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GPS observation of shelter utilisation by Merino ewes

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Abstract. The present study examined how shelter availability, altitude and temperature influence paddock utilisation by pregnant and lambing Merino ewes. Global positioning systems (GPS) attached to collars allowed continuous tracking of ewes' positions within two paddocks, and environmental conditions were also monitored throughout this time using temperature loggers. Animal tracking devices (UNEtracker GPS collars) were used in the spring (September–November) of 2008 (51 days) and 2009 (43 days), 14 days post-shearing, to monitor movement of pregnant grazing fine-wool Merino ewes (5 per paddock per year). The data were used to examine sheep use of lone trees, interior shelter, perimeter shelter and remainder of the paddock during three distinct diurnal activity periods, namely night camping, morning grazing and afternoon grazing. Regular use of shelter was consistently recorded in the two experimental years and in both paddocks. The ewes consistently used sheltered areas and both the leeward and windward sides of shelter, particularly during high sheep chill days. The sheep used the sheltered areas significantly more often than they used the remainder of the paddock, which was devoid of shelter except for lone trees. Night camping did not occur at the highest altitude, but predominantly where shelter was also located. The present study has demonstrated the consistent use of shelter by sheep. The shelter-seeking behaviour of the ewes a month post-shearing suggests that these animals are more sensitive to weather conditions than has been previously reported.

Additional keywords: chill index, climate, GPS tracking, sheep, sheltering behaviour.

Introduction

In Australia, the loss of shorn sheep and lambs during inclement weather is an animal welfare concern (Kelly 1992; Hinch 2008). Sheep in Australia have been reported to exhibit hypothermia within 28 days of shearing and can have mortality rates of between 12% and 34% annually (Radostits *et al*. 2000). However, the average mortality of recently shorn sheep can increase to between 50% and 70% (Buckman 1982; Holm Glass and Jacob 1991) during adverse weather consisting of a combination of rain, strong wind and cold temperatures (Hutchinson and Bennett 1962; Hutchinson 1968; Hutchinson and McRae 1969). These losses are dependent on weather severity and sheep breed, with Merinos appearing to be more susceptible to cold (Geytenbeek 1982). In early studies, Australian Merino lamb losses were estimated to be between 5% and 70% (Slee 1981; Alexander 1986), with losses most commonly between 20% and 25% (Kelly 1992; Hinch 2008). Alexander *et al*. (1980) reported that provision of forced shelter can reduce lamb losses by 10% but there seems little information about the use of shelter by pregnant and lambing ewes.

The protection afforded by paddock shelter is a function of the height of shelter and its permeability (Cleugh 1998). Lower-height grass hedges require more depth (rows) than taller shrubs and trees (Broster *et al*. 2010) to protect the same area. The higher the windbreaks the greater the distance of the downward and upward protection on the leeward and windward side of shelter respectively (Da Silva 2006). However, in many cases producers are reluctant to plant shelter, particularly semi-permeable tree shelter, because of the belief that the period before the trees effectively provide protection is relatively long. Miller *et al*. (1975) found that 4-year-old, highly permeable, tree wind breaks were 1/3 as effective as fully grown shelterbelts. The availability of shade to reduce radiation load, and windbreaks to reduce wind-chill, are recognised as necessary management options, although there are a limited number of studies that have evaluated the capacity of sheep to utilise such protection when it is provided (Geytenbeek 1963; Marshall 1981).

Components of weather are interlinked and the combined impact has been described by the use of indexes that capture the combination of weather conditions, including precipitation, wind-speed and temperature into a sheep chill index (SCI; Bureau of Meteorology 2008). There appear to be no studies that have examined sheep sheltering behaviour in relation to SCI.

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Weather changes are known to influence the behaviour of most ungulate species, although the exact responses of a species may vary according to the level of coat/fleece insulation and behavioural adaptability (Marshall 1981; Da Silva 2006). Sheep responses to different environmental challenges vary from obvious movement or posture changes to physiological changes such as increases in respiration rate. Where animals cannot adapt to the thermal environment through behavioural or physiological changes, there are likely to be significant impacts on animal performance, including decreased growth, reproduction and even survival (Bird *et al*. 1984; Stafford-Smith *et al*. 1985; Da Silva 2006).

Merino sheep are believed to be 'efficiently adapted' to arid zones (Macfarlane 1964), but may still be required to adapt to changes in air temperature, radiation load, humidity, wind and rain, and in many cases the first responses to these stressors are behavioural changes (Conradt *et al*. 2000). Sheep are extremely vulnerable to high SCI immediately after shearing and during the neonatal period. Losses of adult animals immediately post-shearing have also been attributed to inclement weather (Holm Glass and Jacob 1991). Although the 14-day period post-shearing has been recognised as the period of maximum risk, the greatest losses in Australia have occurred during storms ≥14 days post-shearing (Hutchinson and Bennett 1962; Geytenbeek 1963; Mottershead *et al*. 1982). Lambs are born from a warm consistent uterine environment of 39°C into an external environment often <0°C and with possible precipitation and wind, and are highly susceptible to hypothermia (Sykes *et al*. 1976; Pollard 2006). New-born lambs have limited body reserves to utilise and the length of time a lamb can survive without milk is reliant on these internal energy reserves and perimeter environmental conditions (Alexander 1964, 1978, 1986). Behavioural measures such as posture, shelter-seeking, huddling and dispersion relate to the animal's thermoregulatory responses to their environment (Blackshaw and Blackshaw 1994; Kadzere et al. 2002).

Much of the early research effort into understanding landscape utilisation by animals has been conducted with wildlife and endangered species, such as e.g. caribou (Johnson *et al*. 2002), deer (Bowman *et al*. 2000), moose (Girard *et al*. 2002), elk (Biggs *et al*. 2001) and elephants (Blake *et al*. 2001). Research using GPS tracking collars on domestic livestock has been primarily focussed on extensive grazing systems for cattle (Swain *et al*. 2008), on dairy cows (Müller and Schrader 2003) and on the behaviour of sheep (Rutter *et al*. 1997; Thomas *et al*. 2008) and there is very limited information on the use of tracking devices to identify the use of shelter by sheep.

GPS tracking devices offer the potential to remotely monitor behavioural measures such as shelter-seeking and to determine how shelter availability influences paddock utilisation by ewes. The present paper reports on an experiment conducted in two large grazing paddocks over two successive years to examine whether sheep use shelter more often than expected during different activity periods, whether sheep location is related to temperature variations, whether sheep location is related to altitude variations, whether sheep use leeward shelter during periods of high sheep chill and whether shelter use changes after lambing.

Materials and methods

Location

The experiments were conducted during two consecutive shearing and lambing periods in early spring (September–October 2008 and 2009), at 'Blaxland', a fine-wool property located on the southern end of the Northern Tablelands in the New England region of New South Wales, Australia (400 km north of Sydney between Armidale and Tamworth, at 30.99°S, 151.59°E, and at an altitude of 1060–1151 m). The region experiences warm summers, with a slight summer-rainfall dominance. Rain and sleet are not uncommon in early spring, and winter temperatures are often frosty, with ground temperatures low enough to inhibit plant growth for approximately 4 months (Alexander *et al*. 1979).

