et al.,* 2017). This study aimed to investigate how shelter provision affected the prevalence of shepherding problems including neonatal mortality, dystocia, ewe mismothering behaviours and poor lamb vigour. It also considered a range of ewe factors such as breed, age and body condition score to explain variances in ewe shelter-seeking behaviour. This trial is valuable in the fact it was carried out on a working upland farm where ewes were given the choice to seek out shelter. The artificial shelter was designed to be implementable at an industry level as well as highly reproducible for future studies.

This is the first study that has examined the cumulative prevalence of neonatal shepherding problems as supposed to just the binary outcome of mortality (Alexander *et al.*, 1980; Bird *et al.*, 1984; Broster *et al.,* 2017). Poor vigour lambs, dystocia, mismothering and mortality are all welfare issues (Dwyer, 2008) and contribute to a loss of production and an increased workload for the shepherd. It is therefore important to consider the interaction these outcomes have with respect to shelter provision and ewe behaviour. Due to the many variables influencing these outcomes, a much larger sample size would be required to consider these four outcomes individually. Cited lamb vigour and maternal behaviour scoring systems (Matheson *et al.,* 2010) were not suitable for this study due to the variation in lamb age at the point of the first observation, therefore, a binary system was created.

The *Sheltered* field had significantly fewer shepherding problems than the *Exposed* field. Considering the fairly stable weather conditions over the trial period and the relatively low power of the study; a significant P-value suggests that the benefits of shelter can still be observed with small numbers of sheep during fair weather. Based on the trends observed in previous studies, it is predicted that the true effect of this intervention could be greater if this study was to be carried out with a larger sample size and a greater range of climatic variables.

The size of the *Exposed* quadrant was almost identical for both fields; there may not have been a sufficient difference in shelter provision between the two fields to result in a highly significant difference in the prevalence of shepherding problems. In future studies, it would be useful to quantify the wind break effect of the *Natural Shelter* quadrant for both fields. Despite these limitations, the experimental design of this trial is likely to be much more representative of the current industry standard compared to trials carried out in experimental paddocks (Robertson *et al.*, 2011; Broster *et al.,* 2017).

Both breed and age had a significant impact on the prevalence of shepherding problems. Highlander ewes showed a greater PI for the *Sheltered* quadrants, which may explain the smaller prevalence of shepherding problems compared to the Aberfield ewes. Age was also significant in influencing the prevalence shepherding problems for ewes over 5 years (Olsen *et al.*, 1987); however, it is worth noting that this age group only comprised 10% of the flock. As the ewes were 'allocated on the basis of' breed and age, these variables are unlikely to explain the difference in the prevalence of shepherding problems between the two fields.
As BCS was addressed during the ewe selection stage, this variable was unlikely to have an effect.

The mortality rate and the causes of mortality in the trial fields appears to be representative of the rest of the MG flock. The increase in disease observed in the MG flock lambs can be attributed to the increased infection risk due to the increased number of terminal breeds that were housed with shepherding problems and also to the older age of the MG flock lambs (up to 4 weeks).

Wind speed was significant in influencing ewe shelter-seeking behaviour, which is a well cited variable in the literature (Pollard *et al.*, 1999). Rainfall and temperature were insignificant but there was likely to have been insufficient variation over the trial period for these factors to have had a detectable influence on ewe behaviour. The very limited range in mean and maximum temperature and windspeed over the study period suggests that 30 minute intervals for climatic measurements might not have been sensitive enough to demonstrate the true variance during stable weather conditions. If there had been a significant temperature correlation it would have been interesting to calculate 'wind chill' to determine whether an interaction between windspeed and temperature affected ewes' shelter-seeking behaviour. In addition, it would be useful in future studies to consider the impact of weather on mortality rates; this would involve organising the data by birth dates and looking at weather conditions and mortality for the three days following birth (Horton *et al.*, 2019).It would be inaccurate to assume that the *Exposed* quadrant had a uniform degree of exposure across the whole site, given the relief of the trial fields. This may mean that true shelter-seeking behaviour was underestimated as there were naturally more sheltered areas in the *Exposed* quadrant that ewes sought out. Wind speed measurements over the field topography would have been useful to assess the variance in wind speed over the *Exposed* quadrant and compare the wind speed at the different artificial shelter locations. It would have been beneficial to have mapped the wind break effect of all three artificial shelters and the natural shelter (in both the *Sheltered* and *Exposed* fields) to see if this might be an explanatory variable for the difference in ewe utilisation. Rainfall and temperature measurements for the *Artificial* and *Natural Shelter* quadrants would be other important variables to consider (Broster *et al.,* 2017).

