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Spatial behaviour of sheep during the neonatal period: Preliminary study on the influence of shelter

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Abstract

Effective shelter has been demonstrated to reduce neonatal lamb mortality rates during periods of inclement weather. 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, examined impact of artificial shelter on the biological and climatic factors that influence peri-parturient ewe behaviour. Pregnant ewes (n=147) were randomly allocated between two adjacent fields which were selected for their similarity in size, topography, pasture management, orientation to the prevailing wind and available natural shelter. In one field, three additional artificial shelters were installed to increase the available shelter for ewes, this field was designated the *Test* field; no additional artificial shelter was provided in the second field which was used as the *Control* field. 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 issues which required the intervention of the shepherd, termed ‘shepherding problems’. Any ewe observed with dystocia, a dead or poor vigour lamb or who exhibited mismothering behaviour was recorded as a shepherding problem. The prevalence of these shepherding problems which necessitate human intervention represents arguably the most critical limiting factor for the successful management of commercial sheep flocks in outdoor lambing systems. Overall, ewes in the *Test* field with access to additional artificial shelter experienced fewer shepherding problems than those in the *Control* field ($P < 0.05$). A significant breed effect was also observed, with Highlander ewes more likely to seek shelter than

Aberfield ewes ($P < 0.001$), and experiencing significantly fewer shepherding interventions ($P < 0.05$). These findings demonstrate the substantial and significant benefits to animal welfare and productivity that can be achieved through the provision of artificial shelter in commercial, upland, outdoor lambing systems in the UK.

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

Implications

Ewe behaviour around shelter is an important factor in successful outdoor lambing systems. The provision of artificial shelter in this trial resulted in a significant reduction in peri-parturient health and welfare problems; specifically, the cumulative incidence of mortality, dystocia, mismothering and poor lamb vigour. These benefits were observed despite the comparatively mild, stable weather conditions measured over the trial period. The effects observed may have been more pronounced under more severe weather conditions. Breed was an important variable when comparing the spatial behaviour of ewes around shelter. This research demonstrates that both shelter provision and breed choice are important variables when attempting to reduce shepherding workload and improve neonatal outcomes.

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). 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). Hypothermia and other exposure-related conditions are the major contributors to neonatal mortality in 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 30-58% of neonatal mortality cases (Huffman *et al.,* 1985; Olsen *et al.*, 1987).

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 m/s (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 (Gregory, 1995). 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 porosity (influenced by density and species of foliage) are stated as the most important factors to consider when looking at the role of shelters in reducing wind speed (Alexander *et al*., 1979; Gregory, 1995). Shelter placement and the consistency of wind direction are also crucial factors in the efficacy of shelter as variability in wind direction will affect the area protected by the shelter (Wang and Takle, 1996). The utilisation of shelter by lambing ewes is influenced by accessibility, climate, time of day and the duration since the ewes were last shorn (Bird *et al.*, 1984; Gregory, 1995;

Pollard *et al*., 1999). Other factors that might influence behaviour include flock size (Kleemann *et al.*, 2006), stocking density (Alexander, 1984; Broster *et al.*, 2012; Robertson *et al.*, 2012), ewe social interactions (Broster *et al.*, 2010), and visibility to predators. Ewes also have a tendency to separate away from the rest of the flock to lamb (Alexander *et al*., 1979); 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 (Alexander, 1984).

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. Desertion of neonatal lambs is indeed an observed risk factor when ewes are required to travel long distances to seek shelter (Bird *et al*., 1984).

Twins and triplets can be a risk factor for lamb mortality (Huffman *et al*., 1985). A number of studies show that shelter is more beneficial for multiples than singles (Alexander *et al.*, 1980, Pollard, 2006, Robertson *et al.* 2011). Alexander *et al*. (1980) showed overall shelter increased survival by 10% in singles and 32% in multiples. More recently, Pollard (2006) found that the provision of shelter reduced mortality amongst both singles and twins (3-13% and 14-37% respectively) while Robertson *et al*. (2011) found that there was a 10% increase in survival for twins with shelter, but no effect on singles. It is worth noting that as these shelter-related reductions in mortality were only observed during cold, wet and windy periods, the likelihood of poor weather is an important determinant in the success of the shelter.

This study sought to quantify the spatial behaviour of ewes in the presence of natural and artificial shelter and to investigate the climatic and biological factors that might influence shelter-seeking behaviour. The trial aimed to determine whether shelter provision reduced the prevalence of neonatal shepherding problems that impact animal welfare, flock productivity and labour requirement in an upland, outdoor lambing system where the benefits of additional shelter may be the greatest.