The mean daily temperature in 2008 and 2009 during the study period ranged between (a mean minimum and maximum) −6°C and 27°C over the 2 years, with the overall average differing between years by only 1°C (Table 1). Nights were generally still and frost was common over the test period, while days were often sunny and windy (mean maximum of 49.6 km/h). Strong westerly winds prevailed; northerly and southerly winds were unusual. The average total rainfall over the experimental periods in each year was 92.3 mm, with slightly more rain (~6.2 mm) recorded in 2008.

Paddocks

The 'Blaxland' experimental site was chosen because of the availability and configuration (perimeter and interior position) of tree shelter in two rectangular-shaped paddocks within close proximity and with similar altitude variations. Paddock one ('Chain of Ponds', COP) was 25 ha, with an altitude ranging from 1110 to 1118 m. It had perimeter shelter belts (3 or 4 rows of 3–8-m high native trees planted on the exterior perimeter of the northern and western paddock boundary fence lines, ~3–5 m deep) and individual, free-standing trees (lone trees, eucalypt species 10–15 m high) within its fence lines. Three classes of shelter, including 'lone trees', 'perimeter shelter' and 'remainder of paddock', were ascribed to this paddock. Paddock two

Table 1. Cold-, moderate- and warm-temperature areas within Chain of Ponds (COP) and Dads Hill (DH) paddocks (September–October 2008 and 2009)

Temperature category	Temperature (°C) (%)[A] 2008	2009
	COP	
Minimum	13.23	12.81
Maximum	14.30	13.64
Cold	<13.49 (25%)	<13.13 (25%)
Moderate	13.49–13.68 (50%)	13.13–13.34 (50%)
Warm	>13.68 (25%)	>13.34 (25%)
	DH	
Minimum	14.40	13.86
Maximum	14.91	14.32
Cold	<14.56 (25%)	<14.04 (25%)
Moderate	14.56–14.69 (50%)	14.04–14.16 (50%)
Warm	>14.69 (25%)	>14.16 (25%)

[A]Data % for cold, moderate and warm temperature categories.

('Dad's Hill', DH) was 19.6 ha, with an altitude ranging from 1136 to 1189 m. It had perimeter shelter belts (northern, western and southern boundary), an interior shelter belt ('boomerang' shape, 3 or 4 rows of native trees, 3–8 m high on a north–south axis, ~3–5 m deep) and several free-standing lone trees. Four shelter classes, including 'lone trees', interior shelter', 'perimeter shelter' and 'remainder of paddock', were ascribed to this paddock. Both paddocks had improved natural pasture made up largely of *Festcua arundinacea* (fescue grass), *Lolium perenne* (rye grass) and *Trifolium* (clover).

COP and DH perimeter shelter belts consisted of mature stands of native tree species, including *Acacia*, *Eucalyptus* and *Leptospermum* species.

DH interior shelter belt consisted of a mix of native tree species similar to those in the perimeter shelter belts and the south-western half of the perimeter shelter belt in DH consisted primarily of a mature stand of *Pinus radiata*.

Weather equipment

One week before the ewes were placed in the paddocks, weather stations and temperature loggers were installed, calibrated and tested for accuracy. Both paddocks were subdivided by a ~72-m grid and metal star picket posts were used to mount a total of 55 temperature loggers (iButtons DS1921G, Alfa-Tek, Brisbane, Qld, Australia) to record temperatures hourly. The temperature loggers were placed in a Stevenson screen type cover to reduce solar load. These covers were constructed of inverted Décor Australia 361, 2.0-L white-plastic round buckets, with two offset rows of holes drilled around the side and holes in the bottom (inverted became the top) providing ventilation. The temperature loggers were placed in nylon-screen pouches measuring 5 by 5 cm and suspended in the middle of the Stevenson screen cover. The screens were mounted at the World Meteorological Organisations agreed standard height of thermometers, between 1.25 and 2 m above ground (Bureau of Meteorology 2008).

Each paddock also had two EnviroStation weather stations established, one located within ~44 m of the perimeter shelter and the other >145 m from the shelter. These stations captured hourly readings of temperature, rain fall, wind-speed and wind direction. The weather stations were powered by solar panels and screens were mounted at the World Meteorological Organisations agreed standard height above ground. Each weather station in both paddocks was surrounded with a mesh fence to protect the unit from animal rubbing and wire chewing and had an additional temperature logger mounted adjacent to it.

Weather data

The weather station recorded daily maximum and minimum temperature (°C, T), wind-speed (km/h, V), wind direction and accumulated rain-fall within 6 h (P) and this was used to calculate the SCI based on the empirical sheep index model used for the Australian Bureau of Meteorology graziers alert (Nixon-Smith 1972), as follows:

$$\mathrm{SCI} = ((2.7 + \{0.81 \times [(0.514 \times \mathrm{V}) **0.5]\,) \times (40 - \mathrm{T})) + 70 + (1 - \mathrm{e}**[-(\mathrm{P}/25.4)] \times 100).$$

The calculation incorporates animal heat loss in relation to wind speed, with wool and/or hide insulating values built into the equation (Ames and Insley 1975). The BOM graziers' alert falls into the following three categories: high, >230; very high, >250; and extreme, >300. The higher the SCI number, the more adverse the weather conditions are.

The SCI was calculated using the temperature from the temperature loggers within the closest proximity of one of the paddock weather stations, along with the wind speed and precipitation from that particular weather station. To investigate variations in sheep shelter utilisation during high (>250) and low (<200) SCI with easterly and westerly winds, SCI data were scanned to identify three consecutive days with such conditions pre-lambing. In 2008, three consecutive days (an average 11 days pre-lambing) with high SCI with an easterly wind (HSCE), high SCI and a westerly wind (HSCW) and low SCI with a westerly wind (LSCW) were identified. Three consecutive days with HSCE, HSCW and LSCW did not occur in 2009.

Mean temperature areas within each paddock were calculated using an average of the two weather stations located within the paddock. Temperature data were divided empirically into thirds, creating cold, moderate and warm areas for each paddock and each year (Table 1).

Animals and animal care

All research procedures and animal care were approved by the University of New England's Animal Ethics Committee on approval numbers AEC08/100 and AEC09/006 which conform to the Australian Code of Practice for the Care and Use of Animals for Scientific Purposes.

The stocking rate in 2008 for each paddock was 13.9 ewes per ha for DH and 10.9 ewes per ha for COP, while the stocking rate in 2009 was seven ewes per ha in DH and 7.8 ewes per ha in COP. The fine-wool Merino ewes placed in these paddocks ranged in age from 2 to 5 years in both years and were naturally joined for 34 days, except for the flock in DH in 2009, which had been artificially inseminated (AI) after oestrous synchronisation. The ewes were ultrasound-scanned at about a flock mean of 60 days of pregnancy (Fowler and Wilkins 1982) to identify fetal number, and thereafter, single-bearing ewes were allocated to the experimental flocks. Lambing dates were determined on the basis of a gestation length of 148 days, with 80% of ewes expected to lamb in a 14-day period. In 2009, the AI group was expected to lamb over a 7-day period. The pregnant ewes (~130 days of gestation) were shorn in late August or early September as per standard farming practices, before entry into the experimental paddocks.

