GENERAL INTRODUCTION

Australia is one of the world's largest producers of wool. Wool production is common throughout Australia with about half of the world's greasy wool being grown in Australia, making it one of the country's most important agricultural commodities. Wool production in 2009 was 439 Kt (kiloton) of greasy wool with an export value of around 2322 million AU dollars (DAFF, 2010). The Australian Government Department of Agriculture, Fisheries and Forestry estimated in 2008 - 2009, based on the March 2010 Australian commodities report, that there were about 72 million sheep in Australia with 87 million being shorn each year; the higher number of shorn being due to some sheep being shorn twice per year (DAFF, 2010).

In Australia, inclement weather and cold exposure is a major factor contributing to shorn sheep and new-born lamb losses in the cooler regions. Morbidity and mortality are the ultimate measures of the effects of weather on shorn sheep and lamb welfare. Researchers refer to hypothermic shorn sheep losses as 'off-shear losses' and lamb losses as 'starvation-exposure syndrome'. Several studies were conducted in the 1960s and 1970s on lamb losses in relation to shelter while more recently, studies have been conducted on shorn sheep losses during inclement weather.

This review examines our understanding of sheep behavioural response to paddock space, topography and circadian patterns (grazing, resting and ruminating). Flocking animal social interactions may dominate their behavioural patterns, however, weather conditions and availability of shelter and shade may potentially disrupt or activate these flocking behaviours. Sheep behaviours may also vary noticeably when they are in full wool compared to post shearing.

Sheep behaviour (in particular shade and sheltering behaviour) seems less frequently studied than behaviour for many other species and therefore, the following chapter reviews what is known about how sheep choose to utilize paddock topography, shade and shelter, how weather conditions influence their behaviour and alternative means of encouraging them to shelter.

CHAPTER ONE

UTILIZATION OF PADDOCK SPACE BY SHEEP

Sheep grazing and resting behaviours to a certain extent resembles that of their wild ancestors (Key et al., 1980). Some of these behavioural tendencies include flocking behaviour pre, post and during camping and grazing (Arnold and Pahl, 1967; Grubb and Jewell, 1974) and dispersal behaviour while grazing (Jones, 1967). The combination of selective breeding and management practices over the years has led to breed differences in these behavioural patterns (Key et al., 1980). Lynch and Alexander (1973) suggest that Merinos tend to flock and only sub-group when they are young or during high temperatures and during times of food shortages compared to the consistent sub-grouping behaviour of Dorset Horns, and the usual dispersal of the Welsh Mountain sheep which tend to remain dispersed unless disturbed (Key et al., 1980).

The arid and semi-arid climate conditions in Australia contribute to feed, water and possibly shelter shortages, further challenging standard management practices. In light of these challenges the intent is to review work that has been done on sheep behaviour, placing the emphasis on paddock space utilization. The aim is to take inventory of deficiencies of knowledge and indicate future behavioural research requirements in domestic sheep behaviour.

Home range

Behavioural studies of any animal involves detailed observations of how animals interact in their habitat. The concept of territory and home ranges as areas routinely defended or repeatedly used by animals is one way in which this utilization is described. In wild sheep, same sex groups will occupy home ranges that may overlap (Geist, 1971; Syme, 1985). Grubb (1974) found that establishment of home ranges was influenced by the sheep's social system with ewes showing little inclination to stray from the group or to mix aimlessly with other sheep. He also observed that St Kilda Soay sheep groups were typically family units made up of a ewe and her surviving offspring and their offspring. The habits of movement within the home range are learnt from older ewes and are passed down to succeeding generations (Burt, 1943) suggesting long-term spatial memory. The acquisition of learnt behaviour through imitation and positive reinforcement allows individuals to learn home ranges, appropriate feed sources and behavioural responses (Adler and Adler, 1977).

Home range areas have been estimated for cattle to be approximately 160-280 hectares (Kil and Boroski, 1996) and for sheep approximately 25-50 hectares (ha) for Scottish Blackface ewes (Lawrence and Wood-Gush, 1988), South Cheviot ewes (Hunter and Milne, 1963), Soay sheep (Grubb, 1974) and (*Ovis stonei, O. dalli* and *O. canadensis*) American Mountain sheep (Geist, 1971) depending on the season. However, Lynch et al. (1992) and Lynch (1974a) in a semi-arid setting of Australia, found Merino ewes seemed to roam over vast areas up to 2000 ha with no defined home range. This difference may be due to the quality of grazing vegetation or locations of preferred grazing patches along with water source locations. Sheep tend to forage and sample graze choosing most palatable plant species first and have demonstrated memory of spatial locations of preferential feed and water sources within diverse topography and complicated paddocks (Edwards et al., 1996; Hewitson et al., 2005). Sheep have been shown to have the capacity to remember resource locations after only one visit which has also been observed in cattle (Bailey, 1996; Bailey et al., 1989a; 1989b; Laca, 1995).

The use of paddocks may be learnt from older group members over successive generations of paddock use (Hutson, 1984). Paddock shape seems to influence foraging efficiency (Lynch and Hedges, 1979; Scott and Sutherland, 1981; Sevi et al., 2001), however, circadian patterns, pasture quality and water availability may further influence grazing patterns and paddock use in complex ways (Bailey et al., 1996; Gillen et al., 1984).

Circadian patterns of grazing, resting and ruminating

Grazing animals develop food consumption patterns that are circadian in nature. Intake of pasture primarily occurs in a diurnal pattern. For instance, Lynch (1974a) and Scott and Sutherland (1981), found that most Merino sheep would leave the camp site soon after dawn, with a few sheep grazing around the edge of the camp sites. As grazing numbers increased to greater than 10 percent of the mob the sheep would slowly move off and begin grazing into the wind. Directional grazing continued for a while until a dominant arced grazing-front formed moving into the wind during thermal neutral temperature of 0-20°C (Dwyer, 1961; Scott and Sutherland, 1981). The sheep in the front of the arc tended to take two to three steps between bites. Scott and Sutherland called this behaviour ‘drifting’. The remainder of sheep would break camp walking quickly or running in small groups or in single file lines towards the centre of the grazing front with little to no grazing until they reached the centre, which they termed as ‘streaming’. Grazing continued for 3-5 hours (h) with some small groups forming behind the grazing arc. By late morning a synchronised rest period developed with some groups standing or lying down. Resting continued throughout midday and the afternoon and on sunny days shade seeking occurred. While sheep were lying or standing during mid day they would ruminate. Grazing behaviour increased by late afternoon until dusk with afternoon grazing much slower and independent of wind direction. Groups tended to graze, drift and stream to higher ground. At dusk groups would drift towards their night camp sites. “Camp sites” is a general term referring to an area typically at a high, or the highest, point in the paddock where the sheep lay down either during the day or night (Taylor et al., 1987).