Material and methods

Study site

A randomised control trial was conducted at a commercial sheep farm, Innovis Ltd., in Ceredigion, Wales (52° 27’ 26.298” N, 3°57’ 55.195” W) during April 2019. No supplementary feeding was provided to the ewes before or during the study period, as the flock is managed in an extensive, low-input manner. The flock was managed no different to usual during the trial, so as not to impact on sheep behaviour and also to simulate commercial management practises.

Two adjacent fields were selected for the study site for their similarity in size (3.3 ha and 3.0 ha), topography, pasture management, orientation to the prevailing wind and location and size of available natural shelter. The natural shelter in the first field consisted of a continuous 1.0 – 1.2 m deep ditch (approximately 182 m across) and a partially interrupted band of gorse (*Ulex europaeus*) 8 -10 metres deep. This was much greater quality compared to the natural shelter in the second field that had only a shallow 0.1 – 0.4 m ditch and very isolated patches of gorse growth (Figures 1 and 2). In the first field, three additional artificial shelters were installed to increase the available shelter for the ewes, this field was designated as the *Test* field. The second field served as the *Control* field, with no additional artificial shelter provided. Both fields were south facing, situated between 180 and 230 m above sea level (south to north).

Experimental design

Lambing ewes had historically been observed by the shepherds to lamb at the northern margin of the fields amongst the gorse cover. Two linear artificial shelters built in an elongated 'S' shape (Shelters 1 and 3 ; Supplementary Figure S1) and one artificial shelter built in a cross shape (Shelter 2 ; Supplementary Figure S2) were built with tyres approximately 8 m south of the start of the gorse cover in the *Test* field (Figures 1 and 2 ; Table 1). The linear artificial shelters were placed parallel to the natural shelter and were perpendicular to the prevailing wind (southerly). The aim was to expand the total shelter available in the *Test* field. The cross shaped shelter was included between the two elongated 'S' shaped shelters in order to observe whether the sheep appeared to display a preference between the two shelter designs. Optical porosity was determined by the ratio of gaps to rubber in photos of the shelters (Loeffler et al., 1992).

Climatic and spatial parameters

Each field was then divided into quadrants and ewes were recorded as either being situated in the *Exposed*, *Natural Shelter*, or *Artificial Sheltered* quadrants. 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 within the area of gorse cover at the top of the field, they were recorded as using the natural shelter. The *Natural Shelter* quadrant was 1.0% of the total area available, the *Artificial Shelter* quadrant area was 0.1% of the total area available and the *Exposed Quadrant 98.9%*.

To measure the exposed weather conditions, an automatic weather station (**AWS**; Vantage Pro 2, Davis Instruments, USA) was set up at the northern boundary the periphery between the two fields. The AWS recorded rainfall, relative humidity, air temperature, wind direction and wind speed. The shelter zone for *Artificial Shelter* 3 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 the shelter (where 1H distance = 1 × height of shelter). The two anemometers on the leeward side would have been further sheltered by the gorse bushes in the *Natural Shelter* quadrant, situated a few metres above. The aim of these measurements was to demonstrate a windbreak effect in the *Sheltered* quadrants compared to the exposed weather conditions measured by the AWS. Data was recorded at 30-minute intervals and downloaded from the anemometers and AWS approximately every 24 hours.

Ewe selection and identification

Twin-bearing ewes of body condition score 3.0 and above (of a 1-5 scale; Russel, 1984) were selected for the trial to control for litter size and nutritional status as a contributory factor. Two maternal ewe lines were chosen for the study (Highlander (n=66) & Aberfield (n=81)). Both breeds have been developed for their ability to lamb successfully in extensive, outdoor lambing systems. The Highlander ewe is a smaller, hardy ewe that is particularly suited to harsher environments, while the Aberfield is bred to produce larger lambs but from a lower cost grass-based system compared to other commercial hybrids (Innovis Ltd., 2021). The ewes were stratified by breed and age (< 2 years, 2-5 years, and > 5 years) and then randomly allocated between the two fields. 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 ;** Supplementary Figure S3) that correlated to their electronic identifier number (**EID**). Lambs were identified to their dam with spray paint markings shortly after birth.

Behavioural and biological parameters

Prior to lambing, ewes displayed similar behaviour and spatial distributions that had been observed during previous lambing seasons. During lambing, the flock was observed for 14 continuous days where lambing occurred at a steady daily rate and approximately 50% of the flock lambed down. Observations were carried out for one-hour at fixed time intervals (starting at 0800 h, 1000 h, 1200 h, 1400 h and 1600 h) for both the *Test* and *Control* fields. For each observation the ewe visual ID, litter size and instantaneous quadrant location were recorded for all individual ewes. Mismothering behaviour and lamb vigour were also recorded for ewes after they had lambed by observing lamb and ewe behaviour from a distance of approximately 20 m over a 7-minute period. 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).