Water was provided from troughs and dams in each paddock and feed was available from improved natural pasture, with an estimated dry matter availability 3000 kg DM/ha at the introduction of the flocks into the paddocks. The flocks were regularly checked by the producer for disease and availability of water and feed.

GPS collar application

Fourteen days post-shearing and before allocation of the mobs to the two paddocks, 10 UNEtracker (Trotter and Lamb 2008) GPS collars designed for sheep were randomly applied to five focal (single-bearing) ewes from each of the two mobs. The selected ewes were in good condition (Russel 1984), with an average weight of 55 kg.

After collar application, the animals were released into a small holding area among other non-collared ewes and their behaviour was observed for 2 h for signs of discomfort or non-acceptance. The total weight of each UNEtracker, including the leather collar and the GPS unit, was <430 g (~0.8% of the weight of the ewes). The UNEtracker was set to obtain and record the location of the individual animal every 10 min, with data collection commencing 24 h after collar application. The accuracy of the logged positions from the UNEtracker collar was previously reported by Trotter and Lamb (2008) to be 90% of recorded locations within 0.40–4 m of the actual location. Data from the UNEtracker GPS collars were recorded from September through October, for a total of 51 days in 2008 and 43 days in 2009. In total, more than 135 360 position records were documented over the 2 years.

The ewe mobs were transferred to one of the two paddocks and remained there until lamb marking in early November. At lamb marking, the total number of ewes, wet and dry, and the number of lambs were recorded and the GPS collars were removed.

Bi-weekly visits throughout the 2008 and 2009 experimental periods were made to observe ewe and lamb movement and to check the weather-recording equipment. During 2009, daily morning observations at 0900 hours were made on the AI group in DH to identify day of lambing of each of the five collared ewes. These ewes had coloured GPS collars and were temporarily numbered with 'scourer-able wool branding' suitable for greasy wool (AS4054-1992) applied to their sides. Application was in accordance with the Australian Wool Corporation Code of Practice, ensuring the spray did not contact their skin. The numbers and coloured collars allowed easy identification of these animals from a distance of 1–2.5 km.

GPS data

Information on paddock features, topography and boundary was collected by a differentially corrected Trimble Pro XRS receiver coupled to a Trimble Ranger handheld field computer (Trimble, Sunnyvale, CA, USA). These data were manipulated in ArcMap, part of ESRI ArcInfo Desktop version 9.3 (ESRI, CA, USA), to produce maps and for further GIS analysis of the data. Movement parameters for the tracking data were calculated using the Hawths Analysis Tools add-in (SpatialEcolgy.com, ver. 3.27) for ArcGIS 9.3 (esriAustralia.com).

Horizontal velocity (m/s) was calculated as the sum of straight-line distances between successive points over time. The data were scanned for erroneous records, with velocity values greater than 3 m/s being removed as these are frequently associated with GPS error (D'Eon *et al*. 2002; Swain *et al*. 2008). This resulted in the clean point dataset, which was then used for comparison with landscape characteristics. To cope with the large volume of point data generated by the GPS devices, the paddocks were overlaid with a 10 by 10 m grid (Fig. 1) and the points located in each grid cell were summed to provide a continuous grid or surface of the frequency of distribution of the tracked sheep over the

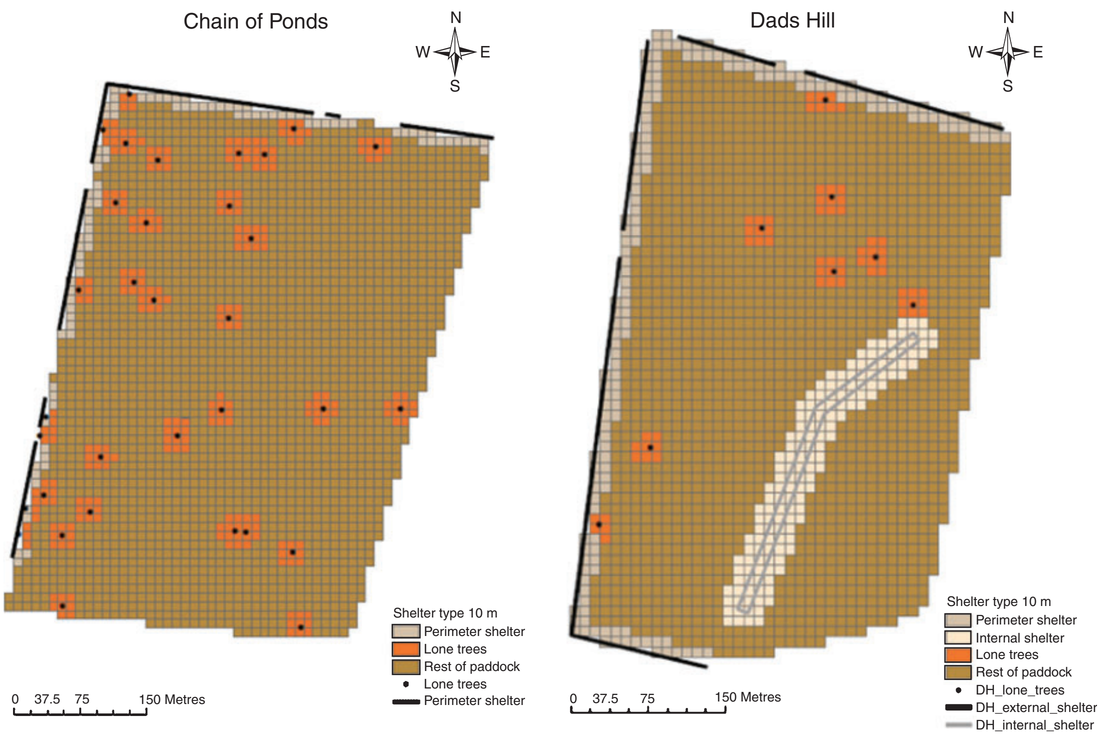

Fig. 1. Chain of Ponds and Dads Hill paddocks with 10 by 10 m grids and paddock-category poly-lines.

deployment period. The selected logged points with specific attributes (i.e. points logged at night camping at 1900–0459 hours, morning gazing at 0500–1159 hours and afternoon grazing at 1200–1859 hours) were plotted and overlaid on paddock-map layers with individually assigned data points, including topography, fence line and pond boundaries, shelter belts, free standing trees, temperature loggers and weather station locations.

