Final report

Spatially Resilient Grazing Systems: Measuring and optimising landscape utilisation in rangeland sheep and goats

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Abstract

There is increasing interest amongst producers in the integration of small ruminant red meat production in Western Queensland. As part of this expansion, the industry is interested to understand how these animals use the landscapes in which they graze and how this might be optimised in terms of productivity and sustainability.

This report provides details of the activities undertaken to quantify small ruminant landscape utilisation by GPS tracking numerous animals on properties in Western Queensland. An analysis of the data collected is provided with a summary of insights gleaned from this also outlined. A review of literature explored the potential interventions that might be implemented to optimise landscape utilisation by small ruminants

Spatial grazing distribution of all animals was clearly impacted by the position of water, particularly when stocking rates were low, and animals were able to become more selective in their grazing area. Where stocking rates were higher or feed less available the spatial grazing distribution expanded to fill most of the available paddock, suggesting animals are searching all available resource areas for feed.

The analysis of sheep and goats co-grazing found that overall, they shared similar grazing distributions. However, whilst sheep tend to graze similar broad areas within their species, goats tend to have smaller individually variable ranges.

Spatial grazing distribution of sheep and goats was also driven by landscape factors, the specific relationships require further analysis. The average distance to water varied, however nearly all animals across all properties did not exceed a maximum distance from water of 2.4km and was on average between 500m and 1200m. Temperature was found to be significantly related to animal behaviour with higher temperatures reducing the distance sheep and goats could be found from available water.

This project was terminated early as COVID related restrictions meant that key research staff could not travel to Australia from the key collaborating organisation New Mexico State University to undertake the required field observations and run proposed intervention trials.

Animal ethics approval was granted for this research (approval number CQU AEC0000021776).

1. Executive summary

Background

The expansion of the sheep and goat industries across the rangelands of Western Qld offers significant economic potential both in terms of diversified income sources but also flexibility in responding to and recovering from drought. However, there is concern around the management of sheep and goats in the context of landscape sustainability. It is generally thought that these smaller ruminants have the potential to cause a higher intensity of patch and paddock overgrazing if not optimally managed. Producers are also keen to understand how they might optimise the productivity of the grazing landscape through managing spatial grazing pressure. However, there has been little objective data collected that measures the landscape utilisation of sheep and goats and how they might interact with the spatially diverse feed-base, water and other resources.

Objectives

The key objectives of this project were: 1. Deliver a review of the management strategies that have been reported in the literature for influencing the spatial grazing distribution of small ruminants in rangeland landscapes; 2. Deploy GPS tracking devices to collect baseline data on grazing distributions of sheep and goats in typical rangeland landscapes; 3. Develop analytical techniques that explore and explain the relationship between grazing distribution and the feed-base, water and other landscape resources; and 4. Explore how variation in weather, particularly thermal stress events might influence grazing distribution and use of key water resources.

Methodology

This project firstly undertook a literature review to understand sheep and goat spatial landscape utilisation and the interventions that might be applied to optimise how these animals use the resources available to them.

The major component of the project involved deploying GPS tracking collars on a number of properties across Western Queensland (Figure 1) to collect objective data from sheep and goats. The data was analysed in collaboration with New Mexico State University to explore a number of key animal behaviours and relationships with landscape features. This project supports a Masters Student (Caroline Wade) at NMSU.

Figure 1 Sheep and goats fitted with GPS tracking collars as part of the

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Results/key findings

- The review of literature highlighted how little information is available around spatial landscape utilisation by small ruminants in comparison to cattle.
- The average daily distance travelled by small ruminants across all sites varied between 5.7km (Rangeland Goats) to 8.1 km (Merino Ewes). The maximum distance travelled across all sites ranged from 6.5 (Rangeland Goats) km to as much as 20.5km (Merino Ewes).

- The maximum distance to water reported across all sites was approximately 2.5km, however animals where on average more likely to be within 500m – 1.2km of water.
- Increasing temperatures had a significant impact on the distance animals were found from water. Not surprisingly as temperatures increased animals were found closer to water, although the effect was only marginal, for every 1 degree increase in temperature distance to water decreased by 5-20 metres.
- Producers can gain significant insights into livestock landscape interactions when provided with objective data from GPS tracking technology from their property.

Benefits to industry

The fact that few animals grazed beyond 2.5 km from a water source confirms the information currently being provided to the industry. However, given that most animals preferred to be within 500m of a water point suggests that a more intensive distribution of water points should be considered by producers seeking to optimise landscape utilisation. This cannot be made as a general recommendation but will provide producers seeking to develop country with new infrastructure some guidance in their thinking.

One of the key benefits to industry is the value of the objective GPS tracking data to producers. For some producers involved it revealed genuinely unknown trends in spatial landscape utilisation. As we sat with producers and worked through the results we were often met with exclamations of surprise that certain areas of a paddock were either used or not used by the sheep and goats. With further research these insights could lead to both productivity and sustainability gains, particularly where properties are being redeveloped with new fence and water infrastructure. There is a genuine opportunity to see this scaled across the entire sector if affordable and reliable GPS tracking technologies can be delivered to the small ruminant industries.

Future research and recommendations

Continued investigation into the spatial landscape utilisation of small ruminants in rangelands is warranted. Although this project has been terminated early, the research in this area will continue to be supported through the Masters student at NMSU and will involve more animal and properties. However, there is a need to gain a broader understanding of how these animals utilise the landscape across a wider diversity of operations in the rangelands as each property has many unique features. The understanding of how animals use water resources and other features (particularly shade and shelter) across more sites will allow more rigorous recommendations to be developed to assist producers in designing infrastructure development programs.

One of the key outcomes of this project was the observed tendency for animal spatial landscape behaviour to vary with temperature. There were clear relationships, however only a limited amount of data was collected to explore genuine thermal stress events. There is an increasing interest within the industry in understanding how heat stress events might be impacting on productivity and sustainability on rangeland ruminant production systems. Further research into monitoring sheep and goat behaviour under genuine thermal stress events and the evaluation of management interventions that might ameliorate the effects of these climate extremes should be prioritised.

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2. Background

The roll out of exclusion fencing across the Queensland rangelands brings with it the potential to shift into profitable smaller ruminant production systems. The expansion of sheep and goat industries across this region offers significant economic potential both in terms of diversified income sources but also flexibility in responding to and recovering from drought. However, this evolution in livestock species dominance is not without a suite of risks and challenges.

One particular concern is the management of sheep and goats in the context of landscape sustainability. It is generally thought that these smaller ruminants have the potential to cause a higher intensity of patch and paddock overgrazing if not optimally managed. There is much conjecture around the benefits and problems that small ruminants might bring to rangelands. However, there has been little objective data collected that measures the landscape utilisation of sheep and goats and how they might interact with the spatially diverse feed-base, and then, how this might be optimised through management intervention.

3. Objectives

The objectives of this project were to:

1. Deliver a review of the management strategies that have been reported in the literature for influencing the spatial grazing distribution of small ruminants in rangeland landscapes;
2. Deploy GPS tracking devices to collect baseline data on grazing distributions of sheep and goats in typical rangeland landscapes;
3. Develop analytical techniques that explore and explain the relationship between grazing distribution and the feed-base, water, and other landscape resources; and
4. Explore how variation in weather, particularly thermal stress events might influence grazing distribution and use of key water resources.

This report also outlines the details around early project termination.

3.1 Report structure

This report will provide a summary of the methodology applied across two separate activities: the first is the review of literature exploring potential interventions to manage the spatial grazing distribution with the second section focussed on analysis of GPS tracking data recorded from sheep and goats.

4. Literature review

The following details a literature review undertaken to explore potential interventions that might be implemented to modify how small ruminants use the grazing landscape.

Working title: Manipulating spatial variability in grazing distribution of small ruminants in rangelands

Abstract

The objective of this review is to explore the published literature relating to manipulation of grazing distribution of small ruminants in rangeland production systems. An initial Scopus search using key terms relating to grazing distribution and rangelands revealed that publication rates where nearly twice as much for cattle as opposed to sheep, with goats reporting less again. Several intervention strategies are reported in the literature including more traditional techniques such as fencing and modifying access to water; shepherding and altering stocking rate and density. More novel techniques such as shade and shelter provision, feed-base modification, strategic supplement placement and a variety of animal selection strategies (individual, social and genetic) could also provide benefits. Virtual fencing, although appearing to have significant potential, appears some way off in terms of practical application to small ruminants. However, there is so little research exploring all these interventions and their potential in different rangeland landscapes that it remains difficult to provide industry relevant guidelines for land managers. Further formal research in many areas is warranted but the synthesis of current industry management practises that influence grazing distribution through producer survey is recommended and could provide valuable insights.

Key words

Goat, Sheep, Grazing distribution, Rangelands, Spatial distribution

Introduction

Livestock grazing extensive pastures are well known to utilize the landscape in a heterogeneous manner (Bailey 2005). In some situations, this is of little concern because the forage resources match the variability in grazing pressure of the livestock. In other situations, however, there is a significant mismatch between the feed-base productivity and the grazing pressure it is subjected to (Oñatibia and Aguiar 2018; Pringle and Landsberg 2004). In this case, the pasture becomes overgrazed with implications for both productivity and sustainability (di Virgilio and Morales 2016). Beyond the immediate reduction in plant regrowth rates (Orr 1980), overgrazing can have numerous long term impacts, including: loss of desirable species (Distel *et al.* 2004); encroachment of less desirable weed species (Wang *et al.* 2020); nutrient redistribution (Stumpp *et al.* 2005); decreased ground cover (Wilcox and Wood 1988) and ultimately erosion and soil loss (Evans 1998).

To optimise the grazing distribution of livestock, producers can implement a number of interventions to either encourage or discourage grazing in particular areas. Broadly speaking, these interventions can be thought of in two main categories: (i) modification of landscape attributes; and (ii) modification of animal behaviour (Bailey 2004; Creamer *et al.* 2019). For the former, development of artificial water points (Fensham and Fairfax 2008), fencing (Department of Agriculture and Food Western Australia 2006; Putfarken *et al.* 2008), shade (Orr 1980; Squires 1974), shelter (Alvarez *et al.* 2013; Squires 1974; Taylor *et al.* 2011) and modification of the feed-base (Cosgrove *et al.* 2002), have been reported as possible ways of manipulating grazing distribution. For the latter, alteration of the stocking rate (Animut *et al.* 2005a; Orr 1980) or stocking density (Oñatibia and Aguiar 2018), shepherding (May and Davis 1982; Platts 1982; Platts 1990), strategic supplement placement (Bailey and Welling 1999), and genetic selection (Moreno Garcia *et al.* 2020) are among the possible animal-based strategies for manipulation.

While this topic has been explored in several reviews and text books for cattle (Bailey 2004; Bailey 2005; Creamer *et al.* 2019; Delcurto *et al.* 2005; Skovlin 1965), less attention has been paid to the topic in small domesticated ruminants which dominate many rangeland production systems across the globe. This review aims to fill this gap and explores the potential techniques and methods that have been reported in the literature which seek to manipulate the spatial grazing pressure exhibited by small ruminants, specifically sheep and goats.

Quantifying the relative scientific investment across species

To get an overview of the quantity of research undertaken in this field and to explore the availability of relevant literature, an initial database search was undertaken in May and June 2020 using the Scopus database. Search terms were grouped into three categories: (i) subject terms, (ii) production system; and (iii) species. Subject terms included 'spatial distribution' OR 'grazing distribution' OR 'grazing patterns' OR 'patch grazing'. Production system terms included 'rangelands' OR 'grasslands' OR 'pastoral'. Species terms included 'sheep' OR 'ovine' and 'goat' OR 'caprine'. Although larger ruminant species were not the focus of this review, an additional search of 'cattle' OR 'bovine' was also conducted for comparative purposes. Each category was joined by the Boolean term 'AND'. Searches were restricted to titles, abstracts and keywords. Additionally, the subject area was also restricted to 'agricultural and biological sciences', 'veterinary' and 'environmental science' to maximise relevance.

Using the above search terms, a total of 492 documents were identified for sheep, 102 for goats and 807 for cattle. There is a noticeable increasing trend for publications over time (Figure 2). Up until 1990 the cumulative number of publications reported for sheep and cattle was the same (n=39), however since this time papers relating to cattle have clearly dominated the literature. The publications related to goats represent only a small proportion of those of cattle and sheep. In general, this suggests the focus of research has been largely aimed at cattle with far less investment in the smaller ruminant species particularly goats.