Patterns of grazing behaviour are based on availability of different fodder, its nutritional value, palatability and consumption behaviour. Dumont et al. (2002) suggest sheep and cattle foraging in patchy grassland were affected by the number of preferred patches available. Grazing time ranges from 5-10 h per day depending on pasture quality. Grubb and Jewell (1974) reported that Soay sheep grazed between 6-12 h, with the higher number of grazing hours occurring during summer months when pasture quality was declining. Thomas et al. (2008) reported that on cool days Merino sheep spent more time grazing areas rarely visited on warm and hot days and Squires (1975) also reported a change in sheep preference for grazing areas as the seasons changed. The seasonal changes in grazing observed by Squires may be related to nutritional changes or to seeking cooler or warmer areas within the paddock but the experiment did not explicitly measure sheltering behaviour.

On average, in Australian rangeland studies, Merinos were reported to walk 8.8 km in summer and 5.6 km in winter (Lynch, 1974a; Lynch, 1974b). These averages may increase and decrease based on the distances between “remembered” feed sources, water sites, weather and time of season (Bailey et al., 1996; Folse et al., 1989; Saarenmaa et al., 1988). Scott and Sutherland (1981) estimated that Merino ewes' activities were grazing (60% of daylight hours) followed by laying (20%) and walking (5%), the remaining 15% during their trial was categorized as unknown due to poor light or rain hindering their observations. Squires (1974) also estimated Merino sheep spent about 3-4 hours during the daylight resting and ruminating and their principal activities were grazing and walking to and from water. Water requirements and availability of water sources in winter verses summer seasons may also influence grazing areas (Squires, 1974).

Availability of water

Australian studies reveal how watering behaviour and water locations influence walking distance and paddock grazing behaviour (Arnold and Dudziński, 1978; Kilgour, 1974; Squires, 1974). Arnold and Dudzinski (1978) found a direct association between preferred feed areas and water locations in paddocks used by sheep and cattle. Seasonal changes, temperature, pasture quality and quantity will also influence drinking behaviour especially in the semi arid climate of Australia. Clark and Jay (1975) observed during limited feed availability that Romney sheep would "fill up" with more water than that required for hydration purposes. Lange (1969) suggested for Australian sheep the paddock water point was the most important focal point even over preferred vegetation types.

During water shortage, sheep have been observed to graze earlier in the morning particularly after a heavy dew or rain-fall and then rest for extended periods during hot days (Scott and Sutherland, 1981). During a summer study in Australia, Lynch (1974b) observed one marked Merino moved to water daily while others only moved to water every three days indicating some individuals are able to make better use of water through physiological conservation possibly by reducing solar radiation and/or by selecting vegetation with a higher water content. Available vegetation also influences water requirements, for example, saltbush planted for shelter and supplementary feed will increase sheep water requirements (Macfarlane, 1964; Squires, 1974).

Circadian patterns such as night camping, and morning and afternoon grazing tend to dictate when and how paddock areas are used. Preferential feed sources along with water locations influence distances travelled and grazing durations within varying shaped paddocks. However, paddock topography and animal energy expenditure may establish how and where grazing of preferential areas and night camping occur.

Paddock slope, altitude and shade

Gillen et al. (1984) reported cattle had the greatest preference for meadow grazing, with eighty percent of grazing activity occurring on gentle sloping hills compared to steeper slopes 150 metres (m) away which received only 5% use. Paddock topography and distance to water have been recognized to influence cattle grazing (Bailey et al., 1989b; Brent et al., 2000; Gillen et al., 1984) while sheep and goats seem to be able to access and graze steeper and rocky slopes than cattle (Squires, 1975). The areas of the paddock most frequently used by Merino and Scottish Blackface sheep for grazing, shade grouping and night camping were at the highest altitude in the paddock and increased grazing activity seemed to occur around these areas as well (Hewson and Wilson, 1979; Mottershead et al., 1982). It is unclear if the sheep preferred the higher altitude or the shade located there or if it was a combination of both.

Paddock shade availability may also determine sheep distribution and day camp site selection. Squires (1975) found on flat rangeland terrain, shade was a major determinant of grazing distribution patterns with Merino flocks using it every day. The day camps in the trials were established near the only shade available, 1-2 m high shrubs. He suggested that Merinos' use of shelter may provide possibilities for manipulating grazing distribution patterns to reduce localized grazing pressure and group gathering which seems to develop around water points.

Circadian patterns of grazing, resting and ruminating in heterogeneous paddocks are influenced by preferential feed and water locations, paddock shape, size and altitude. However, in social ungulate species, social organization may also influence the use of paddock areas and it is unclear if gathering at water points is entirely based on hydration need or is to some degree motivated by the gregarious nature of the species' coordinated collective activities or group communal interactions similar to group gathering in shade areas and at night camp areas.

Impact of social organization

Animals living in colonies (Visscher, 2007), schools (Inada, 2000), flocks (Ramseyer et al., 2009a), herds (Ramseyer et al., 2009b), and troops (Leca et al.,

2003) make numerous "group decisions" daily. Group decisions being defined as group individuals reaching a consensus decision through a process of recruitment (Ramseyer et al., 2009c). For group individuals to maximize the benefits while minimizing the costs of grouping, a whole host of group decisions such as coordinated activities, movement, feeding and travel directions are involved (King and Cowlishaw, 2009; Squires and Daws; 1975). Group activities are common in stable social groups, such as Merino sheep, however, decision making may be influenced by dominance (Rands et al., 2006), relatedness (Ramseyer et al., 2009c; 2009b), internal state (Rands et al., 2003), and levels of obtained information (Couzin et al., 2005; Dyer et al., 2009). Therefore group cohesion and coordinated behaviour requires individuals to harmonize their behaviour with that of their neighbours (Biro et al., 2006; Syme, 1985) which is very apparent in Merino sheep.

Gregariousness and sub-grouping behaviour

Sheep have an innate desire to be with other sheep with their first preference to their own breed. Merino sheep have been noted for their tight group structure (Arnold and Dudzinski, 1978; Nowak, 2008), no dominance rank relationship with leadership (Arnold and Maller, 1974; Syme, 1981), and no consistent movement order or leadership during voluntary movement (Nowak et al., 2008; Syme ,1981, 1985). However, Nowak et al. (2008) and Syme (1981;1985) found there was a closer relationship between forced leadership behaviour (inside woolsheds and outside yard races) and increased exploratory behaviour along with reduced fear responses in the same animals. Lynch et al. (1989) suggest Merino social organization may rely on their leader-follower behaviour, but even more so on the gregariousness and grouping nature of this breed (Arnold, 1985; Syme, 1985).

Sub-grouping (groups of 3 or more individuals) of Merino flocks tends to occur in flocks of young sheep (less than 1 year old) and in sheep flocks under poor feed conditions with sometimes as much as 2 to 3 km between groups in rangeland conditions (Dudziński and Arnold, 1967; Lynch, 1974a). Squires (1975) reported that at Australia saltbush sites, sheep grazed in a single flock or as two sub-groups of 200 to 300 sheep with a mean distance of approximately 2.9 m between sub-groups where as on grassland sites sheep often grazed in 5 to 6 separated groups at a distance of 200 m with all groups amalgamating at camp sites and at water troughs. Squires observed some members of the grazing flock would continually drift between groups. If visual contact was lost Squires (1975) observed that ‘contact calls’ were made by one animal in the group prior to reuniting.