GPS shelter classification

The same 10 by 10 m grids were used to classify the shelter characteristics of each paddock being studied. Each grid cell was assigned a coding on the basis of its proximity to the nearest shelter. Poly-lines were applied 10 m away from the shelter categories (lone trees, interior and perimeter shelters) and the data files were clipped to the poly-lines for three activity periods (night camping, morning gazing and afternoon grazing). Ten-metre poly-lines away from shelter were used on the basis of the findings of Lynch and Alexander (1977) and Sturrock (1972) that showed that the greatest effects of semi-permeable shelter were within 10 m and also to reduce interference of adjacent shelter types. The cells within 10 m of perimeter shelter, interior shelter or lone trees were given shelter codes. The grid cells further than 10 m from a shelter type were recorded as 'rest of paddock'.

The code cells within the polygon were used to analyse the usage of the leeward, windward and remaining sides of shelter during easterly and westerly wind at high and low SCI. Average temperatures and standard deviations within grid cells were also added for analysis. By using the 'count points in polygon' command in Hawths Tools (SpatialEcology.com), tracking datasets were simplified to several occurrences in each grid cell. The points or counts are the number of times (frequency) within 10-min periods that each collared sheep was recorded in that polygon over the data-recording period. One count is taken as one 10-min interval. However, 'time' may also be used, because the number of times the sheep were recorded in that polygon means the number of 10-min periods, and so a certain amount of time overall; however, for this research we used frequency. By selecting tracking point data that were created at particular activities of the day and with specific attributes, new point datasets could be created which could be included in the 10 by 10 m grid.

Statistical analysis

Analysis on the attributes table of the 10 by 10 m grid was performed in SPSS and JMP statistical software to determine comparisons of observed counts with expected counts on the basis of shelter types, wind direction and climate, and significance levels were set at $P = 0.01$.

Data for each year were analysed separately for each paddock. The number of 10 by 10 m cells in each shelter category was used to determine the relative area in hectares of each shelter category in relation to the entire paddock. This relative area was then used to determine the expected number of sheep counts for each category, assuming a random distribution. The sheep counts were analysed for expected distribution *vs.* observed distribution, using Chi-square goodness-of-fit methods (Zar 1999). The distributions were tested to determine whether there were effects of temperature (cold, moderate, warm), HSCE, HSCW and LSCW, first and last 5 days of the experimental periods, and 5 days pre- and post-lambing on paddock and shelter utilisation. A significant ($P < 0.01$) difference indicates that the observed distribution of sheep counts across shelter categories varied significantly from the counts expected on the basis of random distribution across the whole area.

A multiple-regression analysis was used to examine the effects of average temperature (°C), altitude (m), and distance (m) to interior and perimeter shelters and lone trees on sheep location during the three activity periods (morning grazing, afternoon grazing, night camping).

Results

Paddock weather variations

In 2008 and 2009, COP had slightly lower (not significant) average temperature, lower wind-speed and lower SCI than did DH (Table 2). On the basis of the SCI calculations, the elevated DH paddock was colder (more adverse) than COP in 2008 by ~71 points, and in 2009 by ~113 chill points.

Sheep shelter use

The general usage patterns of the shelter categories (within <10 m of shelter) during the three activity periods varied among paddocks. For instance, in COP, where perimeter shelter and lone trees were present, the usage of lone trees and the perimeter shelter was highest during the night and

Table 2. Early spring (September–October 2008 and 2009) weather variations between Chain of Ponds (COP) and Dad's Hill (DH) paddocks

HSCE, high sheep chill east wind; HSCW, high sheep chill west wind; LSCW, low sheep chill west wind; SCI, sheep chill index

Year	Average wind-speed (km/h)	# days <230 SCI	# days >250 SCI	HSCE max.	HSCW max.	LSCW max.
			COP			
2008	6.4	46	5	356	362	185
2009	5.8	36	7			
			DH			
2008	11.1	41	10	421	433	200
2009	7.2	31	12			

Table 3. Percentage of shelter usage and patterns of use in Dads Hill (DH) and Chain of Ponds (COP) for shelter categories in 2008 and 2009 (symbols indicate relative usage compared with expected random distribution)

COP, d.f.(2), $\chi^2 > 9.21$, $P < 0.01$; DH, d.f.(3), $\chi^2 > 11.34$, $P < 0.01$. +, higher than expected; –, lower than expected; *, significant

Category	% of area (ha)	Night	Morning	Afternoon	% of usage Night	% of usage Morning	% of usage Afternoon
			DH 2008				
Interior	14	–	–	+	5	6	9
Perimeter	15	+	+	+	61	18	45
Lone trees	10	+	+	+	17	61	26
Remainder	61	–	–	–	17	15	19
χ^2		182.26*	416.38*	102.14*			
			DH 2009				
Interior	14	+	–	+	24	9	12
Perimeter	15	+	+	+	43	10	25
Lone trees	10	+	+	+	9	66	42
Remainder	61	–	–	–	24	15	21
χ^2		42.0*	382.74*	120.0*			
			COP 2008				
Perimeter	8	+	+	+	32	16	22
Lone trees	30	+	+	+	53	64	50
Remainder	62	–	–	–	15	20	28
χ^2		116.64*	57.79*	34.02*			
			COP 2009				
Perimeter	8	+	+	+	39	20	19
Lone trees	30	+	+	+	46	59	47
Remainder	62	–	–	–	15	20	33
χ^2		117.58*	46.17*	21.64*			

waned during the morning when paddock utilisation was random or driven by grazing behaviour. The usage of the perimeter shelter increased in the afternoon for both 2008 and 2009 (Table 3). The total shelter usage (within <10 m of shelter) in COP was significantly higher than expected, while the utilisation of the remainder of the paddock was significantly lower than expected in all activity periods for both years.

In DH, where perimeter shelter, interior shelter and lone trees were available, the perimeter shelter and lone trees were used more often during the night ($P < 0.01$). The usage of the perimeter shelter, interior shelter and lone trees was significantly higher than expected, while the utilisation of the remainder of the paddock was significantly lower than expected at all activity periods in both years. The usage of the interior shelter was significantly higher than expected only during the afternoon in both years and was significantly higher than expected during the night in 2009 (Table 3), with 24%, compared with 5% usage in 2008. Conversely, the usage of the perimeter shelter averaged 43% in 2009 and 61% in 2008, but these differences were not significant (Table 3).

The remainder of the paddock in both DH and COP was consistently and significantly used less than would be expected with a random distribution across all activity periods and in both years (Table 3). Perimeter shelter in both paddocks was used significantly more often than expected, particularly at night, whereas the usage of the interior shelter and lone trees was not markedly different from random, except during the afternoon (Table 3, $P < 0.01$). For both DH and COP, there was no significant difference in shelter and paddock utilisation between 2008 and 2009 for any of the activity periods.

Sheep location is related to temperature variations

Shelter usage of cold-, moderate- and warm-temperature areas within the paddocks are shown in Table 4.

In COP, the ewes used warm-temperature areas in the remainder of the paddock more often than expected at night and in the afternoon (Table 4).