Continent of publication is also shown (Figure 2). Note, continent details are included for each contributing author. Thus, each publication may be represented across multiple continents. Publications involving European authors were most common for all species (n = 302 for sheep; n = 60 for goats; n = 365 for cattle). This was followed by Asian authors for both sheep (n = 121) and goats (n = 42) and North American authors for cattle (n = 333). The lowest contributing continent was Africa, South America and Asia for sheep (n = 26), goats (n = 6) and cattle (n = 70), respectively. Although this probably reflects the relative scientific output across all domains for each region it is worth noting that more sheep than cattle papers were reported for Oceania and that this region in particular, despite being well known as a large producer of livestock, reports far less than either Europe or North America.

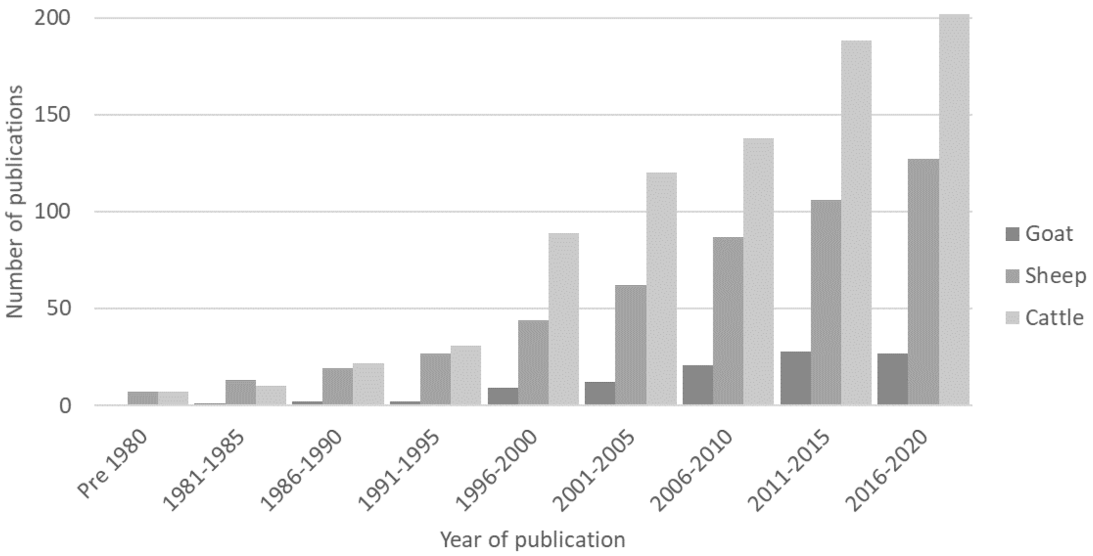


Figure 2 Publications for each species group across time

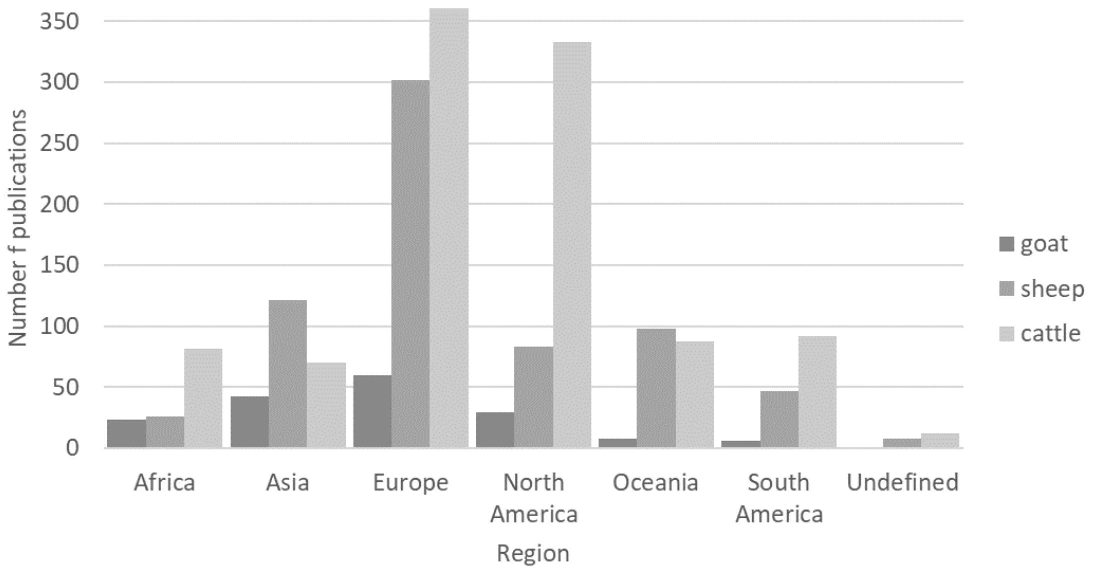


Figure 3 Regional distribution of publications for each species group

Exploring interventions to manage spatial grazing distribution

While focussing on manipulation strategies that influence sheep and goats, comparisons of small ruminant spatial distribution practices to reported results for cattle are included because the amount of research for sheep and goats is limited and the references to cattle research enabled broader discussion and filled gaps where necessary. For similar reasons, we occasionally included reference to literature relating to sheep and goat behaviour in landscapes other than rangelands, most commonly more productive high rainfall pastures.

Modification of landscape attributes

Livestock managers have for thousands of years been manipulating landscape attributes to influence the movement and location of animals. Traditional strategies such as fencing and water point placement are now widely used in the industry, more novel approaches such as drift and virtual fencing, shelter and shade provision and feed-base manipulation are less commonly reported. Each of these techniques is explored in detail in the following section.

Fencing

Fencing represents an obvious strategy to manipulate grazing distribution, allowing the producer to directly prevent and/or allow access to particular areas. Options for fencing include boundary fencing (including whole-farm and internal paddock fencing), non-boundary fencing (also known as drift fencing), or more recently, virtual fencing, with erection of each dependent on the requirements of each individual system.

Boundary fencing

Boundary fencing refers to fencing that encloses the farm itself (external boundary) or fences used to permanently subdivide paddocks (internal boundary). These fences are traditionally constructed with stone or wood (Anderson *et al.* 1994; Pickard 2010) or in more recent times wire (either inert, barbed or electrified), and are widely acknowledged as an acceptable way of controlling livestock distribution (Anderson 2007; Bailey 2004). Acting as a physical barrier, a boundary fence can either prevent access to particular areas or enclose the animal within a particular space. Fences have an obvious impact on sheep behaviour, including grazing site selection (Putfarken *et al.* 2008). Fencing of homogenous areas has been reported to increase the uniformity of sheep grazing (Department of Agriculture and Food Western Australia 2006). This has also been shown in cattle, with animals alternating between similar feeding sites in relatively homogenous pastures (Bailey *et al.* 1990). In domestic goats, the impact of fencing is less clear, although the requirement for better quality fences for containment is noted (Hart 2001; Kott *et al.* 2006; Pahl 2020). If successfully contained, goats will browse all available forage including herbaceous and woody plants (Lovreglio *et al.* 2014). Because of their tendency to browse trees and shrubs their potential for having a significant environmental impact when contained through deforestation has been noted (Lovreglio *et al.* 2014). Although external and internal boundary fencing is beneficial for both containing animals and controlling access to grazing areas, the high economic outlay commonly limits implementation (Anderson 2007; Anderson *et al.* 1994). Topography, vegetation and general accessibility may also impact the ability to install and properly maintain these permanent structures (Anderson *et al.* 1994; Brunberg *et al.* 2015). To address these constraints, temporary fences including electric fencing, are sometimes used to subdivide larger areas (Umberger 2001). Although the capital costs of temporary electric fencing is much lower than permanent boundary fences the time involved in setting them up and maintaining them can limit their applicability.

Given the costs associated with building boundary fencing it is surprising that there is so little literature available on the design of this infrastructure, particularly in relation to the variability in landscape and resources, specifically the feed base and water. Broad recommendations are provided in extension material (Department of Agriculture and Food Western Australia 2006) however the published literature on which these are based are likely to be drawn from a very small number of field observations. This means that while the recommendations might be broadly applicable there may well be efficiencies to be gained if the local conditions and landscape are considered. While other factors are likely to be important in designing internal boundary fencing, particularly animal mustering and handling efficiencies, there is almost certainly an opportunity for refinement of internal fence design to optimise landscape utilisation, production and sustainability.

Non-boundary fencing

Non-boundary fencing includes fencing options that do not enclose a specific area. Non-boundary fences can be used to encourage the dispersal of animals into underutilised areas. Also known as 'drift' fences, these structures are sometimes built between natural barriers such as steep rock, gullies or cliffs (Skovlin 1965). Drift fences are widely used in wildlife studies to control the movement of animals within a habitat and divert them toward new areas (Ellis and Bedward 2014; Tewksbury *et al.* 2002). Published literature detailing the use of drift fences in sheep and goats is limited. In cattle, drift fences have been used to regulate access to riparian zones (Cram *et al.* 2018). Other non-boundary fence options include barriers such as trees, brush or boulders which can be used as a method of limiting access to vulnerable areas (Leonard *et al.* 1997). This intervention strategy requires more research to better understand the impact of non-boundary fencing on sheep and goat grazing distribution.

Virtual fencing

A recent development in animal containment is the use of virtual fencing (VF) to control livestock movement. Unlike traditional fences, VF does not use a physical barrier to control movement. Instead, the animals are free to roam, experiencing an audio cue and subsequent electrical stimulus if they continue to cross the virtual boundary (Anderson 2007; Brunberg *et al.* 2015; Marini *et al.* 2018b). Due to the lack of physical barrier, animals in a VF environment must learn to associate the sound signal with the electric shock, ensuring the animal will learn to turn and retreat from the virtual barrier before receiving the aversive (electric) stimulus. Providing the animals can be trained, VF offers a novel way of managing livestock grazing distribution. However, before this can be realised, the practicalities associated with use, including the trainability of sheep and goats, costs and social acceptability must be explored.

In a study exploring the ability of sheep to learn in a VF environment, only nine of the 24 ewes tested were successfully trained to turn away from the virtual barrier within three repetitions (Brunberg *et al.* 2015). The reactivity of ewes to the electric stimulus was also highly variable, ranging from nil to strong responses (Brunberg *et al.* 2015). High variability of ewes was also found by Marini *et al.* (2018b), with 48% of animals still receiving an electric shock even after a period of learning, including one animal which continued to receive the aversive stimulus up to and including the ninth approach. In a study exploring VF in a mixed crop-livestock context, sheep responded to the audio cue alone after two days of application using a manual training collar (Marini *et al.* 2018a). Normal behaviour was also affected in the two days following VF removal, potentially reflecting increased grazing behaviour as a result of access to the entire paddock (Marini *et al.* 2018a). The effectiveness of VF may also depend on the context of application, with the presence of attractive foodstuff or peers potentially decreasing the success of the barrier (Jouven *et al.* 2012). Presence of thick wool (Brunberg *et al.* 2015; Rutter 2017) and lambs (Brunberg *et al.* 2017) have also been suggested as influencing factors in VF success for sheep, however, their impact is less clear and further research is required.

Early studies of VF in goats demonstrated the ability to confine them within a pre-defined area (Fay *et al.* 1989). In this study, six goats were trained to avoid the virtual barrier, after which field trials were conducted. During training, goats received 4-6 shocks with an apparent learned response to the audio cue occurring after 30 minutes. All of the animals were then successfully contained during the field trial, even with the presence of uncollared animals that left the containment area (Fay *et al.* 1989). Again, similar to sheep, Fay *et al.* (1989) reported variability in animal reaction to the electronic stimulus. This has also been reported in cattle, using automated VF collars [beef: Campbell *et al.* (2018); dairy: Lomax *et al.* (2019)] or manual [beef: (Bishop-Hurley *et al.* 2007)]. Given the variability between animals, application of VF raises ethical concerns regarding the acceptability of animals receiving multiple aversive shocks (Lomax *et al.* 2019). This also highlights the potential requirement for continued use of traditional fencing, at least at the property boundary, with VF unlikely to completely replace the need for a physical barrier (Rutter 2017). Nevertheless, while commercial versions of the technology are not yet available for sheep or cattle, Norwegian based company ‘Nofence’ has reportedly been used successfully in commercial goat systems since 2018 (Nofence AS 2020).