Statistical analysis

A Pearson's *r* correlation was used to investigate correlation between wind speed, rainfall and temperature with the percentage of ewes observed in the *Exposed* quadrant in the *Test* field. Wind speed and ewe location data collected at the same time-points were plotted for both fields and R^2 values determined; 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 concluded (Ferguson, 2009).

'Shepherding problems' were defined as any additional human intervention an individual ewe or its lamb received during the neonatal period. This was recorded for every shepherding intervention for each ewe and included the presence of lamb mortality, lambs of poor vigour, dystocia and/or mismothering behaviour. Ewes that did not lamb during the trial period were excluded from the shepherding problem dataset (n=70). Chi-square tests were used to assess how the proportion of shepherding problems varied between fields, breeds, age categories and ewe body condition score.

In order to quantify ewe shelter-seeking behaviour, a preference index (**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). Following assessment of the PI distribution data, Mood's median and Kruskal-Wallis tests were used to assess differences in behaviour between ewes before and after lambing, and between breeds for each field. Subsequently, a Chi-square test was used to determine if group behaviour (i.e., ewes before and after lambing and ewes belonging to each breed) was significantly different from each other by comparing the actual number of ewes with a PI above and below 1 to the expected number of ewes if spatial behaviour was a result of random chance (i.e., would expect a half and half distribution).

Results

Climatic summary and wind break effect

Total cumulative rainfall over the trial period was 27.4 mm. Mean temperature was 6.18 (± 2.91) °C. Minimum mean temperature was 5.96 (± 2.88) °C. Wind direction was predominantly south east and east south east (62% of total measurements). The mean wind speeds for each distance from Shelter 3 are shown in Table 2*.*

Ewe location and climate

For the ewes in the *Test* field*,* wind speeds were significantly correlated ($P < 0.01$) with increased shelter usage by the ewes, whereas rainfall and air temperature showed no significant correlation.

When wind speed and ewe location data collected at the same time-points was plotted for the *Test* field, a negative correlation existed between the number of ewes observed in the *Exposed* quadrant and increasing wind speed (R^2 > 0.04). Increasing wind speeds were correlated with the number of ewes seeking out *Natural Shelter* (R^2>0.04), although no correlation was observed for *Artificial Shelter*. The *Control* field, where the quality of shelter in the *Natural Shelter* quadrant was very limited, showed no correlation between ewe location and wind speed for either the *Exposed* quadrant or the *Natural Shelter* quadrant. This was as expected given the very limited shelter available.

Shepherding problems in* Control *versus* Test *fields

A Chi-square test for independence showed that field allocation was significant (P < 0.05) in influencing the prevalence of shepherding problems. More ewes in the *Control* field (n=11) experienced shepherding problems than in the *Test* field (n=3).

Shepherding problems and ewe breed, age

A Chi-square test for independence showed that breed was significant (P < 0.05) in influencing the prevalence of shepherding problems. Highlander ewes experienced fewer shepherding problems than Aberfield ewes. Age was significant (P < 0.01) in contributing to an increased prevalence of shepherding problems in ewes over five years old.

Lamb post-mortem examination 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 (n=54) from the rest of the 761-ewe flock over the month of April. The flock PMEs included commercial breed lambs, terminal breed lambs and singles. The actual number of lambs born, over the number of lambs expected based on scanning results (if 100% scanning accuracy and 100% survival assumed) was 73% for the *Control* field and 78% for the *Test* field. A Chi-square of PME outcomes between the two treatments was not significant ($P > 0.05$). The actual number of lambs over the expected number of lambs for the rest of the flock was 74%. The Chi-square between the two trial fields and the rest of the flock was not significant. 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 3. Note that the category of 'Exposure' includes starvation-mismothering-exposure complex (Haughey, 1991) as death from exposure is often multifactorial. The causes of mortality observed in the trial field also appear representative of the rest of the flock.

Ewe post-lambing preference index for **Test** *versus* **Control** *fields*

Field allocation was not significant in influencing PI for the *Exposed* or the *Natural Shelter* quadrant. Field allocation was therefore not a variable for ewe shelter-seeking behaviour.

Ewe total preference index for **Exposed, Natural Shelter** *and* **Artificial Shelter**

In the *Control* field the mean post-lambing PI for the *Natural Shelter* quadrant (3.27) was 3.8 times greater than the mean post-lambing PI for the *Exposed* quadrant (0.86). Likewise, in the *Test* field the post-lambing PI for the *Natural Shelter* quadrant (4.81) was 5.5 times greater than the post-lambing PI for the *Exposed* quadrant (0.87). Post-lambing PI for the *Artificial Shelter* (1.82) was 2.1 times greater than the mean PI for the *Exposed* quadrant.