Leader-follower behaviour

A change of activity or location by the entire group may imply a consensus is reached by the group members (Conradt and Ruper, 2005). Ramseyer et al. (2009c; 2009b) suggest decision making in sheep is based on a behavioural recruitment process to elicit others to follow. Sheep passive recruitment is movement to a new location unintentionally promoted by an individual animal that prompts others to follow. This may be performed without the prompting individual’s knowledge (Ramseyer et al., 2009c). Alternatively, sheep active recruitment occurs when an animal recruits conspecifics to follow by displaying behaviours that influence other members to follow.

Ramseyer et al. (2009c) observed that young Romane ewes displayed group orientation, vigilance, stillness, head movement activities and increased steps before departure after a rest period (lying down). They found the number of neighbours following the first to move influenced and recruited conspecifics to follow. Not only was the first to move, influential but the second and third to move further increased the recruitment process. These observations suggest that decision making in domestic sheep groups is a continuous and distributed process, based on group state, individual behaviour and their social relationship. Gautrais et al. (2007) and Deneubourg and Goss (1989) found the probability of an individual animal joining movement behaviours increased with the number of individuals exhibiting that behaviour. Milinski (1987) defined this as a mechanism for aggregation, cooperation, synchronization or allelomimetic behaviour. Scott (1945) described allelomimetic behaviour as ‘two or more individuals doing the same thing at the same time with some degree of mutual stimulation’.

Merino sheep have been observed to demonstrate allelomimetic behaviour while walking (Fig. 1.1), running, grazing and bedding down together. Allelomimetic behaviour has also been observed in a wide variety of other species including deer (Darling, 1937), ducks (Allee et al., 1947), dogs (Scott and Marston, 1950), primates (Harlow and Yudin, 1933), and fish (Welty, 1934). In sheep it seems that leader-follower behaviour is controlled by visual signals with sheep following individuals moving away from the flock. Franklin and Hutson (1982) in their examination of visual cues used to initiate follower behaviour in laneways (races) reported that Merino sheep would move in the direction of the rump of another sheep or in the direction of movement of filmed sheep. Sheep (mixed breed) have been trained to follow a stockman or a sheep leader for paddock, feedlot and abattoir movements (Bremner et al., 1980). Sheep following behaviour that makes this training feasible may exist more obviously in some breeds than others (Gautrais et al., 2007; Ramseyer et al., 2009c).

Figure 1.1 Allelomimetic or following behaviour in Merino ewes. Photo by D.B. Taylor.

Most actions within a flock of sheep appear organized, peaceful (nonviolent, passive) and coordinated and are possibly preserved by means of constant visual contact between flock members. Crofton (1958) observed that during grazing, most sheep were positioned so that two other sheep were within a 110 degree angle of their own head position (i.e. two sheep in front of one sheep). However, Merinos have been noted for their tight group structure (Arnold and Dudziński, 1978) in the rangeland environments of Australia. It seems no recent research has further investigated sheep grazing positions in relation to sightlines of their conspecifics and if olfactory signals play a role.

Sheep have a visual field of around 270 degrees making them predominantly visual animals (Prince, 1956), and well adapted for predator detection (Walls, 1942 Fig. 1.2). Based on the perceived importance of eyesight and flock connectedness Crofton (1958) suggested that sheep maintain visual contact with at least two other animals and physical objects which may be the basis of orientation. Sheep group cohesion for connectedness, security, information, and other resources are important for individual survival and companionship (Alexander, 1974).

Stolba et al. (1990) found movement was typically initiated by older sheep within the group, which is consistent with other ungulate species such as African elephants (Foley et al., 2008) which have been observed to have elders leading the entire group to specific resources.

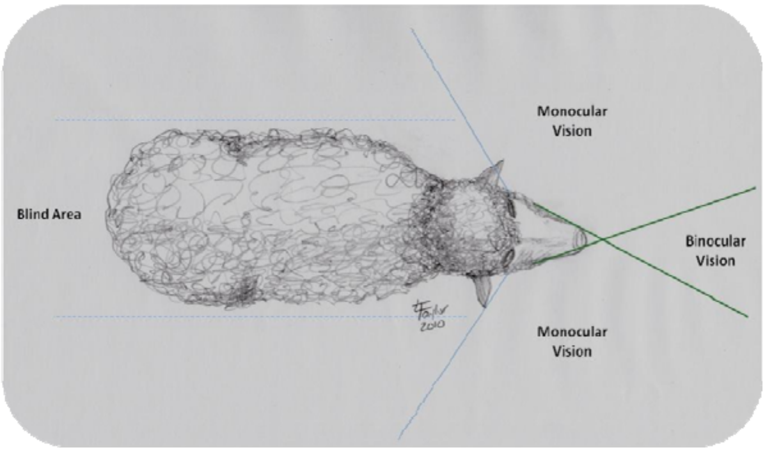

Figure 1.2 Sheep field of vision, showing binocular and panoramic vision enabled by the lateral position of the eyes. Illustration by D.B. Taylor.

Overall, animal behaviour, paddock use, and individual nutritional and water requirements seem to change based on time of year and may be further influenced by weather conditions. Extremely warm or cold conditions may cause a reduction and/or alteration of grazing and animal behaviour. Cold weather may have more effect on feed amounts consumed than on grazing patterns whereas extreme heat, heavy rain, wind and/or snow may significantly change sheep behaviour, grazing patterns and paddock use.

Effects of weather and weather associated behaviour

Mammals are endothermic and maintain their body temperature by generating heat from metabolic processes and attempt to maintain a stable body temperature by facilitating heat exchange between themselves and the ambient environment. The heat exchange must be at a rate that permits the animal to balance metabolic heat production with energy gains and losses (Pollard, 2006). Thermoregulatory behaviour is engaged when environmental factors challenge an animal's capacity to maintain thermoneutrality. 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 outward insulation and behavioural adaptability (DaSilva, 2006; Johnson, 1991; Marshall, 1981; McArthur, 1991).

Sheep responses to different environmental challenges vary from obvious movement or posture changes to physiological changes such as changes 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 that of survival, growth, reproduction, and production of animal products (Bird et al., 1984; Da Silva, 2006; McArthur, 1991; Stafford-Smith et al., 1985).

Environmental stressors that sheep are required to adapt to during their daily pattern of grazing include high ambient air temperature, radiation load (Fig. 1.3), humidity, wind and rain. In many cases, the first responses to these stressors are through behavioural changes (Conradt et al., 2000). These components of weather are interlinked and have been described by the use of indexes which capture the impact of a combination of weather conditions including wetness, wind-speed and low temperature into a sheep chill index (SCI; Nixon-Smith, 1972) and high temperature into a humidity index (THI; DPI Queensland, 1996).