While VF appears to offer a significant opportunity to provide a flexible control strategy, there are several issues which need to be considered before this technology is likely to become widespread (Anderson 2007). One of the key limitations will be the cost of device. Most commercial technology companies are focused on development of a large ruminant (cattle) system (Agersens 2019; Halter 2020; Vence 2018). The exception to this is Nofence, which was specifically developed for the Norwegian sheep and goat industry (Nofence AS 2020). In the case of the larger system, even if the device can be reduced in weight to a point where they are relevant for sheep or goats, the per unit cost is so high it is unlikely to be viable in the short term. In addition, there are still significant social license issues around the deployment of electronic containment devices which need to be worked through before this technology will be accepted by the broader community (Trotter 2018).

Management of water

Provision of adequate water is a critical component of livestock production (Bailey 2005), particularly in rangeland or arid environments where availability of natural water may be limited (Bailey 2004). To counter this, livestock managers may install artificial watering points (Fensham and Fairfax 2008), allowing access of livestock into previously undesirable areas (Pringle and Landsberg 2004). In extensive systems, horizontal distance to water is widely recognised as having an influence on grazing behaviour (Bailey 2005; Fensham and Fairfax 2008; Pahl 2020). In a review of herbivore landscape occupation, sheep were found to have a threshold distance of 2.6 km from the nearest water point in arid areas of Western Australia (Fensham and Fairfax 2008). In a similar Western Australian study of sheep grazing behaviour, sheep travelled a maximum distance of 5.0 km from water, with visitation occurring once every 37.5 h (Thomas *et al.* 2008). Preference for grazing sites in closer proximity to water has also been reported for sheep grazing lowland areas of Germany (Putfarken *et al.* 2008), subtropical grassland in Argentina (Falú *et al.* 2014) and southern rangelands of Australia (Pahl 2020).

The impact of water point location on domestic goat grazing distribution has received considerably less attention in the literature. Overall, however, there is some evidence that this species are less reliant on water than sheep (Fensham and Fairfax 2008; Munn *et al.* 2012; Munn *et al.* 2013). In a study of Australian rangeland goats grazing in arid rangeland environments (Munn *et al.* 2012), rate of water turnover ranged from 2.4 – 4.4 L/day in non-pregnant and pregnant goats, respectively. Comparatively, in a similar study on sheep (Munn *et al.* 2013), rate of water turnover for non-pregnant ewes was 12.5 L/day. In another study of Australian rangeland goats (Freudenberger and Hacker 1997), short-term water closure in the Murray-Darling Basin had no obvious impact on the local goat population, suggesting that limiting access to water may have little impact on rangeland goat landscape utilisation. In direct contrast to this, Letnic *et al.* (2015) and Russell *et al.* (2011) both reported decreased activity of rangeland goats as distance from water increased, concluding that fencing of water sources could be used as a way to discourage grazing of rangeland goat populations. To fully understand the potential for grazing manipulation through provision of artificial water sources in domestic goat systems, further research is required.

In addition to horizontal distance to water, the impact of vertical distance from water should also be considered. This is particularly true in hilly rangeland environments where animals must transverse variable terrain (Bailey 2005). The impact of vertical distance from water has not been widely reported in sheep or goats. However, vertical distance from water is a known contributor to grazing site selection in cattle (Bailey 2005). In one study of cattle grazing in the mountainous regions of Oregon USA, vertical distance from water was negatively correlated with grassland utilisation (Gillen *et al.* 1984). In a similar study, also conducted in Oregon, cattle utilisation declined significantly at 80m above water (Roath and Krueger 1982). This has management implications for livestock grazing in rangeland environments, potentially limiting grazing distribution.

While there is little doubt that the location of water can impact grazing distribution of sheep and goats, the evidence base in the literature is so limited that specific recommendations for different situations (e.g. soils, species compositions, climates) are impossible to make. This is supported by Orr (1980), who hypothesised that water location may be less important for northern rangelands in Australia compared to southern systems, due to an increase in salt-induced thirst when grazing southern pasture species (Squires 1974). To fully understand the impact of context and system nuances, further research is warranted into determine specific recommendations for rangelands, including threshold distance of artificial water source placement for individual species requirements as related to the specific landscape and feed-base characteristics.

Shade

In flat rangeland terrain, shade has been found to be a contributing factor impacting grazing distribution patterns of Merino sheep (Orr 1980; Squires 1974). While wool provides a level of insulation from the heat (Blaxter 1977), shade-seeking in sheep intensifies during high temperatures and increased solar radiation (Stafford Smith *et al.* 1985). When given a choice, sheep appear to select convex-shaped coverage (Taylor and Hedges 1984), and shade provided by individual trees in a paddock (Taylor *et al.* 2011). Distance to shade has also been found to impact grazing site selection in both sheep and cattle (Falú *et al.* 2014). In this study, distance to shade, topography (aspect) and weather variables contributed up to 13% of daily grazing variation for both species. In addition, cattle were found to remain within 20m of shade in hot weather (Falú *et al.* 2014). Other studies of cattle shade-seeking have found similar results, including shade-seeking at the hottest part of the day during hot weather and avoidance of shade during winter (Harris *et al.* 2002). The provision of artificial shade structures has also been used to lure cattle away from riparian areas (Davison and Neufeld 2005). However, in this study, while shade structures were used by cattle, the authors concluded that their provision alone was not able to significantly reduce the use of the riparian areas (Davison and Neufeld 2005).

In penned domestic goats, the provision of shade has been shown to increase time spent at the feeder by 40% (Alvarez *et al.* 2013). Although goats possess numerous characteristics that make them less susceptible to environmental stress [e.g. lower basal metabolism, water conservation ability and higher sweating rate (Lu 1989)], shade provision has been suggested as a method of increasing animal motivation to continue feeding during hot weather (Alvarez *et al.* 2013).

While there is some logic in the implementation of shade for manipulating grazing distribution the extent to which this might be practically applied and the results achieved needs further research.

Shelter

Similar to shade, shelter is another landscape attribute that can impact grazing distribution of sheep and goats. Although it is rarely possible to alter the natural topography, shelter in the form of wind breaks or built structures can be used to encourage broader grazing distribution of cattle (Bailey 2005). The protection from shelter can be considered in terms of height and permeability, with higher windbreaks offering a greater distance of cover for animals (Da Silva 2012). For sheep, preference for shelters located at higher elevations has been reported (Alexander *et al.* 1979). Sheep distribution has also been found to be impacted by wind direction (Orr 1980), with animals displaying a tendency to graze into prevailing winds (Blake 1938). The impact of shearing has also been described, with recently shorn sheep increasing their shelter utilisation (Alexander *et al.* 1979; Mottershead *et al.* 1982). This may be even more pronounced during periods of high wind, with shorn sheep showing an increased preference for shelter located at higher elevations compared to unshorn sheep (Mottershead *et al.* 1982). Shearing has been used as a management strategy to try and influence the spatial landscape utilisation of lambing ewes (Alexander *et al.* 1979; Alexander *et al.* 1980; Stevens *et al.* 1981), with the theory being that ewes will seek shelter for themselves and thus optimise lamb survival.

The use of shelter by domestic goats is less established in the literature. However, for rangeland goats, use of high coverage areas (e.g. rock overhangs and high vegetation areas) with reduced wind and light exposure has been described at parturition (O'Brien 1983). Rangeland goats have also been reported to use shallow caves or rock overhangs for bedding (Smith 1984). Given the impact of shelter on animal behaviour it is possible that the provision of shelter could be used to manipulate spatial utilisation by sheep and goats. This has also been postulated by Taylor *et al.* (2011), who state that strategic establishment of shelter at higher altitudes may encourage more uniform grazing patterns. The extent of this impact requires further research.

Feed-base modification

Modification of the feed base by fertilizer or fire can improve the quality of forage and influence distribution of grazing animals (Bailey 2005; Holechek *et al.* 2001). In rangeland environments, application of nitrogen (N) and phosphorus (P) can increase forage yield and crude protein content of grasses when accompanied by adequate seasonal rain (Guevara *et al.* 2000). In more intensively managed production systems fertilisation improves the competitive ability of pasture species, suppressing the development of weeds in favour of quality grass and legumes (Ruzic-Muslic *et al.* 2012). In these higher rainfall areas sheep have been found to show preference for high N grass compared to low N grass, with grazing times of 320 mins and 90 mins per day, respectively (Cosgrove *et al.* 2002). This may be attributed to the improved digestibility of fertilised grasses (Bazely 1988). In dryland hill systems of New Zealand (Gillingham *et al.* 2003), nitrogen application during winter was also found to significantly improve pasture growth, thus allowing increased stocking rates. Given this impact of fertiliser on pasture productivity, it is possible that fertiliser application could be used in rangeland environments to improve pasture quality and palatability, however the economic value of doing this across large areas is unlikely to be viable (Guevara et al. 2000). One plausible use of fertiliser in some rangelands could be in specifically targeted small-scale applications that increase the attractiveness of certain areas to grazing animals. This is turn could be used as a method of luring animals into previously unused rangeland (Bailey 2004). This concept remains largely untested and needs further research to both prove the concept and demonstrate the value.

Goats have been shown to exhibit discernible flexibility when selecting grazing pasture species (Safari *et al.* 2011). In a study of seasonal grazing habits of goats in Tanzania (Safari *et al.* 2011), the animals were found to graze mostly on herbaceous species in the rainy season, shifting to browse and forbs during the dry season. In another study of goat grazing behaviour in Mexico (Foroughbakhch *et al.* 2013), shrub species constituted 78% of goat diets, followed by 12-18% herbaceous broadleaf species and 6-10% grasses. This was also supported in a comparative study of domestic goats, sheep, cattle and horses grazing in mixed grazing heathlands of the Iberian Peninsula (Ferreira *et al.* 2013), where goats were the only species to show preference for shrublands rather than improved pasture. Preference for wooded landscapes has also been shown in Australian rangeland goat populations (Pahl 2020). Based on this preference for browse or shrub species, it is possible that the use of fertilizers to manipulate grazing distribution will have limited effect in goats, as fertilizers are generally applied to benefit other target species (i.e. legumes). Nevertheless, given that goats are known to combine grazing of woody vegetation and improved pasture when available (Ferreira *et al.* 2013), there is still some plausibility in applying a spatially targeted small scale fertiliser program to influence their distribution. Like sheep this concept needs dedicated research to prove the concept and assess the economic value.

Despite a long history of practice application in the grazing industries the impact of fire on grazing behaviour of sheep and goats is not well documented. However, in cattle (Fuhlendorf and Engle 2004) and bison (Coppedge and Shaw 1998), preference for recently burned grass patches has been demonstrated. This is further explained in Fuhlendorf and Engle (2004), which outlines the intricate interactions between fire and grazing animals. As described, areas of recent fire attract grazing animals, resulting in decreased grass species and increased bare ground as animals graze the area. This in turn reduces the area biomass, thus reducing the probability of fire and therefore the probability that the area will continue to be grazed. Once the animal moves on, the grass species can recover, and the probability of fire increases once more. Based on this, Fuhlendorf and Engle (2004) suggest that grazing animals and fire interact in a shifting mosaic of positive and negative feedbacks, causing heterogenous distribution of grazing across the landscape. Fuhlendorf and Engle (2004) state that the use of patch fire is an appropriate management system for cattle, with the added benefit of improving biodiversity for the entire ecosystem. Some proponents of grazing management suggest that a homogenous grazing distribution is ideal, however this centuries old technique suggests that pursuit of more homogenous grazing patterns may not actually be required for ecosystem health, highlighting a potential alternative for the management of grazing distribution. This should be explored further and reported in published literature in sheep and goat systems.

Modification of animal attributes

Stocking rate

Stocking rate refers to the number of animals grazing an area of land over a specific time period (head.ha^{-1}.time^{-1}) (Bailey 2004). Maintenance of appropriate stocking rate is important to support sustainable pasture growth, limit soil compaction and reduce weed pressure (Ateş *et al.* 2016). In general, low stocking rates are advocated as a method of reducing negative impacts of heavy grazing (Wang *et al.* 2020). Sustainable high stocking rates may only be possible under favourable weather conditions e.g. sufficient summer rainfall to promote pasture growth for the following dry season (Orr 1980). The impact of stocking rate on various aspects of production has been studied in sheep (Animut *et al.* 2005a; Animut *et al.* 2005b; Ates *et al.* 2013; Ateş *et al.* 2016; Birrell 1991; Chong *et al.* 1997; Freudenberger *et al.* 1999; Sibbald *et al.* 2002) and goats (Animut *et al.* 2005a; Animut *et al.* 2005b; Lin *et al.* 2011; Wan *et al.* 2018). However, the exploration of how these stocking rates relate to and influence grazing distribution of these two species is not well reported.