Figure 4 shows the post-lambing PI distributions for the *Exposed* (interquartile range (**IQR**) 0.79-1.01) and the *Natural Shelter* (IQR 0.71-3.70) quadrants for the *Control* field. As discussed, there is considerable variance in ewe PI for the *Natural Shelter* quadrant. Post-lambing PI distributions for the *Exposed* (IQR 0.84-1.05), *Natural Shelter* (IQR 0.00-6.67) and the *Artificial Shelter* (IQR 0.00-1.32) quadrants for the *Test* field. Again, the impact of outliers can be observed.

The PI for each of the artificial shelters is shown in Figure 5. There was a clear preference for *Shelter 1* (IQR 0.00-3.23), with a mean PI value of 4.2, while *Shelter 2* and *3* were rarely used (mean PI of 0.9 and 0.0 respectively).

Ewe preference index pre-lambing versus post-lambing

Ewe behaviour prior to lambing was compared by comparison of pre-lambing PI scores in the *Test* and *Control* groups of ewes. A highly significant difference was observed ($P < 0.001$) between *Test* and *Control* groups.

Ewe behaviour before and after lambing was compared within each group (*Test* and *Control*) using the PI for the sheltered quadrant. In the *Control* field, there was a highly significant difference between their PI score pre-lambing compared to post-lambing ($P < 0.001$). However, in the *Test* field, there was no significant difference in PI between pre- and post-lambing ($P > 0.1$).

Figure 6 shows the similar distribution pre-lambing (IQR 0.81-1.00) and post-lambing (IQR 0.84-1.05) for the *Test* field and the significant change of behaviour pre-lambing (IQR 1.01-1.04) compared to post-lambing (IQR 0.79-1.01) in the *Control* field ewes.

Ewe post-lambing preference index and ewe breed

To investigate the influence of breed on behaviour, the PI scores for the exposed quadrant were compared between breeds (Aberfield vs Highlander), within each of the field environments independently. In both the *Test* and *Control* fields, there was a significant difference in the preference of the Highlander for finding shelter (*P* <0.05 (*Test* Field)) & (P=0.01 (*Control* field). To investigate any potential effect of the 'field' group, preference was compared within each breed between *Test* and *Control* fields and no significant difference observed (*P* > 0.1 Aberfield and *P* > 0.1 Highlander). Figure 7 shows displays this breed difference with a significant difference between Aberfield (*Test* IQR 0.92-1.05, *Control* IQR 0.93-1.01) and Highlander (*Test* IQR 0.77-0.96, *Control* IQR 0.61-0.95) behaviour.

Discussion

Effective shelter can provide protection from both exposure and heat-stress, improve lamb growth rates, improve pasture quality and provide drainage (McArthur, 1991). 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 on a commercial sheep farm in the UK. Every shepherding interaction observed over this trial period fell in to one of these four categories and are important factors impacting on animal welfare and lamb survival (Binns *et al.*, 2002, Dwyer, 2008). The cost savings and improved financial sustainability of outdoor lambing systems derives from the reduction in skilled labour required for handling ewes (Carson et al., 2004). Therefore, by using the prevalence of shepherding problems as a measure of shelter effectiveness, we are considering arguably the most critical limiting factor for successful management of outdoor lambing systems. This is the first study that has examined the cumulative prevalence of neonatal shepherding problems as opposed to just the binary outcome of mortality (Alexander *et al.*, 1980; Bird *et al.*, 1984; Broster *et al.,* 2017).

The *Test* field experienced significantly fewer shepherding problems than the *Control* field. 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.

Both breed and age had a significant impact on the prevalence of shepherding problems. Highlander ewes showed a much 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 to *Test* and *Control* fields using a stratified randomisation system that accounted for breed and age, these variables are unlikely to confound the difference in the prevalence of shepherding problems observed between the two fields.

Wind speed was significant in influencing ewe shelter-seeking behaviour in the *Test* field where substantial shelter was available, 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. 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.

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). Interestingly, ewe shelter-seeking behaviour in the *Test* field did not vary substantially pre- and post-lambing, however, there was a significant change in behaviour in the *Control* field. This could indicate that the ewes in the *Test* field were able to exhibit a behavioural preference by virtue of the provision of increased shelter. If the ewes indeed have agency, then the addition of artificial shelter is an effective, cheap and easy modification to result in a positive impact on ewe and lamb welfare, reduce shepherding workload, with no evidence of negative consequences.