Radiation and temperature

The high insulation value of sheep fleece provides protection from moderate heat and cold. However, the effectiveness of fleece insulation varies according to fleece length and density (Blaxter, 1977) with shearing providing a major disruption or shock to sheep ability to adapt to changes in cold and possibly hot temperatures. For sheep, air temperatures between 0-20°C are recognised as being in the "thermal neutral" zone. Critical temperatures, ranging from 25-35°C and above cause behaviour functions to change rapidly depending on the breed (Marshall, 1981; Scott and Sutherland, 1981). Scott and Sutherland (1981) suggest the optimum grazing temperature is around 12°C and that temperature may have a greater influence on sheep activity than wind or precipitation based on their study of Merino grazing behaviour on the South Island of New Zealand. It has been reported that livestock adapt their behaviour in response to weather conditions (Conradt et al., 2000) by improving foraging efficiency (Stephens and Krebs, 1986) and conserving energy, managing high water requirements and reducing thermal load (Thomas et al., 2008). Thomas et al. observed that Merino sheep travel more quickly and further from water sources on cool days (≤22°C) compared to warm days (23-25°C) and hot days (≥26°C). Murthy et al. (2005) found ambient temperatures above 26°C reduced sheep live-weight gain with more energy expended as temperatures increased [338 kJ/kg body mass $^{0.75}$ per °C body temperature] (Shinde et al., 1998)

Evaporative heat loss increases with increasing air temperature which prevents the core body temperature from rising. Sheep attempt to increase evaporation via their respiratory tract (panting) and through their 'exposed' skin of the face, ears, nose and legs (sweating, Hales and Brown, 1974; Hawke, 1991; Hofmeyr et al., 1969; Hopkins et al., 1978; Stafford-Smith et al., 1985). It is estimated between 20-90 percent of evaporative loss occurs through sweating during high temperature periods with estimates varying based on breed of sheep (Hofmeyr et al., 1969; Hales and Brown, 1974; Hopkins et al., 1978). Physiological effects of heat stress in sheep are: depressed appetite, increased thirst and water intake, and reduced wool growth. Similarly, during heat stress dairy cows have suppressed appetites and lower milk production (Bird et al., 1984; Hawke, 1991; Johnson, 1987, Thwaites, 1968) and in extreme cases hyperthermia. Sheep and cows alter grazing patterns to graze earlier in the morning and later at night (cooler times of the day) avoiding the hottest part of the day. In an attempt to reduce radiation, sheep will create shade circles if shade is unavailable. Shade circles comprised of 2-20+ sheep standing alongside each other with their heads down and/or directed inward in the shade of the other sheep (Scott and Sutherland, 1981).

Extended exposure to clear sky solar radiation increases heat gain. Macfarlane et al. (1956) reported that the surface of a black sheep's fleece, exposed to strong sunshine in Australia's tropics can reach temperatures as high as 87°C but the fleece may protect sheep from excessive radiation absorption. They found shorn sheep had increased respiration rates compared with non-shorn sheep when both were in strong sunlight for extended periods of time. Cloud cover provides partial relief from solar radiation. Lumb (1964) and Mount and Brown (1984) estimated solar radiation transmittance to be 15-30 percent through thick clouds. Stafford-Smith et al. (1985) used a 25 percent rate of solar radiation transmittance on completely overcast days for their sheep heat balance studies and found a slight reduction in shade seeking behaviour on the completely overcast days.

An animal's physiological response to environmental temperature can be influenced by the moisture content in the air. Temperature humidity index (THI) is an index based on the impact of the combination of relative humidity and air temperature on animals and was first developed to quantify the stress impact on dairy cattle in hot and humid conditions (Johnson, 1987). A threshold level of 78 (occurs at 27-30°C and relative humidity of 45-70 percent,) has been determined as the point at which milk production of dairy cows will begin to decline (DPI Queensland, 1996). Animals exhibit the following behaviour in order of increasing severity when THI is ≥ 78: shade seeking, crowding over water, refusal to lie down, agitation/restlessness, grouping to use the shade cast from other animals, laboured breathing with mouth open, excessive salivation, ataxia/inability to move, collapse, convulsions, coma, death (DPI Queensland, 1996).

Heat transfer between sheep and their environment occurs by conduction, convection, radiation and evaporation (Fig. 1.3). Radiation heat is received directly by the sun, or from the animals' environment via the ground, fences, buildings, and rocks that have been heated by the sun (Fig. 1.3). Thermal radiation provides heat which is avoided in hot environments and sought after in cold environments. Animal radiation exchange increases under a clear sky particularly at night causing the animal to experience temperatures approximately 20 degrees lower than that of the measured air temperature and ground radiation has been estimated to be as much as 15 degrees below that of air temperature (Hawke, 1991; Hutchinson and Bennett, 1962). Tree canopies can reduce sun radiant heat by up to 50 percent and significantly decrease clear sky night radiation levels. Night ground radiation is highest on clear sky nights. Sheep behavioural adaptations to the above conditions can range from shade seeking, standing in the shade cast by other animals, resting and/or sleeping under tree canopies during the day and long grasses at night.

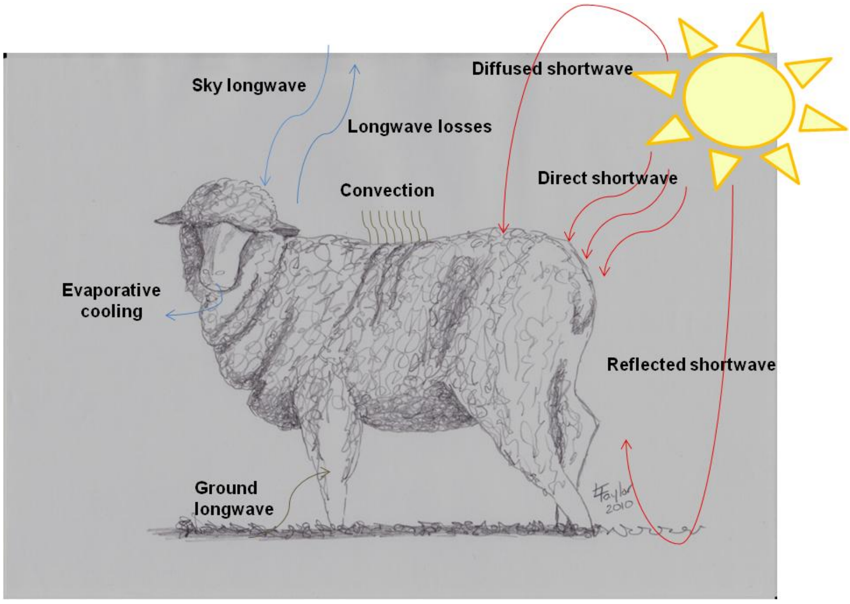

Figure 1.3 Acquired heat (radiation) load and emitted heat loss of sheep in the field. **Illustration by D.B. Taylor.**

Conduction losses occur through the feet of sheep while standing and through their bodies while lying down on cool surfaces such as bare-ground and damp short grass, however, long soft grasses can reduce ground conduction (Lynch and Alexander, 1976). Convection is the loss of body heat to the air which occurs when environment temperature is lower than that of the animal's surface temperature which produces a cooling effect. Air speed increases the effect of convection cooling which may be why on hot days sheep and cattle can be found standing on mounds in the paddock possibly to catch a breeze.