The shelter zone was defined as 5H from the shelter as a small perimeter increased the probability that the ewe had chosen to seek out artificial shelter as supposed to be in that quadrant by random chance. Wind speed data from *Shelter 3* showed that the shelter design resulted in a reduction in wind speed on both the leeward and windward sides.

There did not appear to be significant variation in ewe post-lambing PI between quadrants. However, considering the very limited period of observations compared to the duration of time the ewes had access to the shelter, it was unlikely that any variation would be detectable. The use of PIs to quantify ewe behaviour would have provided greater statistical power if it were possible to monitor ewe movement continuously throughout the day (Broster *et al.,* 2017). It is likely that actual shelter usage was underestimated due to the limited number of observations a day. There were also no observations during the night; when there is usually an increase in shelter-seeking behaviour (Lynch *et al.,* 1980).

There was a significant change in ewe shelter-seeking behaviour post-lambing'.This correlates with the findings of previous studies (Pollard *et al.,* 1999). This effect is likely to have been underrepresented as there was a significant lag phase of up to 14 days of observations after the ewes had lambed down. By focusing on the 48 h prior to lambing and the 72 h after lambing, it might have been possible to get a more accurate representation of how ewe behaviour changes during the peri-parturient period (Pollard *et al.* 1999). BCS was insignificant in influencing PI or the prevalence of shepherding problems; which was as expected as only ewes of BCS 3 or 4 were included in the trial.

Shelter 1 was the most popular of the three artificial shelters. *Shelter 2* saw limited use and *Shelter 3* was hardly used at all. It is possible that the presence of the climatic equipment and the fact that the observer entered the field near to *Shelter 3* deterred lambing-ewes from using it. To reduce this impact, the observer should enter the field at a point remote from any of the shelters. The most popular area of the *Natural Shelter* quadrant for lambing–down appeared to be to the West, above the location of *Shelter 1*. Anecdotally, the study ewes preferred to lamb down in *Natural Shelter* and then use *Shelter 1* as a camp area once the lambs were over a day old. The prolonged use of shelters as a camp area, when it no longer offered a thermoregulatory benefit, is discussed in a study by Lynch *et al.* (1980).. During periods of inclement weather, ewes tended to congregate around *Shelter 1,* irrespective of whether they had a lamb at foot, leading to high stocking densities unsuitable for lambing ewes.

This study, due to the small sample size and the known influence of group behaviour on flocks, would greatly benefit from further replications. If the trial were to be repeated with a larger sample size, it would be advantageous to be able to view both fields simultaneously – this could also allow for a greater number of daily observations. In this study, the time delay between checking the two fields was minimal and hence the impact on the accuracy of the time-point data negligible. Likewise, if it were possible to view the field remotely (possibly with the use of GPS tagging and a UAV) then this would remove the behavioural errors caused by the presence of the observer and allow for much more detailed observation.

5. Conclusion

Windspeed and the presence of a lamb were highly significant in increasing ewe shelter-seeking behaviour which replicates the results of previous studies. The provision of shelter resulted in a significant reduction of shepherding problems in both Aberfield and Highlander breeds. The Highlander breed demonstrated both a greater preference for shelter and a reduction in the prevalence of shepherding problems. The link between breed type preference for shelter and the prevalence of shepherding problems should be considered in the context of other variables.

In all weather conditions, when ewes are given free choice to access shelter, increased shelter utilisation can result in a reduction in peri-parturient problems and shepherding workload. Although both breeds benefitted from the intervention, breed choice is an important variable to consider when determining the efficacy of shelter provision in sheep livestock farming systems.

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