In a study of Australian sheep grazing patterns (Birrell 1991), average time spent grazing was found to increase at high stocking rates compared to low stocking rates. Perennial grass yield in semi-arid

Australian woodland was also found to deteriorate at high stocking rates, impacting on animal productivity and increasing the variability of available pasture (Freudenberger *et al.* 1999). In upland UK systems, high stocking rates have been shown to reduce sward growth rates (Sibbald *et al.* 2002). In more intensive Malaysian systems, increased proportion of undesirable species is considered consequence of high stocking rate (Chong *et al.* 1997). Medium stocking rates of 0.8 sheep/ha have been recommended as a method of pasture sustainability in Australian rangeland systems (Orr 1980), allowing for control of desirable species whilst still maintaining forage reserves.

In goats, high stocking rates are associated with increased grazing intensity, including time spent grazing (Lin *et al.* 2011). In line with this, low stocking rates have been associated with increased time spent ruminating (Wan *et al.* 2018), potentially due to increased forage mass and accessibility. In sheep and goat co-grazing systems, the number of steps taken increased linearly with stocking rate (Animut *et al.* 2005a), potentially suggesting further distribution of both species over the landscape, however movement and distribution are not necessarily correlated. In another study of sheep and goat co-grazing (Animut *et al.* 2005b), increased stocking rate resulted in decreased nutritive value of forage and reduced average daily gain. Given these negative impacts, the rationale for low stocking rate as a method of improved pasture sustainability is evident (Ates *et al.* 2013; Wang *et al.* 2020). However, low stocking rate may also have negative consequences, allowing increased species selectivity (Cosgrove *et al.* 2002; Parsons *et al.* 1994) and reduced uniformity of grazing (Ates *et al.* 2013). This has also been discussed for cattle systems (Bailey and Brown 2011) although the author's state that adverse impacts on grazing uniformity and overuse of preferred species can be overcome with good management. Based on this, further research is warranted to determine optimal stocking rate for sheep and goat grazing in rangeland systems, ensuring both sustainability of the system and improved animal production.

Stocking density

Similar to stocking rate, stocking density has also been suggested as a management tool to manipulate grazing distribution. Stocking density refers to the number of animals per unit of area at any given time (head.ha^{-1}) (Bailey 2004). Increased stocking density can be achieved by reducing the amount of space available to animals, and/or by increasing rotational frequency between paddocks (Earl and Jones 1996). In a study of sheep grazing distribution in the Patagonian steppe (Oñatibia and Aguiar 2018), decreased paddock size was found to significantly reduce the heterogeneity of grazing. Reducing paddock size was also found to lessen the degradation of preferred areas and improve accessibility to less preferred areas (Oñatibia and Aguiar 2018). Complementary to reduced paddock size, rotational grazing (RG) can also help to redistribute grazing pressure, improve uniformity of sward defoliation and allow time for pasture recovery (Bailey and Brown 2011; Gonçalves *et al.* 2018). RG is most often achieved through paddock subdivision, though shepherding can also be used (Glimp and Swanson 1994). In a comparative study of RG and continuous grazing (CG) in New South Wales, Australia, ground cover significantly increased over two years of RG and pasture composition significantly improved (Earl and Jones 1996). These benefits were also evident in Argentina, including increased litter cover and proportion of desirable forage species. Of note, given that many paddocks in rangeland environments are large and heterogenous (Bailey and Brown 2011), practical application paddock subdivision and RG may be limited due to high cost of fencing and artificial water installation (Oñatibia and Aguiar 2018). In addition, the effectiveness of altering stocking density alone for grazing management is debated in cattle, with researchers reporting no effect of stocking density on grazing distribution if stocking rate was held constant (Bailey and Brown 2011).

Shepherding

Shepherding (also known as herding) refers to the use of human presence to control the movement of animals. Shepherding requires significant input from the producer, in terms of labour, resources and time (Tanaka *et al.* 2007). Nevertheless, it is still used as a method of controlling animal distribution. Shepherding enables control over grazing location, timing and intensity (Swanson *et al.* 2015) and allows producers to take advantage of optimal seasonal conditions (Glimp and Swanson 1994). Shepherding can also be used to minimise environment damage, including nutrient overload from faeces and urine or vegetation damage (Glimp and Swanson 1994). Shepherding has been identified as an appropriate management tool to manage sheep use of riparian areas (May and Davis 1982; Platts 1982; Platts 1990). Low stress herding has also been shown effective to reduce the use of riparian areas in cattle (Bailey *et al.* 2008). In the same study, stubble heights of pasture in riparian areas was also greater in herded groups compared to the control, highlighting the effectiveness of this management strategy (Bailey *et al.* 2008). These benefits are also likely to increase with consistent shepherding, with the effectiveness of herding known to increase over time (Butler 2000). While shepherding represents an effective grazing management strategy, this has mostly been replaced by traditional fencing in Australian rangelands (Pickard 2007).

Strategic supplement placement

Supplementation can be used to as a ‘reward’ to lure animals to underutilised areas (Distel *et al.* 2004). Supplementation can also reduce the grazing pressure through enhanced satisfaction of nutritional requirements (Baraza *et al.* 2010). In sheep, supplementation at predictable time intervals and locations can cause problems, including search behaviour around the expected time of supplementation or over-grazing of the new area (Distel *et al.* 2004; Laca 2009). To counteract this, Laca (2000) hypothesised that random placement of supplements would encourage a more widespread search behaviour, resulting in increased distribution over the landscape. This was partially supported by Distel *et al.* (2004) with the time sheep spent in unfertilised areas increasing as the predictability of supplementation declined. In goats, the research regarding supplementation as a method of controlling grazing distribution is lacking. There is some evidence that supplementation of polyethylene glycol (PEG) can modify grazing distribution by allowing access to underutilised tannin-rich areas (Landau *et al.* 2002; Silanikove *et al.* 1996). Location of the supplement within the paddock is also considered important, with closer proximity to water found to increase supplement consumption in goats (Kawas *et al.* 2010).

The benefits of supplementation for manipulation of spatial distribution is well established in cattle (Bailey 2004). In a study of *Bos indicus* cattle in Mexico (Solano *et al.* 2018), the location of supplementary feed was found to impact spatial distribution of animals grazing 1 ha irrigated paddocks. When placed in the same corner as supplementary water, cattle maximised their use of the area and increased the distance to peers (Solano *et al.* 2018). In rangeland animals, strategic placement of low-moisture blocks increased utilisation of areas within 600m of the supplement (Bailey *et al.* 2001c). This was similarly found by Stephenson *et al.* (2017) with cattle spending 7.5 h per day near supplement locations. The type of supplementation may also impact distribution. In a Montana-based study of winter grazing heifers, supplements in the form of hand-fed cakes resulted in increased selection of grazing locations closer to the supplement site compared to animals grazing *ad libitum* protein concentrate (Wyffels *et al.* 2019). Based on the impact of supplementation on cattle distribution, it is possible that supplementation could be used as a method of manipulating sheep and goat distribution in rangeland environments and warrants further research.

Individual selection for spatial distribution

Individual animals are known to display marked differences in their grazing behaviour (Moreno Garcia *et al.* 2020). The diversity of grazing personalities can be used to regulate grazing intensity and forage defoliation (Moreno Garcia *et al.* 2020), thus representing a potential method of manipulating grazing distribution (Bailey 2004). For example, in a study of sheep behaviour (Sibbald *et al.* 2009), 'bold' animals were more likely to separate from their peers compared to 'shy' animals, resulting in an increased distance from their nearest neighbour (9.2m vs 6.9m). Bold animals also displayed increased landscape utilisation compared to their shy counterparts (Sibbald *et al.* 2009). This finding was supported by Michelena *et al.* (2009), with bold sheep more likely to move away from their peers to explore the environment, hence increasing their utilisation of dispersed patches. In goats, individual dominance has also been shown to impact grazing behaviour, with more dominant animals increasing their shrub consumption in comparison to less dominant animals (Barroso *et al.* 2000). Selection of individual animals traits has also been explored in cattle (Bailey *et al.* 2006; Creamer *et al.* 2019). For example, in a comparative study of 'hill climber' or 'bottom dweller' cattle grazing behaviour (Bailey *et al.* 2006), hill climber animals displayed increased uniformity of forage utilisation, increased use of areas more distant from water and higher stubble heights in riparian areas. This suggests selection of individual animals based on their grazing behaviour has the potential to improve uniformity of grazing, and represents a possible tool for manipulating grazing animal distribution in rangeland environments.

In addition to innate individual aspects of personality, the propensity for individual learning and level of experience can also impact grazing behaviour and might be used to influence distribution. Utilisation of animal learning as a method of controlling grazing patterns relies on the concept of operant conditioning (Creamer *et al.* 2019). Operant learning uses positive and negative reinforcement or punishment to encourage or discourage voluntary behaviour. Aspects of operant conditioning already discussed in this review include the use of VF, shepherding and strategic supplement placement (Creamer *et al.* 2019). For VF, positive punishment in the form of an electic shock is used to discourage the animals from crossing the virtual barrier. For shepherding and strategic supplement placement, reinforcement is used to strengthen desired grazing patterns, with the stimulus either removed (by removing pressure from the shepherd) or added (by provision of palatable supplement), to encourage animal movement. Once learned, this previous experience can result in discernible changes in grazing behaviour. For example, in studies of sheep grazing leafy spurge (*Euphorbia esula* L.), experienced lambs were four times more likely to consume leafy spurge compared to their naïve counterparts (Olson *et al.* 1996). Experience can also impact forage intake in goats, with kids raised on pasture containing blackbrush (*Coleogyne ramosissima Torr.*) more likely to consume the plant at 9 months of age compared to inexperienced kids (Distel and Provenza 1991). In cattle, older cows with increased knowledge of the terrain have been found more likely to uniformly graze over the landscape, compared to less experienced or young animals (Bailey 2004). Older cows have also been found to spend less time in riparian areas compared to younger animals (Delcurto *et al.* 2005). Based on these latter findings, Delcurto *et al.* (2005) postulated that the selection of older, more experienced cows may assist in improving cattle distribution, providing desirable forage is available in other areas. There does appear to be some potential in individual animal selection to influence grazing distribution, however a substantial body of research would be required to explore the topic and then understand the benefits it might bring.

Manipulation of social interactions

In addition to individual differences in grazing behaviour, animals must also balance social interaction with resource acquisition in hetergeneous environments. In a study of sheep social dynamics (di Virgilio and Morales 2016), mixed-flock animals (containing ewes, wethers and hoggets) were more likely to select a variety of vegetation, with patterns for selection differing between animal class. That is, ewes selected more productive areas, while hoggets and wethers selected less preferred areas. This pattern was also evident in ewe/wether flocks. However, when the ewes were removed, the remaining wether/hogget flock displayed uneven selection of preferred areas. This was particulalry true for hoggets which displayed a marked change in their resource selection behaviour (di Virgilio and Morales 2016). Social hierarchy has also been shown to impact feeding behaviour in goats (Barroso *et al.* 2000), with low-ranking and high-ranking animals more likely to eat forbs and shrubs, respectively. This pattern was found to be stable over different seasons, though increased competive selection was more obvious as food abundance increased (Barroso *et al.* 2000). In addition to herd composition, the impact of social interactions following introduction of new animals should also be considered, with some findings suggesting reduced ewe home range and interaction with the main flock following introduction to an unfamiliar mountain area (Morgan-Davies *et al.* 2016).