There was significant ewe shelter-seeking behaviour pre-lambing, however this was not significant post-lambing; contradicting findings from previous studies (Pollard *et al.,* 1999). It is possible the study was under-powered for the number of ewes that lambed during the trial period. This change in ewe behaviour may also be confounded by differences in mobility associated with lamb-following behaviours. 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, and a potential risk factor for mismothering (Alexander, 1984).

The results of this study demonstrate significant variation in the use of shelter between and within breeds of sheep. However, due to the constraints of conducting research in a commercial farm environment it was not possible to include replicates in our experimental design, and thus, our findings should be used with caution until reproducibility has been demonstrated in subsequent research. We believe it is reasonable to assume that other ewe-level variables that were controlled in this study, such as litter size, may also influence shelter-seeking behaviour during the perinatal period. Group level variables may also influence shelter-seeking behaviour, such as the topography, stocking density and weather conditions. These are inevitable limitations of any randomised control trial study design. To understand the extent to which these results can be generalised to commercial sheep farming systems, it would be necessary to replicate the study in a wider range of conditions to understand these complex behavioural, physiological and environmental interactions.

Conclusion

The provision of shelter resulted in a significant reduction of shepherding problems in both Aberfield and Highlander breeds. The Highlander breed demonstrated a greater preference for shelter than Aberfield ewes. Even in fairly stable weather conditions, when ewes are given free choice to access shelter, increased shelter utilisation can result in improved welfare, improved lamb survival and a reduction shepherding costs and workload. These benefits may be substantially greater in severe weather conditions. Further research conducted in a multi-farm, multi-year environment with replicate groups within farm would improve the robustness of our findings and is required to fully understand how to optimise shelter design to maximise the benefits for the sheep and the shepherd.

Ethics approval

Not applicable.

Data and model availability statement

None of the data were deposited in an official repository. The data that support the study findings are available upon request.

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Author contributions

CP conducted field work, statistical analysis and drafted the manuscript. AS, AW, PD and DJ conceived the project, assisted in design, sampling and analysis. CP, AS, AW and PD contributed to writing the manuscript.

Declaration of interest

None.

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Tables

Table 1 Description of artificial shelters, shape, physical dimensions, and optical porosity used to evaluate the shelter seeking behaviour of sheep**.**

Name	Shape	Height (m)	Length (m)	Breadth (m)	Optical Porosity (%)
Shelter 1	Elongated S	0.7	16.5	5.5	0.05
Shelter 2	Cross	0.7	8.0	7.5	0.05
Shelter 3	Elongated S	0.7	26.5	8.5	0.05

Table 2 Mean and maximum wind speed measurements taken at fixed distances from Shelter 3 used to evaluate the shelter seeking behaviour of sheep during study period.

	Position of anemometer			
	Exposed	Distance from shelter		
Wind speed[1]		0.5H North[2]	5H North	5H South
Mean (m/s)	3.73 (2.30)[a]	1.62 (1.07)	2.19 (0.88)	2.41 (0.98)
Maximum (m/s)	6.85 (3.35)	3.57 (1.69)	4.30 (1.60)	4.56 (1.74)

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

[2] Where H = height of shelter

[a] ± SD included in brackets

Figure captions

Figure 1 Schematic diagram of quadrants for *Test* and *Control* trial fields used to evaluate the shelter seeking behaviour of sheep.

Figure 2 Satellite map of *Test* field with artificial shelters and *Control* field used to evaluate the shelter seeking behaviour of sheep (Google Maps, 2021).

Figure 3 Cause of lamb death identified on post-mortem examination for trial and flock lambs during an evaluation of the shelter seeking behaviour of sheep (all lambs were sourced from the same company farm).

Figure 4 Ewe post-lambing Preference Index (PI) score for the *Exposed* and *Natural Shelter* quadrants in the *Control* and *Test* field during an evaluation of the shelter seeking behaviour of sheep (boxplot with median bar, quartiles and standard error).

Figure 5 Ewe post-lambing Preference Index (PI) score for the *Artificial Shelter quadrant* during an evaluation of the shelter seeking behaviour of sheep (boxplot with median bar, quartiles and standard error).

Figure 6 Ewe Preference Index (PI) score for the *Exposed* quadrant pre- and post-lambing during an evaluation of the shelter seeking behaviour of sheep (boxplot with median bar, quartiles and standard error).

Figure 7 Breed and ewe post-lambing Preference Index (PI) score for the *Exposed* quadrant during an evaluation of the shelter seeking behaviour of sheep (boxplot with median bar, quartiles and standard error).