Wind, rain and temperature

The air surrounding animals is seldom still. At low velocity (<14 km/h) the wool is not directly affected (Fig. 1.4A); however, when wind velocity increases (>15 km/h) it affects the thermal boundary layer, which is a layer of air several millimetres thick surrounding an animal's skin or coat. As wind speeds increase, body heat loss increases to the moving air (Fig. 1.4B; Munro, 1962). High wind velocities (>40 km/h) affect the thermal properties of wool, fur or hair by separating the fibres exposing or almost exposing pelt, hide or skin (McArthur, 1991; Osczevski and Bluestein, 2005, Fig. 1.4C). At high wind velocities, a complete destruction of insulation value can occur due to the separation of hair or wool fibres especially when the wind hits the body at an angle (Ames and Insley, 1975; Hutchinson and Bennett, 1962). It is unclear if the 5 cm staple length sheep pelts used in Ames and Insley's experiment were Merino, therefore it is unclear if Merino wool which seems to have a tendency to clump at the outer ends of the long fibres, will separate as much as fleece that is (non-clumping) long and fine.

During low to moderate wind speeds on warm days sheep tend to graze into the wind. However during high wind speeds on cold and wet days they walk with the wind, eventually stopping at the end of the paddock and stand with their rear to the wind (Geytenbeek, 1963; Marshall, 1981). Wind can reduce or increase the thermal strain on livestock depending on the air temperature. Rain, and more specifically the amount of rain wetting an animal can further increase thermal strain. Prolonged rain can increase animal heat loss when wind speeds are high (Blaxter et al., 1964). A wet fleece can reduce fleece insulation value by 20% at wind speeds of 1.6 km/h and up to 30% at wind speeds of 7.2 km/h (Joyce et al., 1966). Bennett (1972) reported that shorn sheep exposed to prolonged rain and wind in air temperatures of 15°C were susceptible to death by hypothermia.

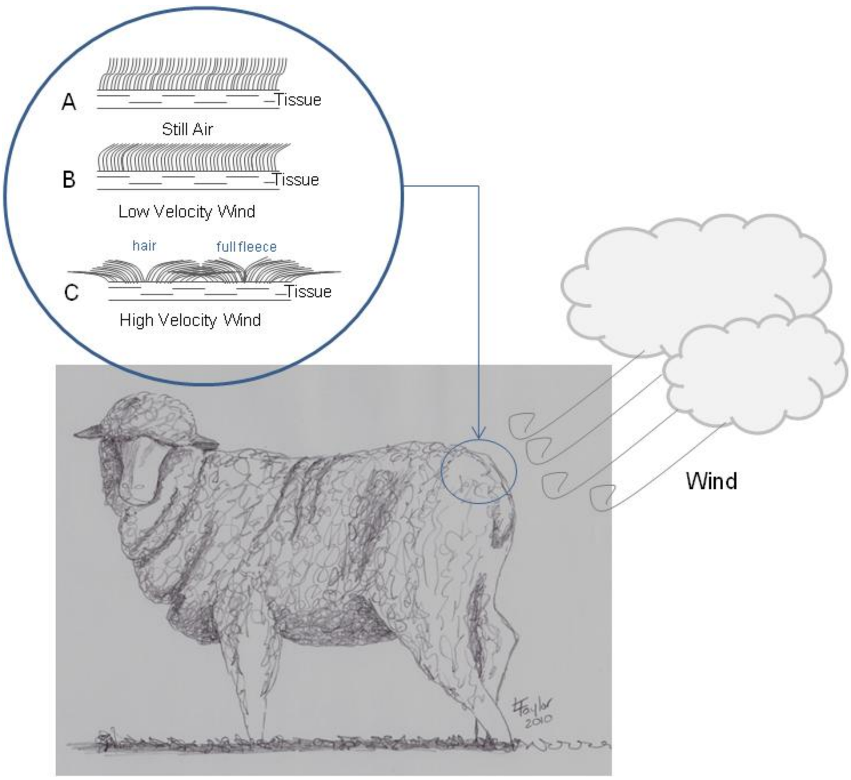

Figure 1.4 Wind effect on sheep wool (5 cm staple length). **Illustration by D.B. Taylor.**

The use of air temperature and wind velocity in a calculation was first used to predict adverse weather conditions for humans. It is called the ‘wind chill index’ and it was developed in 1941 by Seple and Passal (1945). Their calculations were based on the sensitivity of human exposed facial skin. Their calculation model was further developed to predict skin temperature and heat transfer that could lead to frostbite. The wind chill index was successful for humans but to be used for non-human animals the calculation required consideration for animal heat loss in relation to wind velocity and insulation values for an animal’s hide/pelt and hair/wool (Ames and Insley, 1975).

A similar concept has been used by the Australian Bureau of Meteorology to develop a ‘graziers alert’ to inform grazier’s of severe weather conditions that may impact on shorn or lambing sheep and was introduced in an attempt to reduce animal losses due to hypothermia. The graziers alert is based on an empirical model developed by Nixon-Smith (1972). The equations used were derived from lamb mortality research and weather (temperature, wind speed and rain) observations in Western Victoria during the 1960s and 1970s.

Research by Alexander (1968) and others found recently shorn sheep (14 days post shearing) were particularly vulnerable to hypothermia in wind speeds greater than 32 km/h with an air temperature less than 16°C and during times of greater than 42 mm of precipitation. They also found that wet lambs exposed to greater than 20 km/h wind could become hypothermic at less than 13°C ambient temperature. Obst and Ellis (1977) found mortality of lambs between 6 hours and 3 days old could exceed 70 percent when wind was greater than 18 km/h with rain fall of 1.5 mm compared to losses of 5-10 percent when wind was 0-8 km/h and zero rain fall. Hence the sheep chill index (SCI) used in the graziers alert calculation combines temperature, wind velocity and rain.

The SCI calculation incorporates animal heat loss in relation to wind velocity with wool/hide insulating values built into the equation (Ames and Insley, 1975) along with the changing variables of: wind velocity (km/h), air temperature (°C) and precipitation (mm of rain in past 6 h). Changes in animal behaviour have been observed in relation to high and low temperatures, wind and precipitation but there seems to be no published studies available on sheep behaviour during high and low SCI. Also it is unclear how Merino sheep alter their behaviour post shearing and during lambing to adapt to an extreme SCI.

Merino sheep have long been recognized as being well adapted to arid zones and hot environments (Macfalane, 1964; Stafford-Smith et al., 1985). However, significant losses of shorn Merino sheep and new born lambs during cold weather have been reported in Australia and there is evidence that this breed may be particularly susceptible to cold conditions (Stafford-Smith et al., 1985). Prolonged exposure either to heat extremes or cold can lead to hyperthermia and hypothermia (Bird et al., 1984) and behavioural responses to these situations include shade seeking and group huddling (Pollard, 2006; Webster, 1996). The provision of shade to reduce radiation load and windbreaks to reduce wind-chill are recognised as important management tools but there are a limited number of studies that have evaluated the capacity of sheep to utilize such protection when it is provided.