The impact of social interactions could have important management implications for sheep and goats, with the potential for more uniform grazing using hetergenous flock structures, compared to more homogenous flocks. This has also been shown in cattle, where heterogenous herd structures allow for fluid associations between cattle (Stephenson *et al.* 2016), and potentially improved grazing uniformity. Inclusion of specific animal groups has also been explored in cattle. For example, in a study of cattle social behaviour, castrated mature males were found to improve group cohesion by providing leadership for younger animals (Sueur *et al.* 2018). In that study, the author's concluded that, if trained, inclusion of castrated mature males could be used to increase grazing in targeted areas (Sueur *et al.* 2018). Alteration of herd composition by other means, for example animal age, has also been studied in cattle as a method of modifying grazing distribution (Beaver and Olson 1997). To improve the understanding of this impact on sheep and goat rangeland systems, including the impact of hetergenous flocks consisting of multiple animal classes and experience levels, further research is required.

Genetic selection for spatial distribution

Livestock managers may be able to improve uniformity of grazing distribution by selecting livestock that are more suited for the landscape (Bailey 2004). Breed differences are known to impact on sheep (Alexander *et al.* 1983; Arnold and Dudzinski 1978; Arnold and Maller 1985; Key and Maciver 1980) and goat (Aharon *et al.* 2007; Fedele *et al.* 1993) behaviour and there is a possibility that this could translate to grazing distribution. In sheep, Merino animals are known to form tight flocks with strong group cohesion (Arnold and Maller 1985). In contrast, Dorset Horn sheep are known to easily form temporary sub-groups in grazing situations (Arnold and Maller 1985). In a study of different sheep breeds, Dorset Horns were found to disperse more widely than most other breeds, with a maximum area of occupany of 67m^2 compared to 28m^2 in Merinos (Arnold and Maller 1985). Flock size was also found to contribute to spatial distribution between breeds, suggesting breeds with strong group cohesion such as the Merino, require larger flock sizes to disperse more broadly (Arnold and Maller 1985).

In goats, a study of local Mamber breed and Boer goats grazing rangelands in Israel found the Mamber spent more time grazing herbaceous plants compared to the Boer breed (44% vs 22% of observed time for Mamber and Boer breeds, respectively), although the Boers spent more time eating overall (39% vs 63% of total grazing time for Mamber and Boer breeds, respectively) (Aharon *et al.* 2007). In another study of Angora, Boer and Spanish goats (Beker *et al.* 2010), Angora goats spent less time grazing grass-forb pastures compared to the other breeds. In another study of grazing goats in Italy, Maltese goats were more selective than the Rossa Mediterranea breed, with a preference for grasses over forbs (Fedele *et al.* 1993). This selectivity of Maltese goats was somewhat mitigated by the provision of concentrate supplementation, with no observed affect on the Rossa Mediterranea (Fedele *et al.* 1993).

Given the impact of breed on grazing behaviour, it is feasible that selection of breeds appropriate to the rangeland conditions may help to improve distribution of animals throughout the landscape. This has also received attention in cattle, with breeds developed in the French Alps (Tarentaise breed) more likely to use landscapes at higher elevations than Herefords (UK origin) in northern Montana (Bailey *et al.* 2001b). Similar findings are also reported for cows sired by Piedmontese bulls compared to Angus bulls (Italian Alps origin and east Scotland origin, respectively), with the former utilising landscapes at higher elevations (Bailey *et al.* 2001a). Based on these differences in breed behaviour, it has been proposed by Moreno Garcia *et al.* (2020) that identification of preferred genotypes and subsequently, the corresponding genetic markers could help to faciliate selection of animals with desired grazing behaviours. This has been explored by Bailey *et al.* (2015) and (Pierce *et al.* 2020), with reported genetic markers associated with spatial grazing patterns of beef cattle grazing rugged and extensive rangeland pasture. These preliminary studies in beef cattle demonstrate that the potential for genetic selection for grazing distribution in sheep and goats. However, to fully explore this, further research is required.

Co-grazing

Co-grazing of species refers to the practice of managing two or more species of herbivore using a common forage resource (Beck *et al.* 2011). Co-grazing can lead to more uniform overall grazing patterns as different herbivore species display different grazing preferences (Beck *et al.* 2011; Ferreira *et al.* 2013). The method of defoliation and faecal disposition also varies between species (Wrage *et al.* 2011), impacting both pasture quality and productivity (Abaye *et al.* 1994). Sheep and cattle both tend to avoid grazing near dung of their own species (Jerrentrup *et al.* 2020). This may contribute to uneven utilisation of landscapes or residual herbage that is not grazed. Co-grazing may counteract this, with sheep found more likely to graze closer to cattle dung (Forbes and Hodgson 1985) and cattle more likely to select mature species that are avoided by sheep (Dumont *et al.* 1995). In a study of co-grazing sheep, goats, cattle and horses in Spain (Ferreira *et al.* 2013), differences in grazing time and plant preference were evident among the four species. Overall, sheep and goats had the lowest grazing time per day averaging 481 min/day and 496 min/day, respectively, compared to 530 min/day for cattle and 610 min/day for horses. In addition, while herbaceous plants were the predominant diet of cattle, sheep and horses in all seasons, goats more commonly selected woody species even when the availability of herbaceous species was high (Ferreira *et al.* 2013). This preference of goats may be attributed to the agility of the species, allowing them to select attractive species in less accessible areas (Ferreira *et al.* 2013). Based on these results, co-grazing of animal species could be a valuable method of achieving more uniform grazing patterns across the landscape. While Ferreira *et al.* (2013) concluded that any combination of the four species would be valuable in improving the use of heathland areas, the use of the goat would provide the lowest dietary overlap, thus maximising the benefits of the co-grazing strategy. There is a distinct opportunity for further research focussed on exploring the impact on co-grazing on the distribution of grazing over diverse landscapes.

Management of competition and predation

In rangeland systems, small ruminants may be in direct competition with other herbivores, either wild (e.g. kangaroos, unmanaged goats) or domestic (e.g. cattle, managed goats, horses). Although the extent of competition has been debated in the literature (Munn *et al.* 2010; Pahl 2019), dietary overlap between herbivore species is commonly reported (Ferreira *et al.* 2013; Pahl 2020). In a comparative review of sheep and kangaroo grazing behaviour (Pahl 2020), sheep are noted to prefer annual grasses and ephemeral forbs, which they consume in large quantities. Once these species dry out, the animals generally switch their preference to perennial forbs, followed by dry perennial grasses. Similar to sheep, kangaroos are also noted to prefer annual grasses and ephemeral forbs, switching to perennial grasses when the former are scarce (Pahl 2020). Competition between sheep and kangaroos has also been noted by Edwards (1990), particularly during periods of limited food resource. Competition between species is also evident in domestic systems. For example, in a study of co-grazing goats, sheep, cattle and horses, intense competition for quality grassland was evident for sheep, cattle and horses, with the greatest similarity in grazing time and diet competition between sheep and cattle (Ferreira *et al.* 2013). Based on this, control of herbivore competition, either through methods of wild herbivore population management (Edwards 1990) or strategic combination or separation of competing species (Ferreira *et al.* 2013), may be necessary to ensure proper grazing management. It is also probable that manipulation of herbivore competition would have impacts on grazing distribution, and thus, should be considered as a possible intervention strategy.

Similar to competition, the presence of predatory species may also impact the behaviour of grazing animals. In studies of domestic sheep, ewes are reported to increase their vigilance behaviour when grazing alone than when in a group (Dumont and Boissy 2000). Vigilance behaviour is a known anti-predator behaviour response, increasing the likelihood of predator or threat detection (Elgar 1989). In wild bighorn sheep, increased vigilance behaviour associated with smaller flock size has been found to impact the grazing efficiency of the species (Berger 1991), presumably as the animals are more focused on identifying potential threats. Thus, effective control of predator populations represents a potential method of controlling grazing behaviour, potentially increasing distribution across a landscape. This is supported in a study of ewe behaviour in the presence of livestock guardian dogs (LGD), where ewes were found to increase their daily distance travelled when accompanied by the LGD (Webber *et al.* 2015). As a result, the author's state that presence of LGD may be used to increase exposure to varied foraging opportunity, encouraging more effective use of the pasture resource.

Integration of multiple strategies to influence grazing distribution

For effective optimisation of grazing distribution in small ruminants, it is likely that a combination of multiple intervention strategies will be necessary (Creamer *et al.* 2019). This may involve modification of multiple landscape attributes or animal attributes in isolation, or integration of the two. This has been reported for cattle (Creamer *et al.* 2019), for example combining water and supplement placement (Ganskopp 2001) or stocking rate and supplement type (Gutman *et al.* 2000). The literature available for sheep and goats is significantly less and as such reported evaluation of formally integrated strategies are scant. Extension material make references to the integrated use of water access and fencing (Department of Agriculture and Food Western Australia 2006). In this case recommendations are based around establishing permanent boundary fencing and then using water access to move animals within these confines. There is certainly an opportunity for more research to explore how integration of selected interventions might be applied across sheep and goat production systems to influence spatial landscape utilisation.

Conclusion

As livestock producers seek to improve the efficiency and sustainability of grazing systems there is an increased interest in maximising the production of every hectare of land under management. The need to increase production efficiency to maintain financial feasibility is challenged by the requirements to maintain landscape sustainability, both for genuine long-term viability and social license requirements. The ability to manipulate grazing distribution has always been a key factor in achieving production and sustainability outcomes and finding new ways, validating existing techniques, or finding locally relevant strategies to achieve this will be an important part of small ruminant production systems into the future. This review has demonstrated that more research has been invested into cattle grazing systems compared to sheep, with goats attracting even less attention again. There is clear opportunity for further research to explore techniques for managing small ruminant grazing distribution in rangeland production systems.

Despite the dearth of literature there are several strategies that have a clear impact on grazing distribution of sheep and goats. Fencing and water placement and access remain two of the most commonly reported and applied across the industry. Whilst this infrastructure can have clear outcomes the cost of implementing it across large areas of rangeland will always be a limiting factor. More novel landscape-based strategies for changing grazing distribution include the provision of attractants such as shade, shelter and optimised feed-base. While these appear to have some impact a broader body of research needs to be established to ascertain their effectiveness and viability. One key technology has captured the attention of the grazing industries more than any other is virtual fencing (VF). Whilst this technology is being explored extensively for cattle, its application in sheep and goats remains limited.

Modifying animal attributes such as stocking rate and stocking density have well known impacts on grazing distribution however the way in which this information is applied within the industry remains scant. Traditional techniques such as shepherding, whilst still effective and viable in some areas of the world cannot be sustainably used in many developed countries. Other more novel strategies are being explored in cattle and may well have application across sheep and goats but required dedicated research investment to validate both broadly and at a local regional scale.

One of the key missing pieces of research in this field is a simple survey of the current knowledge and techniques used by industry practitioners. Anecdotal evidence gathered by the authors suggest that a wide range of strategies are currently used or have been attempted by graziers and the synthesis of this knowledge could provide significant insights into both intervention effectiveness and economic viability. These insights could be used to both shape some early recommendations for producers seeking to manipulate grazing distribution and provide further direction to the future research suggested throughout this review.

5. GPS tracking and data analysis

5.1 Introduction

This section reports on GPS tracking data generated from all properties and explains how it has been analysed to explore several key issues relating to animal behaviour and landscape utilisation. In this results section we will first explore basic movement parameters reported for individual animals before analysing the data to understand how they are interacting with the landscape in which they graze.

Methodology

This project worked with data from three small ruminant properties in Longreach, Queensland. Between the three properties, data from a total of 30 animals was collected for analysis. Numerous collars failed for various reasons throughout the trial ranging from collar loss to failed electronics through moisture ingress or a failure of the device to properly record data.