The ewes in DH used cold areas located near the interior shelter more than expected, but used cold perimeter shelter less than expected during all activity periods in both years (Table 4). The ewes also used warm-temperature areas in the remainder of the paddock significantly more often than expected at night and in the afternoon, a pattern similar to the one observed in COP (Table 4).

Sheep location is related to altitude variations

Temperature and altitude were the main factors influencing paddock position (Table 5), particularly at night camping and during afternoon grazing. They were not important in determining position during morning grazing (Table 5). These effects were similar for both paddocks, with temperature, altitude, and then shelter types (lone trees, interior shelter and perimeter shelter) being of lesser impact (Table 5). Night camping did not occur at the highest altitude in each paddock, but rather apparently at a high altitude where some form of shelter was located.

Table 4. Shelter category use in cold-, moderate- and warm-temperature areas within the paddock in 2008 and 2009

+, higher than expected; –, lower than expected; *, significant; n.s., not significant = $P > 0.01$; χ^2, >13.28, $P < 0.01$

Category	% of area (ha)	Night (1900–0459 hours)	Morning (0500–1159 hours)	Afternoon (1200–1859 hours)
		DH 2008, cold		
Interior	14	+	+	+
Perimeter	15	–	–	–
Lone trees	10	+	+	+
Remainder	61	–	–	–
		DH 2008, moderate		
Interior	14	+	+	+
Perimeter	15	+	+	–
Lone trees	10	+	+	+
Remainder	61	–	–	–
		DH 2008, warm		
Interior	14	+	+	+
Perimeter	15	+	–	+
Lone trees	10	+	+	+
Remainder	61	+	–	+
χ^2		3189.94*	4286.30*	1326.71*
		DH 2009, cold		
Interior	14	+	+	+
Perimeter	15	–	–	–
Lone trees	10	+	+	+
Remainder	61	–	–	–
		DH 2009, moderate		
Interior	14	+	+	+
Perimeter	15	+	+	+
Lone trees	10	+	+	+
Remainder	61	–	–	–
		DH 2009, warm		
Interior	14	+	+	+
Perimeter	15	+	+	+
Lone trees	10	+	+	+
Remainder	61	+	–	+
χ^2		1227.54*	3416.03*	1381.29*
		COP 2008, cold		
Perimeter	8	+	+	+
Lone trees	30	+	+	+
Remainder	62	–	–	–
		COP 2008, moderate		
Perimeter	8	+	+	+
Lone trees	30	+	+	+
Remainder	62	–	–	–
		COP 2008, warm		
Perimeter	8	+	+	+
Lone trees	30	+	+	+
Remainder	62	+	–	+
χ^2		994.08*	684.89*	296.42*
		COP 2009, cold		
Perimeter	8	+	+	+
Lone trees	30	+	+	+
Remainder	62	–	–	–
		COP 2009, moderate		
Perimeter	8	+	+	+
Lone trees	30	+	+	+
Remainder	62	–	–	–

Table 4. (*continued*)

Category	% of area (ha)	Night (1900–0459 hours)	Morning (0500–1159 hours)	Afternoon (1200–1859 hours)
		COP 2009, warm		
Perimeter	8	+	+	+
Lone trees	30	+	+	+
Remainder	62	+	–	+
χ^2		30 406.10*	1374.03*	1839.63*

Table 5. Multiple regression of relative contribution of temperature average, altitude and distance to shelter (m) to predicting sheep counts in 2008 and 2009

B*, unstandardised coefficients. *$P < 0.05$, **$P < 0.01$, ***$P < 0.001$

Variable	Dads Hill		Chain of Ponds	
	B*	Predictor variable	B*	Predictor variable
2008 night	7.170*	Temp Av	1.053	Altitude
	–0.111*	Altitude	–1.001***	Temp Av
	–0.089***	DisIntShelter	0.025***	DistPerShelter
	0.030***	DisLoneTrees	–0.02	DistLoneTrees
	0.003	DisPerShelter		
R^2	0.22		0.05	
2008 morning	8.095***	Temp Av	0.11	Altitude
	0.049	Altitude	0.087	Temp Av
	0.036***	DistLoneTrees	–0.046***	DistLoneTrees
	0.007*	DisPerShelter	0.019***	DistPerShelter
	–0.001	DisIntShelter		
R^2	0.08		0.07	
2008 afternoon	–1.618	Temp Av	–5.121***	Temp Av
	0.226***	Altitude	1.013***	Altitude
	0.027***	DistLoneTrees	0.026***	DistLoneTrees
	0.019***	DistIntShelter	0.015***	DistPerShelter
	0.018***	DistPerShelter		
R^2	0.4		0.18	
2009 night	4.771	Temp Av	20.463***	Temp Av
	0.543***	Altitude	0.674***	Altitude
	0.043***	DistPerShelter	0.039***	DistLoneTrees
	0.029***	DistLoneTrees	–0.003	DistPerShelter
	–0.014*	DistIntShelter		
R^2	0.32		0.12	
2009 morning	–4.649*	Temp Av	0.306	Temp Av
	0.025***	DistLoneTrees	–0.042	Altitude
	0.015***	DistIntShelter	–0.046***	DistLoneTrees
	0.012	Altitude	0.018***	DistPerShelter
	0.01**	DistPerShelter		
R^2	0.07		0.06	
2009 afternoon	2.929*	Temp Av	12.519***	Temp Av
	0.172***	Altitude	0.137***	Altitude
	0.011***	DistPerShelter	0.0162***	DistLoneTrees
	–0.007**	DistIntShelter	0.008***	DistPerShelter
	–0.005*	DistLoneTrees		
R^2	0.19		0.28	

Sheep use leeward shelter during high sheep chill

Sheep counts within 10 m of the particular sectors of shelter (leeward, windward and the remaining side of the shelter) during the selected days for periods of HSCE, HSCW and LSCW are shown in Tables 6 and 7 and Figs 2 and 3.

In COP, during the periods of HSCE, the ewes used the windward side of the perimeter shelter at night significantly

Table 6. Chain of Ponds ewe counts within 10 m of particular sectors of shelter during high sheep chill east wind (HSCE), high sheep chill west wind (HSCW) and low sheep chill west wind (LSCW) in 2008 pre-lambing

P, perimeter shelter; L, lone trees; R, remainder of paddock and the compass point (N, S, E, W) location within 10 m. Values not followed by the same letter within columns are significantly different. *, significant