Shade and shelter seeking behaviour

Shade may provide advantages to grazing animals through a combination of the following: avoidance of radiation, more efficient use of water, safety and security. The use of shade and its thermal benefits to sheep are uncertain due to the varying insulation value of different fleece lengths and the individual animal preferences to seek shade. Newly shorn animals are more sensitive to solar heating (clear sky radiation load) than sheep with long wool according to Johnson (1987), Parer (1963) and Stafford-Smith et al. (1985), but in their studies, individual animals seemed to vary markedly in their inclination to use and seek shade under trees or behind shrubs and fence posts. In the absence of shade, they will create their own ‘shade circles’ with groups of sheep forming a tight standing group while holding their heads in the shade of the other animals’ bodies (Squires, 1975). Such behaviour demonstrates the importance of shade for the individuals in the group. Scott and Sutherland (1981) found shade circle groups did not form until air temperatures of greater than 15°C were experienced and that circle incidence was also determined by the amount of cloud cover and the time of day. They observed less shade circle grouping activity in the late afternoon, during high wind speeds and on cloudy days. The shade circle groups typically occurred on higher cooler terraces, breezy banks or on patches of bare soil in shade free paddocks.

When observing Merino mobs, Stafford-Smith et al. (1985) found that some animals would stand in the shade while others would lie in the sun on the edge of the shade suggesting the possibility that heat tolerance differs between individuals. The sheep in the sun would typically lie down while sheep in the shade would stand. These authors found that standing sheep had a metabolic rate 26% higher than those lying down suggesting that a mechanism of adaptation to high radiation load may be for animals to lower their metabolic heat load by lying down.

The sheep's fleece provides some insulation value from radiation loads. Brown (1971) found unshorn sheep would seek shade on hot days suggesting animals in full fleece may experience the adverse effect of a high solar heat load. Sherwin and Johnson (1987) found an association between time of day spent in the shade and the daily maximum air temperature which implies that thermal factors are major determinants of a sheep's choice to use shade.

The loss of wool insulation properties post shearing make recently shorn sheep most susceptible to cold and inclement weather. Shearing sheep with a cover-comb or snow-comb, which leaves 5 mm of wool compared to 3 mm of fleece with the standard-comb, can increase fleece insulation value (Dabiri, 1995; Hutchinson and Bennett, 1962) and reduce susceptibility to hyperthermia and hypothermia.

Recently shorn sheep normally seek shelter from the wind in cold weather (Lynch et al., 1980) and Lynch and Alexander's (1989) results suggested Merino sheep, given access to phalaris hybrid grass hedges (planted 10-20m apart at right angles to the predominant winds) within four weeks of shearing, use the shelter as a night camp site and during the day in inclement weather. This was reported to last for up to 8 weeks post-shearing. The unshorn sheep in Mottershead et al. (1982) study did not voluntarily seek shelter (Phalaris hedges) and Alexander et al. (1979) reported the same outcome, however, recently shorn sheep made use of shelter. In the study of Mottershead et al. (1982) the shorn sheep did not attract the unshorn sheep to shelter but conversely the presence of nearby unshorn sheep did draw shorn sheep away from sheltered areas. Lynch and Alexander (1977) found pre-parturient shorn Merino ewes would seek shelter during cold, wet and high wind (>40 km/h) weather conditions.

Shearing ewes prior to lambing as a means to facilitate phalaris shelter use was tested by Lynch and Alexander (1976) who found a large proportion of recently shorn (<2 weeks) Merino ewes lambed near grass hedges. They observed that on the first night in a paddock the sheep moved between 23:00 h and 03:00 h from their camp to shelter and continued to routinely use the shelter area as the new camp. It was suggested by these authors that the continued use of the shelter area as a camp-area was due to the soft grasses on the ground which provided body insulation from the soil as well as wind protection. However, it was not clear from this study if the animals retained memory of this site at subsequent times of exposure to cold conditions and there appear to be no studies that have examined the length of memory retention for such sites.

Lamb losses due to hypothermia

Lambs are born from a warm consistent uterine environment of 39°C into an external environment often less than 0 degrees C with possible precipitation and wind, making them highly susceptible to hypothermia (Pollard, 2006; Sykes et al., 1976; Vince and Billing, 1986). New-born lambs have limited body reserves to utilize in their attempt to maintain body temperature and rely on rapid milk intake to replenish energy utilized in maintaining body temperature. The length of time a lamb can survive without milk is reliant upon initial energy reserves (i.e. brown fat and glycogen) and external environmental conditions (Alexander, 1986; 1964; 1978) that will determine the rate of energy utilization. Alexander et al. (1980) reported that 'bad' weather at the time of birth increased the incidence of neonatal hypothermia, especially in lambs with low birth weights, and even slight hypothermia can suppress the lamb's suckling response creating a vicious cycle that can include a lowered body temperature, decreased strength to stand and suckle, as a result, a lack of nutrients to increase temperature and overall energy levels.

Lamb neonatal mortality in Australia has been estimated to be at least 20 percent, increasing during extreme weather conditions (Kelly, 1992; Obst and Day, 1968; Sheep CRC, 2008). Alexander et al. (1980) reported the provision of forced shelter reduced such lamb losses by 10 percent but the same study showed ewes were only attracted to the shelter if shorn two weeks prior to lambing, which is not an ideal husbandry practice.

Shorn sheep losses due to hypothermia

Losses of adult animals immediately post-shearing have also been attributed to inclement weather with losses in some Australian flocks of up to 17 percent (Holm et al., 1991). Although the 14 day period post shearing has been recognized as the period of maximum risk, the greatest losses in Australia have occurred in storms ≥14 days post shearing (Geytenbeek, 1963; Hutchenson and Bennett, 1962; Mottershead et al., 1982).

Hutchenson and Bennett (1962) during their wind tunnel experiments found recently shorn (standard-comb) Merino sheep exposed to 4.8-12 km/h wind at 1.7-3.3°C for 18-20 hours, could not withstand the conditions. They reported after 7 hours the sheep rectal temperature rapidly decreased and the sheep were unable to stand (signs of hypothermia). These findings would be even more severe with the addition of rain, lower temperatures and stronger winds which would be encountered in a paddock. Conversely, 7 of 8 sheep shorn with a snow-comb or cover-comb and exposed to the above conditions were found by Hutchenson and Bennett to be able to maintain normal rectal temperature during the 18-20 hour exposure. The majority of sheep shorn in Australia are shorn using a standard-comb, suggesting a greater need for shelter provision for these animals.

Management options to reduce effects of weather

Reducing both shorn sheep and neonatal mortality by providing shelter was the focus of several studies conducted in Australia during the late 1960s and early 1970s. Most animal shelter studies used perimeter shelter which was found to increase water and soil nutrients retention, reduce wind speed, transpiration losses and soil erosion while increasing plant productivity and extending plant growing seasons even in cold climates (Da Silva, 2006; Lynch and Donnelly, 1980; Nichols, 1982). The shelters used in previous studies have largely been windbreaks on paddock fence lines (horticultural type shelter) and have been comprised of trees and/or grasses or, if within paddocks, tall grass windbreaks of species such as *phalaris tuberosa* planted in rows (Egan et al., 1976) and the phalaris hybrid (*P. tuberose* x *P. arundinaceae*) at right angle hedges planted approximately 20 m apart (Alexander and Lynch, 1976). Lynch and Alexander (1976) found phalaris hedges were superior to sarlon (horticultural shade-cloth) shelters not only for reducing wind speed but also because ewes had a clear preference for the phalaris. They suggest other factors contributing to this preference may have been due to protection against night-sky radiation, visual screening and wind speed reduction. Alexander et al. (1979) observed shorn sheep and lambing ewes making use of shelter belts that were as far as 240 m apart and McCutcheon et al. (1981) suggested that as the distance between shelter belts increases the time spent by ewes in shelter decreased. This observation indicates that further investigation is required to determine whether the sheep chose to be in shelter or were observed in shelter by default due to the close spacing of the shelter belts.