5.1.1 Camden Park Dorper sheep and Rangeland goats

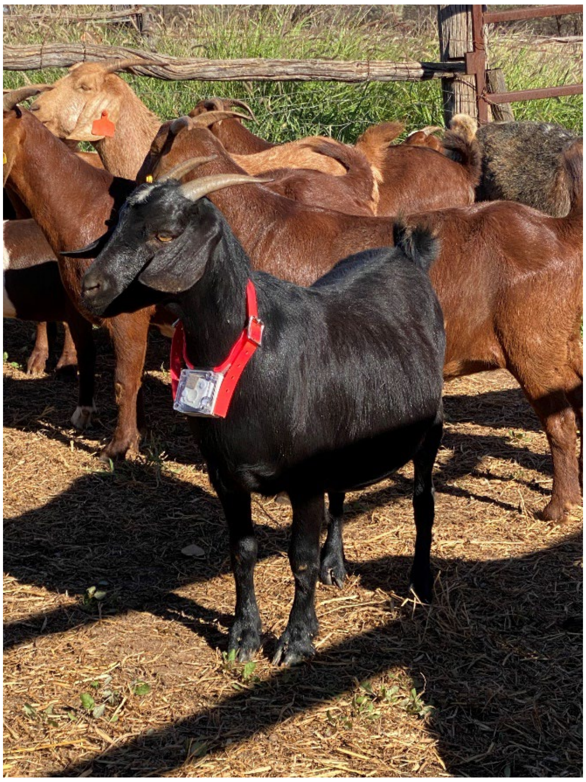


Figure 4 A rangeland goat fitted with GPS tracking collar as part of the study

At Camden Park the collars were in the field from the beginning of August 2019 until mid-March 2020. Not every GPS collar accurately recorded points for the entire time period, therefore dates that did not have data from all collars were removed. For example, 6/12/2019 was the last date that the majority of the goat collars collected data, so the goat data frame runs from 11 August 2019 to 6 December 2019. The sheep data set runs from 10 August 2019 to 31 January 2020, because after January the sheep were penned which is not an accurate representation of the movement of sheep on rangeland. One sheep collar and one goat collar stopped collecting GPS coordinates in the middle of October 2019, so both of those collars were removed from the analysis. One collar provided GPS data with errors and is still being evaluated. GPS movements of 7 goats and 7 sheep were used for analysis on Camden Park. The feed base during the deployment of these sheep and goats was, while not high, not considered limiting as these herds were run at very low stocking rates.

Fairfield merino ewes

GPS collars were deployed on 11 Merino sheep in Fairfield. These collars were in the field from mid-December 2020 to the end of March 2021. The data from three collars was not used in the analysis because they stopped collecting GPS data too early. The data set for the other 8 sheep runs from 14 December 2020 to 28 March 2021. The feed-base at Fairfield was considered limiting at the

Figure 5 Dorper sheep on Camden Park fitted with GPS collars as part of the project

commencement of the study with supplement being provided to the sheep. These sheep were run under a normal commercial stocking rate.

Rosebank merino weaners

In addition, data from four GPS collars previously placed on Merino sheep at Rosebank, a smaller property. The data set runs from 20 November 2017 to 20 February 2018. The sheep at Rosebank were Merino Weaners and the paddock had limited available feed during the deployment period. The sheep were run under a normal commercial stocking rate.

Data processing

Once the collars were removed from the animals, the GPS data was downloaded and cleaned to remove all erroneous coordinates. It was cleaned using the IGotU cleaning method, through the Animal Tracker Application developed by New Mexico State University (NMSU). The distance between each coordinate point was calculated in Excel to determine the daily distance walked per animal. Activity time was calculated using a speed threshold of 0.03m/s after consulting the diurnal activity graphs of animal speed.

ArcMap software (a part of ArcGIS) was used to measure the distance between each GPS position and the nearest water source. These values were averaged across the tracking period to provide distance to water measurements for each animal. Animal speed was calculated between sequential GPS locations by dividing distance between locations by the actual time interval between position recordings. The speeds were plotted against time to determine the speed threshold between active and inactive movement of the animals. ArcMap was used to visually assess the movement of the animals and create a spatial grazing distribution analysis based on active and inactive movement. The daily distance travelled, average distance to water, daily average speed, and max distance to water of all animals were compared to the maximum and minimum ambient temperatures of each day, as well as other weather factors provided by the Longreach airport.

5.2 Results

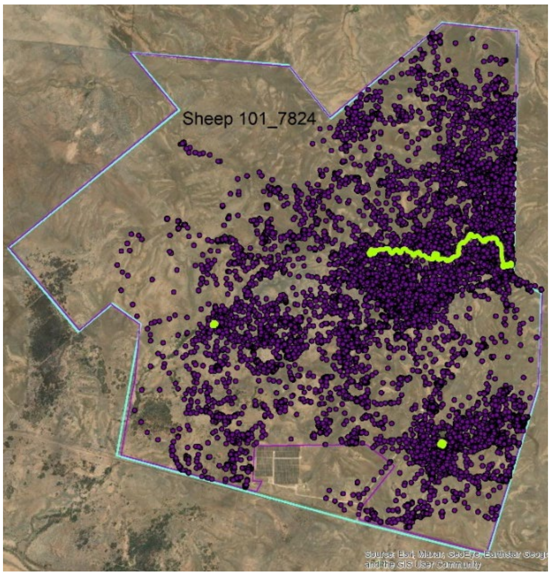
5.2.1 Raw data presentation

Figure 6 to Figure 9 show the basic data generated by the GPS tracking devices for each individual animal. While this basic data presentation shows some trends further analysis will reveal more detailed insights.

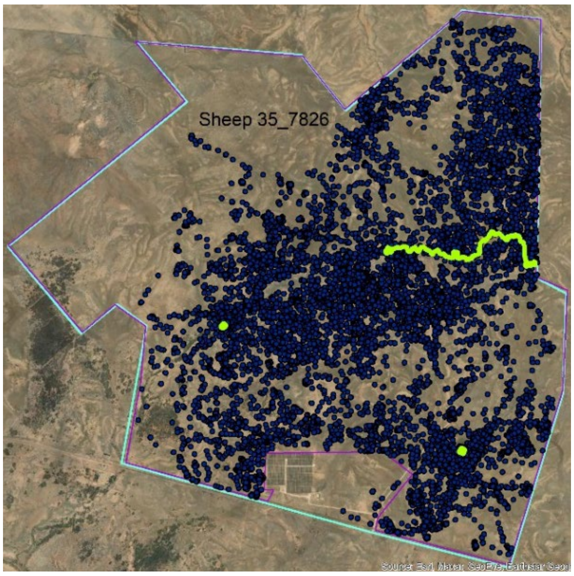
Camden Park 2019-2020

Dorper sheep

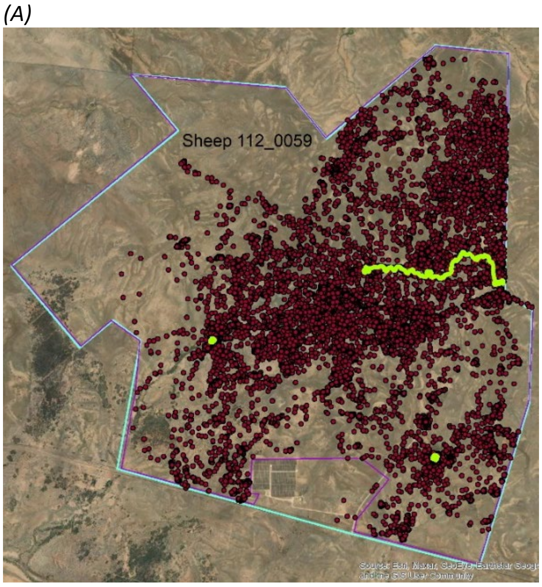
The basic data for Dorper sheep on Camden Park reveals that these sheep do not use the paddock evenly with some areas reporting much greater use than others. In particular large areas in the North Western corner of the paddocks available to them were not visited.



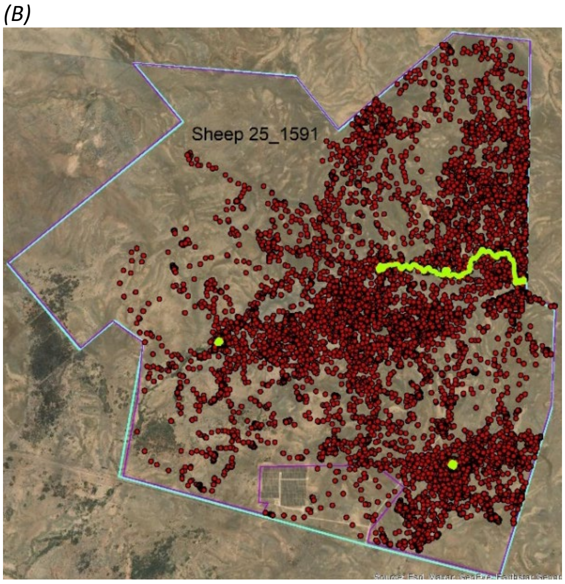
(A)



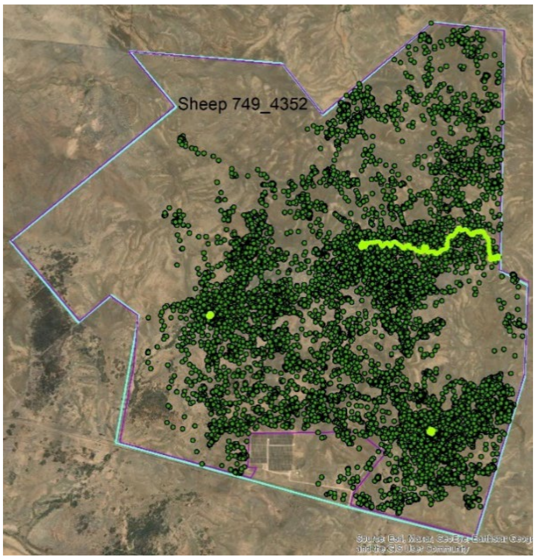
(B)

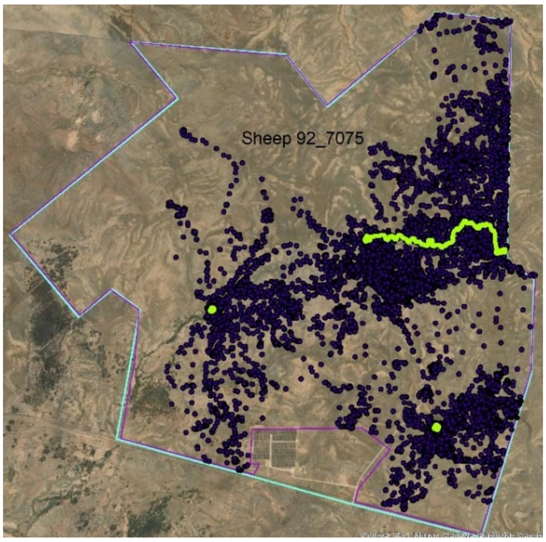


(C)

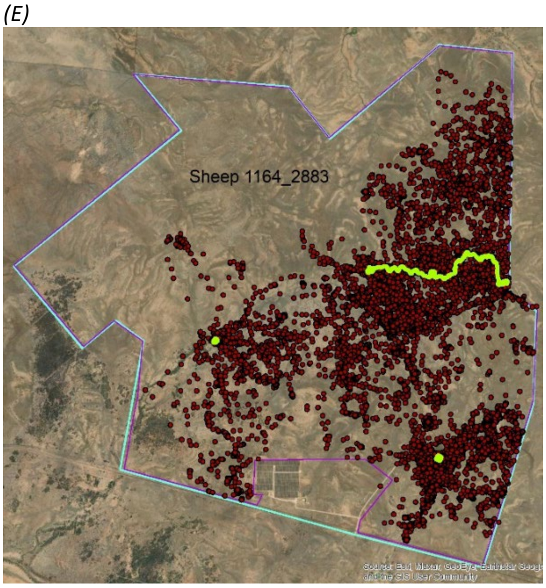


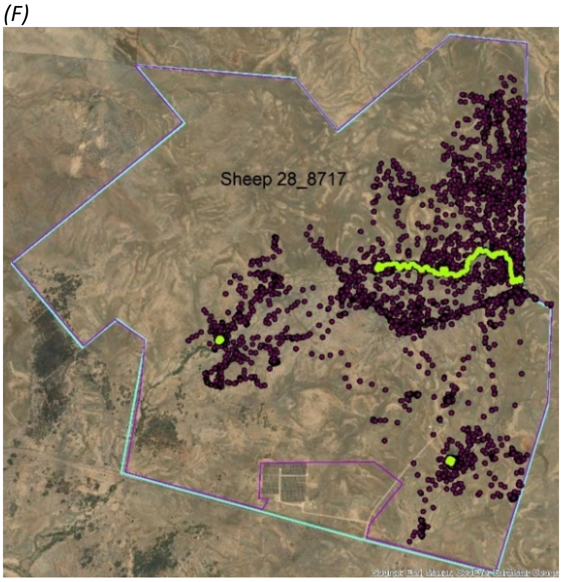
(D)