Shelter	COP HSCE – 2008			COP HSCW – 2008			COP LSCW – 2008		
	Night (1900–0459 hours)	Morning (0500–1159 hours)	Afternoon (1200–1859 hours)	Night (1900–0459 hours)	Morning (0500–1159 hours)	Afternoon (1200–1859 hours)	Night (1900–0459 hours)	Morning (0500–1159 hours)	Afternoon (1200–1859 hours)
PN	0.0bc	0a	0c	0.32c	0.02d	0.00d	0.23abc	0.13a	0.00c
PW	[B]1.63a	[B]0.07a	[B]0.04bc	[A]3.11a	[A]0.43ab	[A]0.70a	[A]1.13a	[A]0.02c	[A]0.15bc
LE	[A]0.16bc	[A]0.16a	[A]0.22a	[B]0.15c	[B]0.34abc	[B]0.13cd	[B]0.52abc	[B]0.72a	[B]0.12c
LN	0.26bc	0.15a	0.3a	0.38c	0.51a	0.34bc	0.33abc	0.69c	0.75a
LS	0.06bc	0.12a	0.01c	0.22c	0.16cd	0.16cd	0.21bc	0.42b	0.13c
LW	[B]0.84ab	[B]0.01a	[B]0.18ab	[A]2.10b	[A]0.20bcd	[A]0.56ab	[A]0.94ab	[A]0.09c	[A]0.35b
R	0.22c	0.08a	0.08bc	0.05c	0.07d	0.08d	0.18c	0.09c	0.11c
P-value	0.0036*	0.8414	0.0002*	<0.0001*	<0.0001*	<0.0001*	0.0212*	<0.0001*	<0.0001*

[A]Leeward side of the shelter.
[B]Windward side of the shelter.

Table 7. Dads Hill ewe counts within 10 m of particular sectors of shelter during high sheep chill east wind (HSCE), high sheep chill west wind (HSCW) and low sheep chill west wind (LSCW) in 2008 pre-lambing

P, perimeter shelter; L, lone trees; R, remainder of paddock and the compass point (N, S, E, W) location within 10 m. Values not followed by the same letter within columns are significantly different. *, significant

Shelter	DH HSCE – 2008			DH HSCW – 2008			DH LSCW – 2008		
	Night (1900–0459 hours)	Morning (0500–1159 hours)	Afternoon (1200–1859 hours)	Night (1900–0459 hours)	Morning (0500–1159 hours)	Afternoon (1200–1859 hours)	Night (1900–0459 hours)	Morning (0500–1159 hours)	Afternoon (1200–1859 hours)
PN	0.00b	0.02b	0.00de	0.00d	0.00d	0.00d	0.00b	0.00d	0.00c
PS	0.00b	0.00b	0.11bcde	4.37a	0.00d	1.89a	0.74b	0.00e	0.68ab
PW	[B]0.00bc	[B]0.01b	[B]0.00e	[A]0.00d	[A]0.01d	[A]0.00de	[A]0.08b	[A]0.01e	[A]0.07c
IE	[A]0.22b	[A]0.05b	[A]0.43a	[B]3.65ab	[B]0.51abc	[B]0.41b	[B]2.14a	[B]0.51c	[B]0.54b
IW	2.42a	0.34a	0.05de	[A]3.11bc	[A]0.79a	[A]0.34bc	[A]2.11a	[A]0.92ab	[A]0.45b
LE	[A]0.00b	[A]0.00b	[A]0.00de	[B]0.00d	[B]0.17cd	[B]0.00bcd	[B]0.11b	[B]0.50bcd	[B]0.00c
LN	0.00b	0.15ab	0.05de	0.00d	0.25cd	0.00cd	0.05b	1.30a	0.00c
LS	0.00ab	0.00b	0.21abcde	0.21d	0.14cd	0.00bcd	0.00b	0.21cde	0.00c
LW	[B]0.00ab	[B]0.14ab	[B]0.43ab	[A]0.07d	[A]0.71ab	[A]0.07bcd	[A]0.00b	[A]0.36cde	[A]0.00c
R	0.41b	0.10b	0.11d	0.17d	0.11d	0.13cd	0.26b	0.09e	0.13c
P-value	0.0525*	0.0751	<0.0001*	<0.0001*	<0.0001*	<0.0001*	<0.0001*	<0.0001*	<0.0001*

[A]Leeward side of the shelter.
[B]Windward side of the shelter.

($P < 0.01$) more often than expected (Table 7, Fig. 2). During the periods of HSCW, the ewes used the leeward side of perimeter shelter at night and afternoon significantly ($P < 0.001$) more often than expected, and the leeward side of lone trees at night (Fig. 2) and in the afternoon ($P < 0.001$, Table 5). During the periods of LSCW, the ewes used the leeward side of the perimeter shelter at night, but significantly less ($P = 0.02$) than they did during the HSCW at night (Table 6).

In DH, during the periods of HSCE, the ewes used the windward side of the interior shelter at night significantly ($P < 0.001$) more often than expected (Fig. 3), and the leeward side of the interior shelter in the afternoon ($P < 0.001$, Table 7). During the periods of HSCW, the ewes used the leeward and windward side of the interior shelter at night significantly ($P < 0.001$) more often than expected (Fig. 3), and used the perimeter shelter located at the southern end of the paddock at night and in the afternoon (Table 7). During the periods of LSCW, the ewes used the leeward and windward side of the interior shelter at night more often than expected ($P < 0.05$, Table 6).

Shelter use changes after lambing

During the 5 days pre- and 5 days post-lambing for each individual ewe, the use of COP and DH shelter categories did not change significantly. There was a slight (not significant) increase in the use of the remainder of the paddock in the 5 days pre-lambing in both years (Table 8).

In DH, during the 5 days pre-lambing, the perimeter shelter was used significantly ($P < 0.01$) more often at night than were