Egan et al. (1972) and McLaughlin et al. (1970) both concluded that confining ewes so they cannot escape from an area of known shelter was the best shelter system. Alexander et al. (1980) reported that windbreaks improved the survival rate of fine-wool Merinos by an average 10 percent during a 5 year study when they were in ‘forced shelter’ structures. Lynch and Alexander (1977) also observed that closely spaced sheltered areas increase the number of ewes sheltered, not by choice but by default because a higher proportion of areas were sheltered in a paddock. Producers seem reluctant to create paddocks with appropriate forced shelter for lambing ewes and shorn sheep use. However a better understanding of sheep preference for shelter types and location may provide valuable insight on appropriate shelter provision.

Attempts to encourage sheep to use shelter by placing shelter at their camp sites were unsuccessful in the studies of Lynch and Alexander (1980) as the camp was used only at night. Preferences for different shelters such as woven jute fabrics, sarlon, phalaris hedges, trees of varying species, stone walls, sides of buildings, rows of hay bails, tents, corrugated iron and timber shelter seem to vary considerably (Alexander et al., 1980; Egan et al., 1972; 1976; Lynch and Alexander, 1977; Pollard, 1999). It remains unclear what form of shelter is consistently successful, what characteristics sheep might seek in choosing shelter or how selection may affect paddock use and grazing behaviour especially during extreme weather conditions.

Observation studies prior to the use of global positioning devices have been restricted to visual observations from dawn to dusk from raised platforms or towers located in the paddock or adjacent paddocks with the added challenge of inclement weather. Recent studies in livestock research have been done with relatively new technologies such as global positioning systems (GPS) devices. GPS devices provide continuous 24 hour periods of unobtrusive animal observation during both fair and foul weather. GPS has been used to understand many wildlife species movement (Bowman et al., 2000; Rempel et al., 1995) and is becoming more common in livestock research to better understand and cope with increased livestock density and the prevention of overgrazing. Such studies include animal, plant and soil interactions (Trotter and Lamb, 2008), cattle grazing (Brent et al., 2000), free range cattle activity (Ungar et al., 2005), sheep foraging (Bertiller and Ares, 2008), hill sheep grazing (Rutter et al., 1997), sheep spatial grazing (Bertiller and Ares, 2008), Merino grazing patterns on warm and cool days (Thomas et al., 2008), and Scottish Blackface ewe circadian feeding behaviour (Hulbert et al., 1998). There are no known publications describing the use of GPS collars to understand sheep sheltering behaviour post shearing and during lambing.

It is also unclear whether or not sheep can be trained to move to shelter areas. There are reports that sheep can be trained to lead other sheep in abattoirs while opening and closing gates (Bremner et al., 1980), turn on heaters by intercepting a light beam with their nose and to operate a switch for food, light or heat (Baldwin, 1972). These training outcomes highlight that training sheep can be useful for management in some contexts but there appear to be no studies that have evaluated cues most suitable for training sheep nor the retention time of responsiveness to such cues or the success of transference of the learned task to a novel area.

If sheep can be trained to respond to cues then the possibility exists for use of such cues in manipulation of sheep flock movement for a variety of management purposes including shelter use, paddock and yard movement. Moreover, the possibilities of training sheep as flock leaders has the potential for moving flocks not only to shelter but for a whole host of other management practices.

RESEARCH PLAN

The research that follows was designed to address some of the above issues and gaps outlined in this chapter, primarily focusing on how sheep choose to utilize paddocks topography, shade and shelter, how weather conditions influence their behaviour and potential alternative means of encouraging them to use shelter.

Chapter 2 reports on studies where global positioning system (GPS) devices were used to examine the factors influencing pregnant and lambing Merino ewe use of shade and shelter in relation to weather conditions over two lambing seasons (2008 and 2009).

Chapter 3 reports on studies to determine if Merino sheep can be trained to respond to visual and auditory cues, assessing the importance of spatial cues compared to visual cues, and investigating the influence of temperament on speed of learning and memory.

Chapter 4 investigates the potential to use trained sheep to influence the movement of naive (non-trained) Merino sheep to a combined visual and auditory stimulus, assessing if flock size reduces responsiveness to follower initiated behaviour and whether sub-grouping will hinder group movement.

Chapter 5 presents an overview of the combined research results, discussion and conclusion.

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CHAPTER TWO

GPS OBSERVATION OF SHELTER UTILIZATION BY MERINO EWES[1]

Chapter Contents Published

Taylor DB, Dobos RC and Hinch GN. (2011) "Bayesian change-point analysis of grazing sheep behaviour to identify lambing." *Rangeland Ecology Management* (under preparation)

Taylor DB, Schneider DA, Brown WY, Price IR, Trotter MG, Lamb DW and Hinch GN. (2011) "GPS observation of shelter utilization by Merino ewes." *Animal Production Science*, 51, 724-737.

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CHAPTER THREE

THE IMPACTS OF SPATIAL CUES AND MEMORY WHEN TRAINING MERINO SHEEP TO RESPOND TO A VISUAL AND AUDITORY STIMULUS[2]

Chapter Contents Published

Taylor DB, Brown WY, Price IR and Hinch GN. (2010) "Training Merino sheep to respond to visual and auditory cues." *Animal Production Science*, 50: 541-545

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CHAPTER FOUR

EFFECTS OF FLOCK SIZE, PADDOCK COMPLEXITY AND TIME OF DAY ON RESPONSE TO TRAINED LEADERS[3]

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CHAPTER FIVE

GENERAL DISCUSSION

The objective of this research was to further develop an understanding of Merino ewes sheltering behaviour and paddock utilization; plus investigate an alternative means of attracting or moving flocks within paddocks. Detailed below are the outcomes of the first body of research to use GPS collars to observe Merino sheep paddock utilization and sheltering behaviour and the first data to confirm experimentally and to highlight the potential for the use of visual and auditory cues in manipulating movement of Merino sheep and flocks within paddocks. The major findings from this research are discussed below and the issues associated with shelter availability and trained leader movement that have arisen during this research are examined.

MAIN FINDINGS

The study outlined in chapter 2 has demonstrated that pregnant and lambing Merino ewes used all shelter categories available considerably more than expected and more than the remainder of the paddock that was devoid of shelter. The fact the ewes consistently used shelter suggests there may be wellbeing issues associated with inadequate provision of shade and shelter throughout the year. In particular it appears that during high sheep chill periods the ewes use shelter of any type which was more than expected. It was notable that this shelter use occurred even for ewes with more than 28 days of wool growth suggesting that ewes maybe more sensitive to chill than previous studies suggests (Alexander, 1974; Mottershead et al., 1982).