(E) *(F)*



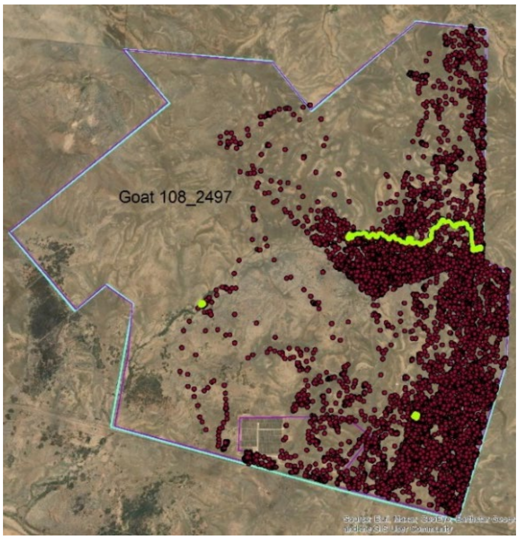


(G) *(H)*

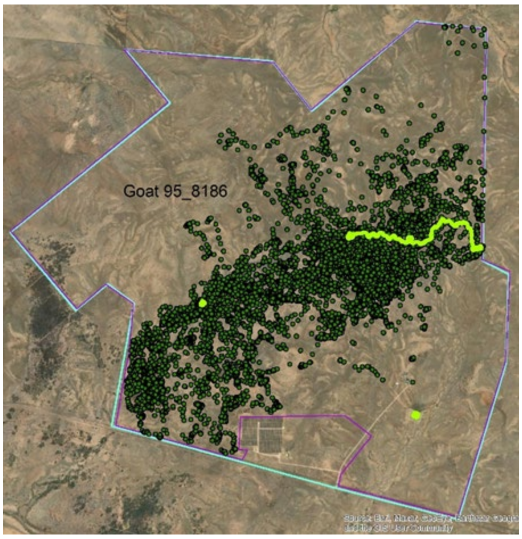
Figure 6 Data points generated by GPS tracking of Dorper sheep on Camden Park

Rangeland goats

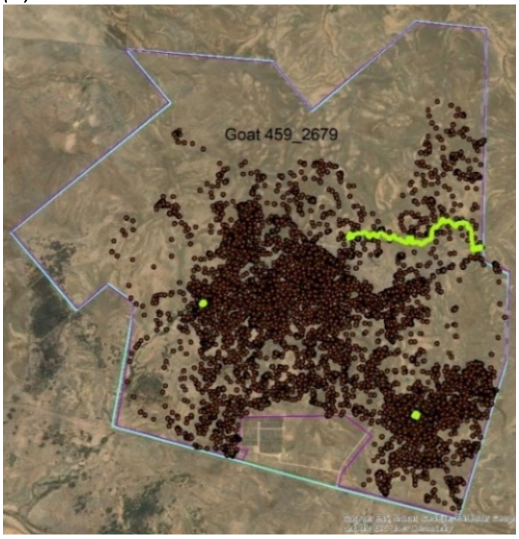
The Rangeland goats tracked on Camden Park showed much more variation between individuals than is apparent in the sheep (Figure 7). Some animals focussed their attention on the eastern side of the paddocks available to them (A - B), others used the centre (C - D) while others confined most of their activity to the south-east corner (E - G).


Goat 108_2497

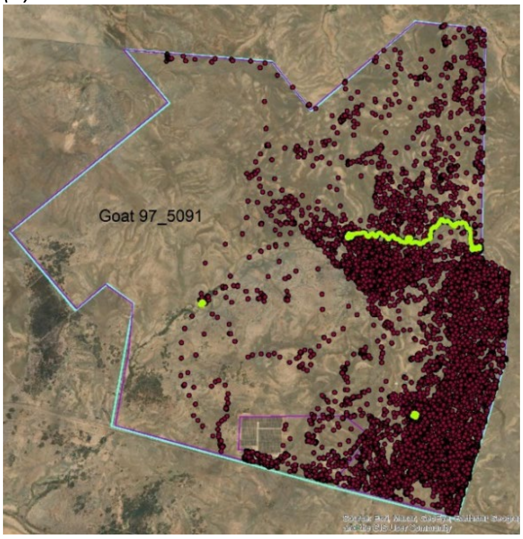
(A)


Goat 95_8186

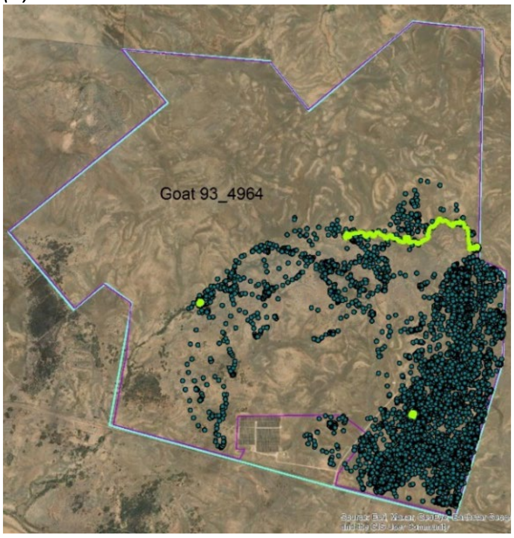
(B)


Goat 459_2679

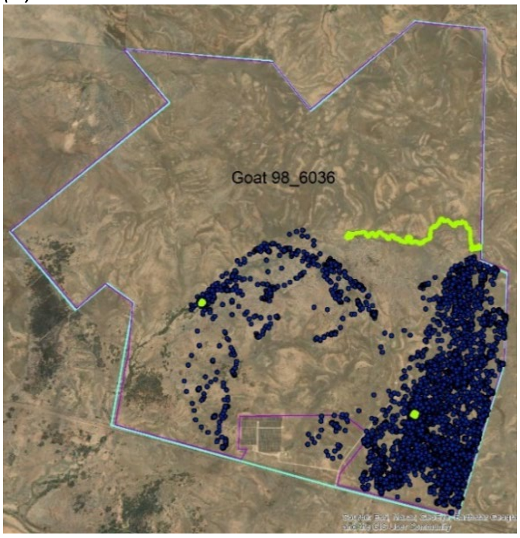
(C)


Goat 97_5091

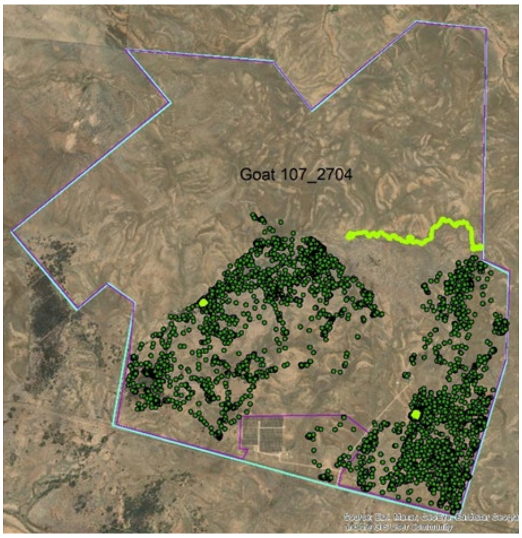
(D)


Goat 93_4964

(E)


Goat 98_6036

(F)

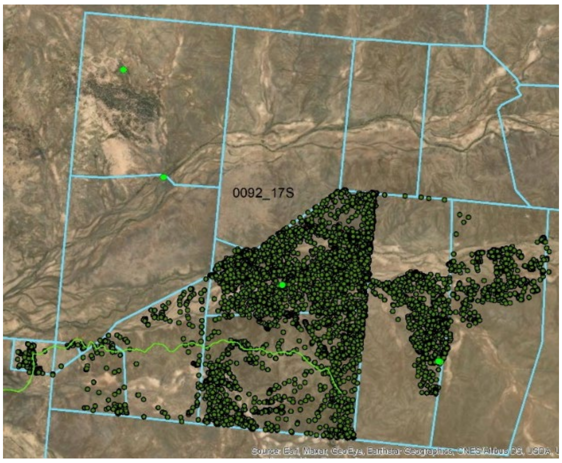


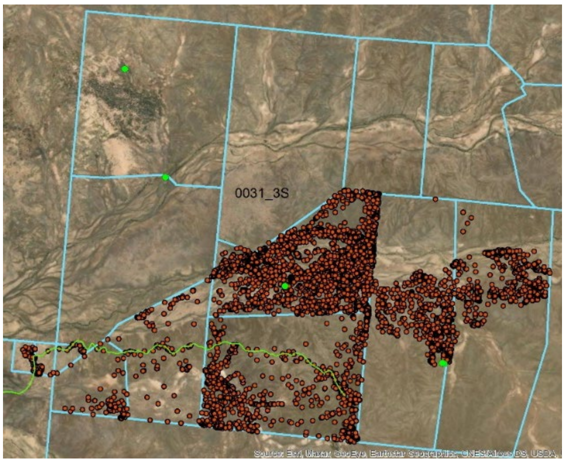
(G)

Figure 7 Data points generated by GPS tracking of Rangeland Goats on Camden Park

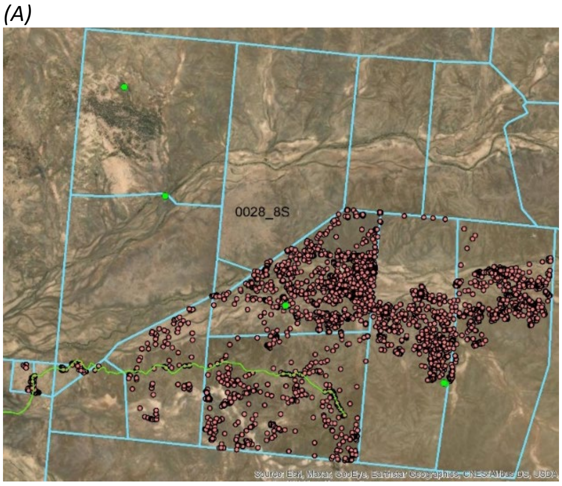
Fairfield - Merino sheep

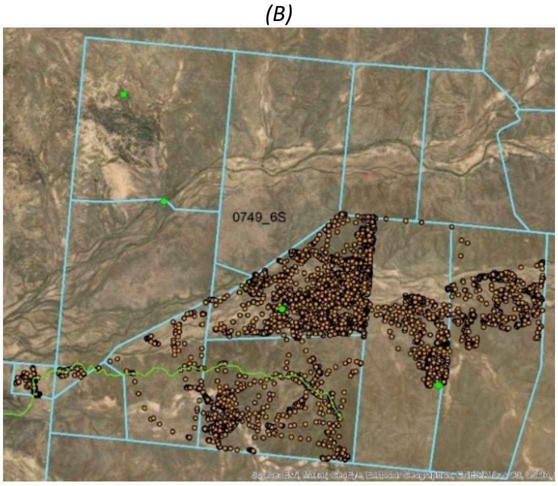
Most sheep tracked on Fairfield demonstrated a similar spatial landscape utilisation pattern. At the commencement of the study sheep only had access to two central paddocks. However, storms in January meant that flood waters destroyed fences and allowed animals access to neighbouring property paddocks to the east (Figure 8). One sheep (J) took an alternative route to the others and escaped into a Northern paddock.