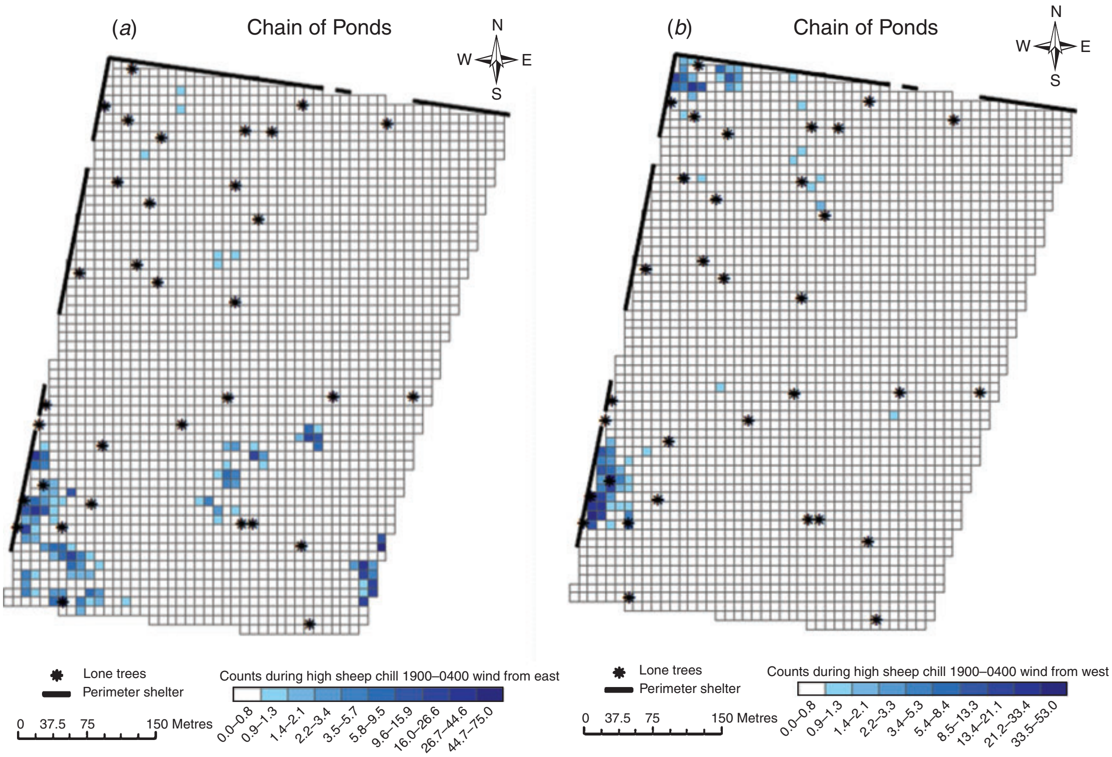

Fig. 2. Sheep distribution in Chain of Ponds paddock at night during (*a*) high sheep chill east wind (HSCE) and (*b*) high sheep chill west wind (HSCW).

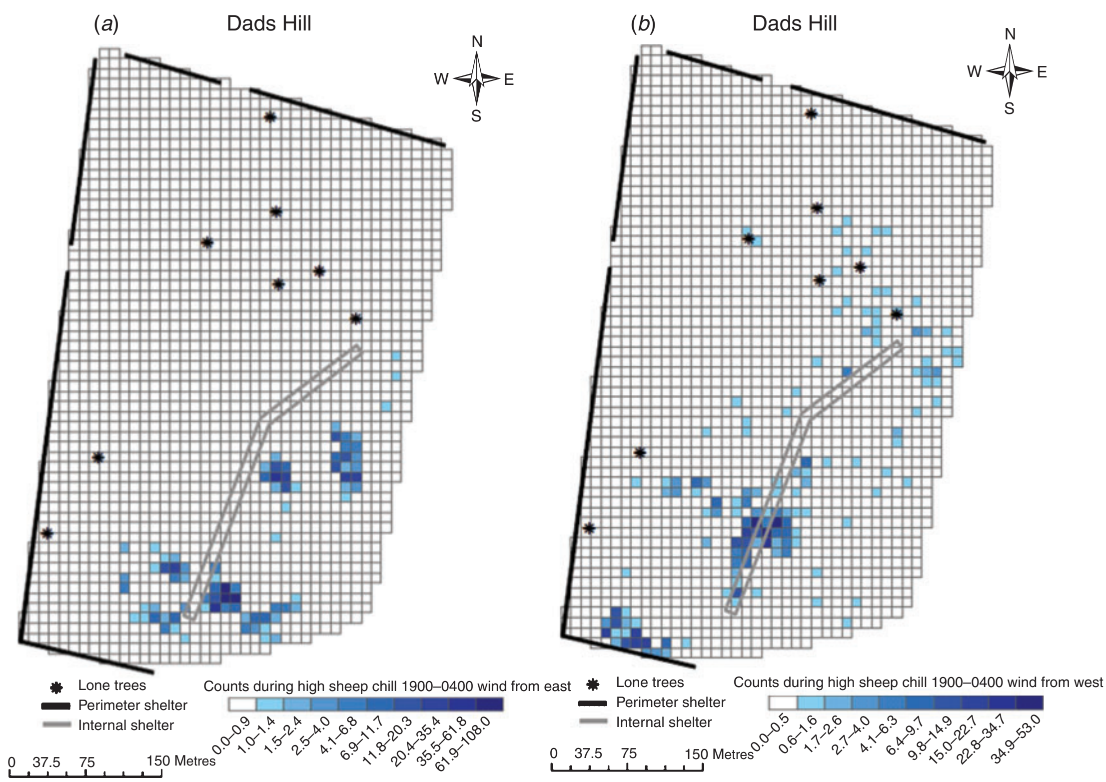

Fig. 3. Sheep distribution in Dads Hill paddock at night during (*a*) high sheep chill east wind (HSCE) and (*b*) high sheep chill west wind (HSCW).

Table 8. Shelter-use patterns in Dads Hill (DH) and Chain of Ponds (COP) higher or lower than expected 5 days pre- and 5 days post-lambing in 2008 and 2009

COP d.f.(2), $\chi^2 > 9.21$, $P < 0.01$; DH d.f.(3), $\chi^2 > 11.34$, $P < 0.01$. +, higher than expected; –, lower than expected; *, significant; n.s., not significant, $P > 0.01$

Category	% of area (ha)	5 days pre-lambing Night	Morning	Afternoon	5 days post-lambing Night	Morning	Afternoon
				DH 2008			
Interior	14	–	–	+	–	–	–
Perimeter	15	+	+	+	+	+	+
Lone trees	10	–	+	+	+	+	+
Remainder	61	–	–	–	–	–	–
χ^2		14.99*	39.54*	13.63*	6.30n.s.	45.21*	11.20n.s.
				DH 2009			
Interior	14	+	+	+	+	–	+
Perimeter	15	+	+	+	+	+	+
Lone trees	10	+	+	+	–	+	+
Remainder	61	–	–	–	–	–	–
χ^2		1.45n.s.	25.44*	9.86n.s.	6.26n.s.	50.96*	21.14*
				COP 2008			
Perimeter	8	+	+	+	+	+	+
Lone trees	30	+	+	+	+	+	+
Remainder	62	–	–	–	–	–	–
χ^2		11.17*	6.84n.s.	2.47n.s.	6.57n.s.	4.57n.s.	2.28n.s.
				COP 2009			
Perimeter	8	+	+	+	+	+	+
Lone trees	30	+	+	+	+	+	+
Remainder	62	–	–	–	–	–	–
χ^2		63.49*	9.04n.s.	3.69n.s.	11.18*	6.00n.s.	1.88n.s.

lone trees (Table 8) and this pattern did not change in DH or COP during any of the activity periods and in either year.

Discussion

It has been demonstrated that sheep will seek shelter during periods of heat stress (Johnson 1991) and the present study has now demonstrated that sheep (1 month post-shearing) will also seek shelter during times of high SCI. Sheltering behaviour was consistently observed throughout the two experimental years and in both paddocks (COP and DH). The fact that the ewes consistently used the shelter more often than the unsheltered remainder of the paddock suggests that the wellbeing of sheep may be compromised if inadequate shade and shelter are provided (Da Silva 2006). Lynch and Donnelly (1980) found that sheep in sheltered paddocks had increased productivity within the first year at low stocking rates and higher production at high stocking rates over all for the 4 years of their study. They concluded that shelter increased plant and animal production (4 kg heavier and increased wool).