Night camping did not occur at the highest altitude (chapter 2), as previously reported (Hewson and Wilson, 1979; Mottershead et al., 1982), 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). However, night camping use of tree umbrellas to reduce night radiation (Taylor and Hedges, 1984) and wind (Miller et al., 1975) may be as important to sheep as predation vigilance.

Lambing is an event that can be identified using known and predictable behavioural responses (Arnold and Morgan, 1975), for example lambing ewes have a tendency to remain with their offspring in the period immediately after lambing. Bayesian change-point (bcp) analysis was successfully used to identify a change-point in the ewes mean daily velocity that could be associated with lambing in most ewes. Based on the analysis, the time period 0500-1159h appeared to be the best window to evaluate and estimate lambing. This finding highlights the possibility that GPS tracking information may be able to be used to identify behavioural patterns other than those associated with spatial movement.

Chapter 3 confirmed that sheep, once trained, can retain memory of a visual and auditory stimulus for at least 4 months without food reinforcement and it would seem that this “knowledge” can be transferred between a familiar location and a novel one without loss of responsiveness. This suggests that such information is stored in reference or long term memory (Bailey, 1996) as opposed to their working or short term memory. Dumont and Petit (1998) and Bailey et al. (1989b; 1996) found cattle and sheep remembered food locations in a maze longer (20 days) than the depleted food sources (1 day). The sheep in all three experimental groups showed evidence of rapid extinction of the learnt approach response when a food reward was no longer contingent on approaching the stimulus (test with less than 3 days between them). However, in the test with more than 30 days between test events 90% of the visual+auditory group again approached the stimulus, suggesting that this group (possibly in contrast to the auditory group and visual group where correct responses were lower) retrieved long-term memory associations of both cues and food reward.

Sheep have been described as visual animals (Walls, 1942; Prince, 1956; Geist, 1971) and therefore it might be expected that visual cues would predominate over auditory cues. Vocalizations are typically confined to mother-young interactions and distress calls (Nowak et al., 2008). In the study reported in chapter 3, a combination of visual and auditory cues were the most effective in inducing learnt responses from the sheep which suggests that cues used in training are possibly best chosen to activate more than one sensory system.

In chapter 4 it was demonstrated that sheep trained to respond to a combination of a visual and auditory stimulus do provide leadership when mixed with naïve sheep flocks and consequently can cause a flock to rapidly change position to congregate around an activated stimulus. This behaviour was consistently repeated for a variety of flock sizes, leader to flock ratios and in paddocks of varying complexity and at different times of day. All sheep in the small flock approached the stimulus at both levels of complexity and it would appear that the trained sheep initiated flock movement through a combination of passive recruitment (Ramseyer et al., 2009c) and allelomimetic behaviour (Scott, 1945). These findings suggest that trained animals could be used to manipulate animal movement for farm management purposes.

As outlined in chapter 4 some of the individuals from the naïve flock initiated movement and demonstrated lupin eating behaviour after the first phase of testing. This was particularly noticeable in the smaller flocks (SM and MM) which may reflect differences in the ratio of “teachers” to naïve animals (Lynch et al., 1983) but also might simply reflect the amount of lupin reward available for each sheep and the reinforcement effects of this reward (Carlson and Buskist, 1997). These findings possibly highlight the importance of having older sheep in flocks for sharing learned information. Similar learning has been reported by Burt (1943) who suggested that the habits, movement and home-range of wild sheep are learned from older ewes and passed across generations.

FUTURE RESEARCH

As suggested in chapter 2, sheep do not randomly use their paddock environment pre and post lambing and further research should explore sheep paddock utilization pre and post shearing and seasonal changes in use of paddock shelter, and the main determinants of use. This research could provide additional information about the appropriate designs and positioning of trees and shrubs in programs such as Landcare that aim to improve tree cover on grazing properties.

Bayesian change-point analysis used to identify behaviours other than grazing behaviour and spatial patterns may provide a way of expanding the use of GPS tracking data. This approach might also be further developed for incorporation into decision support tools useful for producers' decision making particularly during lambing.

Sheep learning (chapter 3) seemed to follow similar patterns to those found in other species (Galef and Laland, 2005) although further clarification of principles that may be used for vigilant flocking species is required. An investigation into the success of intermittent reinforcement rather than continuous reinforcement may prove useful in avoiding extinction and thus maintaining responsiveness of animals to cues attracting them to sheltered areas.

The successful movement of naïve flocks (chapter 4) was observed for Merinos in this study but further studies on less gregarious sheep breeds, group size (greater than 45), larger paddocks (more than 20ha), are still required. Investigation into a visual and auditory stimulus automatically activating during high sheep chill index and monitoring of trained sheep flock movement into sheltered areas may reduce shorn sheep and lamb mortality.

CONCLUSION

In conclusion, the findings of this thesis research highlights the importance of shelter for Merino sheep in Australia not only to reduce shorn sheep and presumably lamb hypothermia but potentially also to improve animal welfare throughout the year. The GPS tracking of lambing ewes during 2008 and 2009 has highlighted that Merino sheep do require shelter and it appears are as sensitive to heat as to cold. The ability to train Merino sheep and the potential for the trained sheep to pass on the learned information to their conspecifics suggests a means of flock movement during inclement weather or during general husbandry practices. Shelter provision and flock movement with trained sheep has the potential to improve animal wellbeing during inclement weather. These findings support the need for further research that examines trained animal leadership during high sheep chill index conditions, sheltering behaviour of sheep pre and post shearing and seasonal changes in paddock and shelter utilization.

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CHAPTER SIX

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CHAPTER SEVEN

LIST OF PUBLICATIONS

Peer reviewed scientific journals

Taylor DB, D.A. Schneider, Brown WY, Price IR, Trotter MG, Lamb DW and Hinch GN. (2011) "GPS observation of shelter utilization by Merino ewes." *Animal Production Science, 51*, p. 724-737.

Taylor DB, Dobos RC and Hinch GN. (2011) "Bayesian change-point analysis of grazing sheep behaviour to identify lambing." *Rangeland Ecology Management* (under preparation)

Taylor DB, Brown WY, Price IR and Hinch GN. (2011) "Effects of Merino flock size, paddock complexity and time of day on response to trained leaders." *Small Ruminant Research*, *97*, p. 35-40.

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Peer reviewed conference abstracts

Taylor DB, D.A. Schneider, Brown WY, Price IR, Trotter MG, Lamb DW and Hinch GN. (2010) "GPS tracking use of shelter and shade by Merino ewes." Proceedings of the Sheep CRC Conference 2010, Adelaide, Australia, p. 55.

Dobos Robin, **Taylor Lee**, and Hinch Geoff. (2010) "Bayesian change-point analysis of grazing sheep behaviour to identify lambing." 1st Australian and New Zealand Spatially Enabled Livestock Management Symposium 2010, Armidale, NSW Australia, p.18.

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"Sheep shelter study may reduce winter losses." August 12, 2009. The Armidale Express (news paper) p. 7.

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"Study on creature comforts." July 06, 2009. The Walcha News (news paper) p. 3.