Wet, cold and windy conditions can increase shorn-sheep mortality rates (Pollard *et al.* 1999; Pollard 2006) and the reduction of wind-speed will dramatically decrease the likelihood of loss. Likewise, wind-speeds of >15 km h^{-1} can increase mortality (by 21%) of single-born lambs in wet weather without shelter and Alexander *et al.* (1980) demonstrated a reduction in lamb mortality of 10%, with the provision of grass wind breaks as shelter. In the present study, ewe shelter utilisation was evident during a high SCI; particularly, during HSCW the ewes used the leeward side of the perimeter shelter and the leeward and windward sides of the interior shelter and perimeter shelter that was located in the southern end of the paddock, particularly at night (Figs 2, 3) and in the afternoon. During the periods with HSCE, the ewes also used the leeward and windward sides of the interior shelter, lone trees and the perimeter shelter at night (Figs 2, 3) and in the afternoon. It is notable that during these periods of HSCW and HSCE, the ewes had more than 28 days of wool growth; past studies have suggested that shelter is most utilised up to 14 days post-shearing (Lynch and Alexander 1980). The present study has provided the first evidence that sheep respond to cold beyond the 14 days and suggests that sheep may be more sensitive to the cold and wind chill and contrary to the belief that unshorn sheep are well insulated against the cold (Alexander 1974; Mottershead *et al.* 1982). Munro (1962) suggested that sheep sheltering behaviour was largely dependent on high wind-speeds, and sheltering behaviour increased as wind-speed increased and temperature decreased.

The leeward and windward sides of permeable windbreaks provide wind protection from upward and downward wind flow or wind reduction curves or drag coefficient (Miller *et al.* 1975). Wind breaks markedly reduce wind-speed and act as a barrier lowering ground wind-speed by deviating and splitting the airstream (Da Silva 2006). The higher the windbreak, the greater the distance of upwind and downwind protection being recorded at distances two to five times the height of the trees (Ruiz-Vega 1994). The use of the windward side of the interior shelter in DH during HSCE (Fig. 3*a*) may be due to the interior shelter being located 21–72 m down the west-facing hill which would also provide some wind protection.

Shade-seeking behaviour during the day appears to show a preference for individual trees in both paddocks. The insulation value of sheep fleece provides moderate protection from heat and cold, depending on fleece length (Blaxter 1977), but extended exposure to clear-sky solar radiation on hot days increases heat gain, causing unshorn and some shorn sheep to seek shade (Brown 1971; Stafford-Smith *et al*. 1985). This appears to be true in this environment even on what could be classed as very temperate conditions. Squires (1974) suggested that on flat rangeland terrain, shade was a major determinant of grazing distribution patterns in Merino flocks that utilised the shade areas every day. Taylor and Hedges (1984) found that the most utilised shade trees by Merino sheep provided high or flat umbrella-shape shade coverage. The present study would seem to confirm that individual trees providing canopy protection are the shelter areas used during the rest periods of the afternoon in particular.

Morning grazing is traditionally known to focus on food harvesting, but interestingly, the ewes displayed a preference for moderate-temperature areas in this period of the day. Thomas *et al*. (2008) found that the grazing positions of Merino ewes within the paddock were related to the daily ambient temperature, suggesting that temperature thresholds may exist for grazing-site selection as a means of energy conservation, internal water management and thermal-load reduction. Afternoon grazing, shade seeking and afternoon camping occurred normally at higher altitudes and under lone trees, interior shelter or perimeter shelter, which might be a reflection of a reduced emphasis on food gathering in the afternoon, suggesting social interactions rather than hunger needs might be predominant.

The ewe's paddock utilisation of moderate-temperature areas, higher altitude and shelter in the afternoon was similar to their paddock usage at night (Scott and Sutherland 1981). It seems the two key influences on paddock use in both paddocks were temperature and altitude. Night camping in the present study did not occur at the highest altitude, as previously believed, but rather at a high altitude where shelter was located. Night camping at high-altitude shelter areas may be related to predation vigilance (Gurarie *et al*. 2009). During night camping, the use of tree umbrellas also reduces night radiation (Taylor and Hedges 1984) and wind (Miller *et al*. 1975) and therefore heat loss through convection, ground and clear sky conduction, radiation and evaporation (Webster 1997; Pollard 2006). Sheep will seek resting areas with insulation in the form of tree umbrellas (Taylor and Hedges 1984) and dead grasses rather than bare ground to reduce radiation (Lynch *et al*. 1989).

In this study, the use of shelter by the ewes 5 days after lambing closely reflected their use of shelter 5 days pre-lambing. Stevens *et al*. (1981) also found that the use of shelter pre- and post-lambing was similar and suggested that this was largely determined by the gregarious nature of the breed.

The use of the remainder of the paddock increased somewhat 5 days after lambing, possibly due to ewes being scattered throughout the paddock with lambs as reported by Stevens *et al*. (1981), who found lambs congregated around tree and grass shelter and increased lamb interaction with other lambs (Pollard 1999; Nowak *et al*. 2008).

These findings suggest that further studies are required to more closely investigate how ewes use the shelter pre- and post-shearing and whether strategic location of the shelter at high altitudes within paddocks may encourage a more unified grazing pattern within paddocks and provide well protected night-camp sites. The present research focussed on SCI; however, future studies could examine in more depth the use of shelter from wind by sheep during days with warm and cold temperatures and the use of shade during days with high and low temperature humidity index. It would also be valuable to assess pasture quality in and out of shelter areas to determine how plants can influence shade and shelter use.

The use of GPS collars to study domesticated livestock behaviour (Turner *et al*. 2000; Thomas *et al*. 2008) permits the control and replication of experimental treatments more easily than perhaps in wildlife studies (Swain *et al*. 2011) and, with the ability to perform more focal observations, may allow for a greater distinction between technology and biology (Swain *et al*. 2011). However, with improved collar designs and less weight ensuring animal comfort may allow for more confidence in the use of the technology in behavioural studies. For example, Hulbert *et al*. (1998) found no difference in circadian rhythm and bite rate between collared and non-collared sheep when the GPS collars weighed less than 2.2% of the mean body mass of the study ewes.

A minimum number of GPS-collared animals required (at present, the cost per animal is high) to accurately describe animal group behaviour has yet to be established (Swain *et al*. 2011). However, the synchronisation of sheep eating, ruminating, idling (Rook and Penning 1991) and their gregariousness (Lynch *et al*. 1989), which influence each other, suggests that focal individuals (collared animals) from within a flock cannot be considered as behaviourally independent of group dynamics during an experiment (Boe and Faerevik 2003). Consequently, small numbers of GPS collars provide a non-invasive means to observe and better understand animal behaviour and environment utilisation, to improve animal welfare. The results of the present study confirmed the importance of shelter provision for sheep on the Northern Tablelands of NSW, whether they are in full fleece or recently shorn. Provision of shelter for sheep throughout the year and particularly during shearing and lambing has the potential to reduce shorn-sheep and lamb losses during inclement weather, increase animal wellbeing throughout the year and ultimately increase flock sizes (Lynch and Donnelly 1980; Bird *et al*. 1984).

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