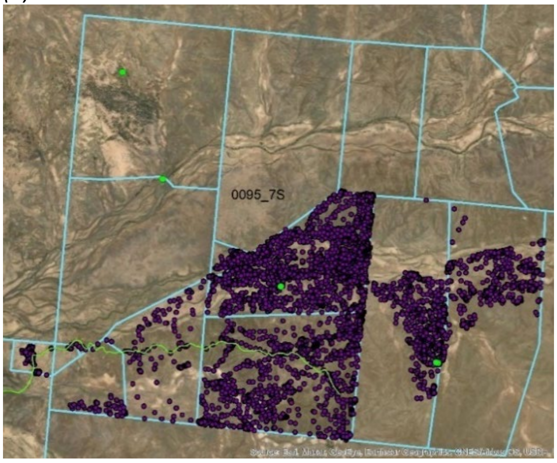


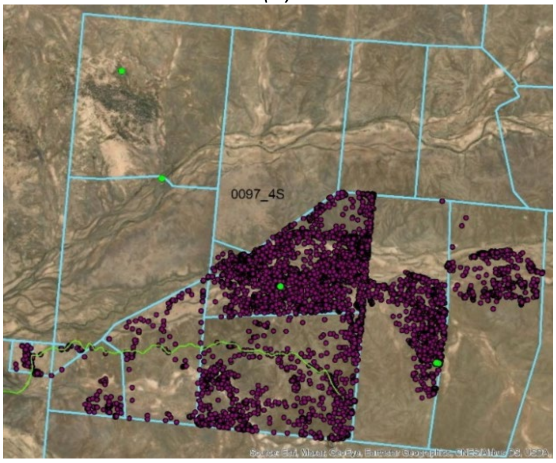
(A) *(B)*



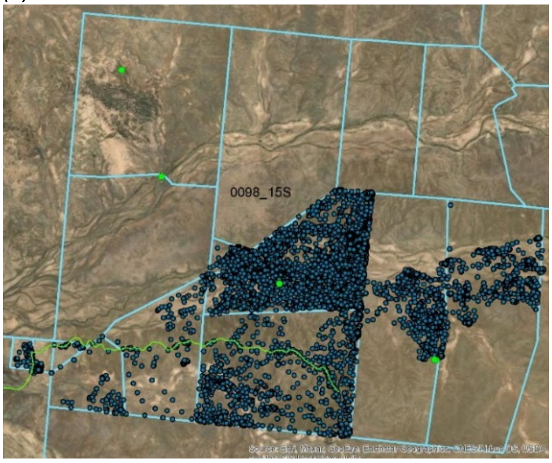


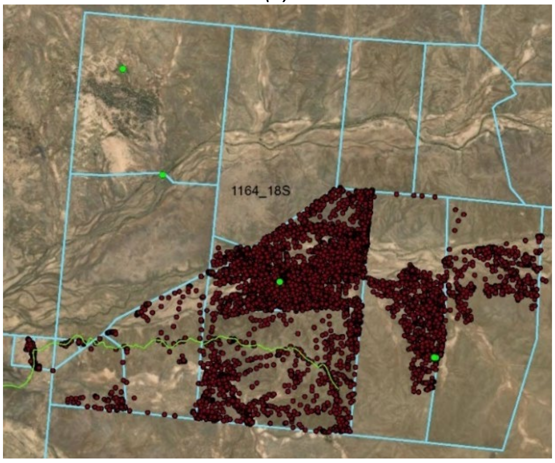
(C) *(D)*



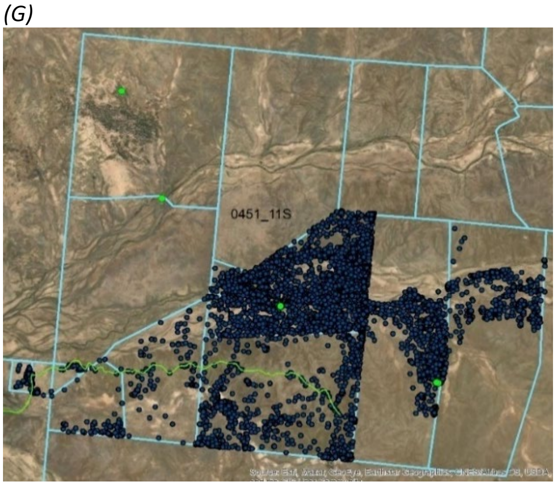


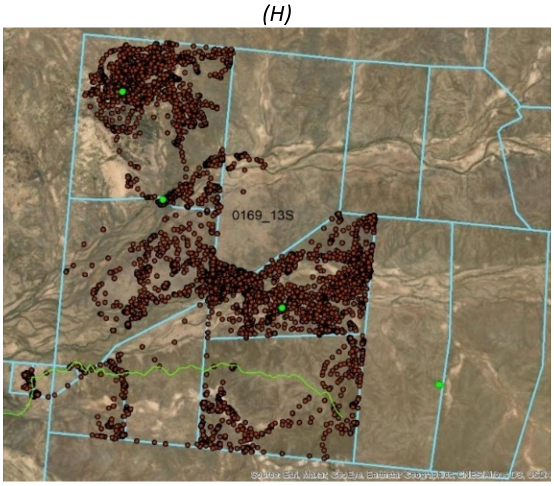
(E) *(F)*





(G) *(H)*





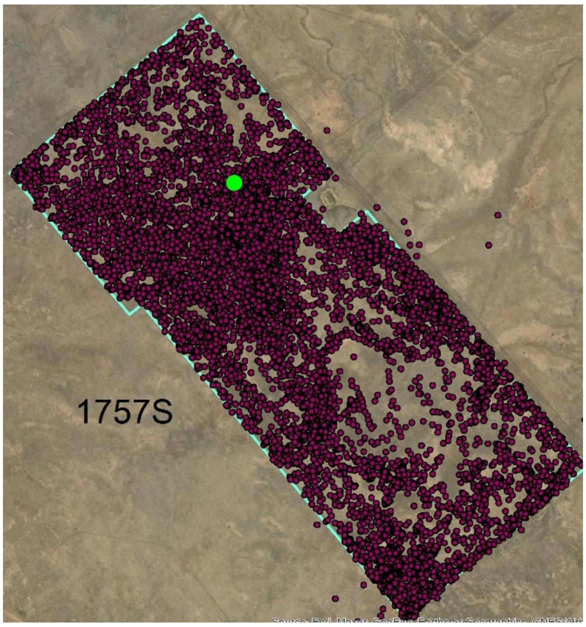
(I) *(J)*

(K)

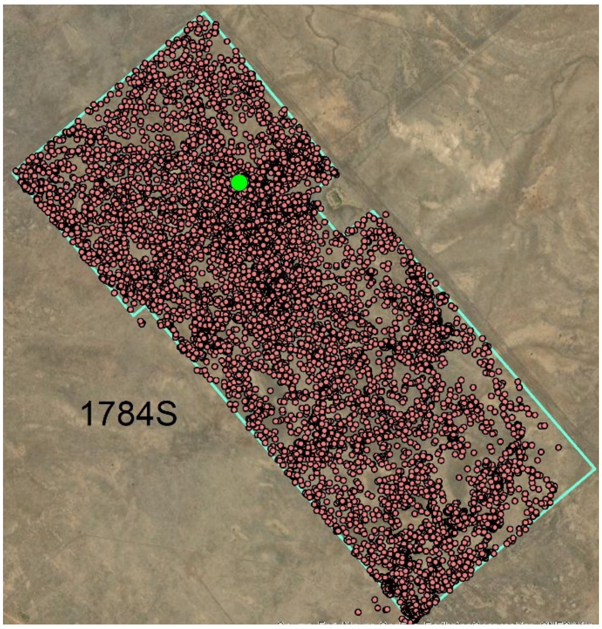
Figure 8 Data points generated by GPS tracking of Merino ewes on Fairfield

Rosebank - Merino sheep (weaners)

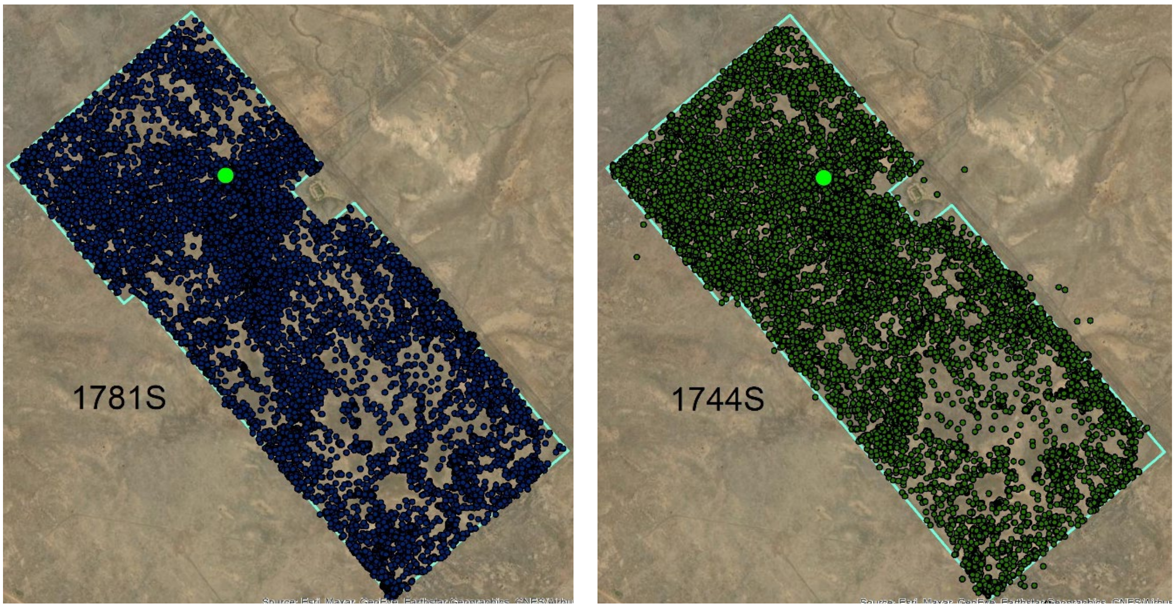
The analysis of data from the weaner sheep tracked on Rosebank shows a relatively even use of the paddock area compared to other properties, primarily due to the much higher stocking rate of this field (Figure 9). Some variation is still apparent and will be explored later in this report.



(A)



(B)



(C) (D)

Figure 9 Data points generated by GPS tracking of Merino Weaners on Rosebank

5.2.2 Basic movement parameters

Camden Park - Dorper sheep & Rangeland goats

Time spent active

Using the speed data, Camden Park sheep were considered to be inactive when below a speed of 0.03 m/s, and active at 0.03 m/s and above. Given this threshold, the sheep were 45% active and 55% inactive over the course of the study.

Table 1 Average time spent active by Dorper sheep on Camden Park (%)

Animal	Aug	Sep	Oct	Nov	Dec	Jan	Average
0059S	46	45	51	47	42	39	**45**
1591S	41	42	46	44	40	42	**43**
2883S	46	48	48	49	41	44	**46**
4352S	48	54	54	53	45	46	**50**
7075S	41	46	46	42	38	39	**42**
7824S	43	41	45	43	39	40	**42**
7826S	45	47	49	48	43	41	**45**
Average	**45**	**46**	**49**	**47**	**41**	**42**	**45**

Table 2 Maximum time spent active by Dorper sheep on Camden Park (%)

Animal	Aug	Sep	Oct	Nov	Dec	Jan	Average
0059S	58	55	70	60	55	56	**59**
1591S	52	55	54	70	54	55	**57**
2883S	56	61	63	66	59	56	**60**
4352S	58	69	74	76	58	59	**66**
7075S	49	56	57	58	55	54	**55**
7824S	50	50	57	56	53	51	**53**
7826S	52	59	61	60	57	54	**57**

Average	**54**	**58**	**62**	**64**	**56**	**55**	**58**

Table 3 Minimum time spent active by Dorper sheep on Camden Park (%)

Animal	Aug	Sep	Oct	Nov	Dec	Jan	Average
0059S	32	31	41	11	30	29	**29**
1591S	24	32	36	21	22	28	**27**
2883S	34	39	42	36	23	30	**34**
4352S	32	41	44	34	32	28	**35**
7075S	28	32	31	19	28	26	**28**
7824S	36	23	34	34	29	21	**30**
7826S	29	29	38	39	33	26	**32**
Average	**31**	**32**	**38**	**28**	**28**	**27**	**31**

Table 4 Average time spent active by Rangeland goats on Camden Park (%)

Animal	Aug	Sep	Oct	Nov	Dec	Average
1295G	51	55	52	49	50	**51**
2497G	45	49	50	47	51	**48**
2769G	43	49	50	48	41	**46**
4964G	46	46	47	48	44	**46**
5091G	42	48	43	46	43	**44**
6036G	43	49	49	49	42	**46**
8186G	38	42	46	44	43	**43**
Average	**44**	**48**	**48**	**47**	**45**	**46**

Table 5 Maximum time spent active by Rangeland goats on Camden Park (%)

Animal	Aug	Sep	Oct	Nov	Dec	Average
1295G	59	68	69	64	56	**63**
2497G	100	59	63	57	57	**67**
2769G	52	57	65	60	50	**57**
4964G	64	58	58	62	54	**59**
5091G	48	56	63	59	51	**55**
6036G	53	60	57	61	52	**56**
8186G	47	54	58	53	53	**53**
Average	**60**	**59**	**62**	**59**	**53**	**59**

Table 6 Minimum time spent active by Rangeland goats on Camden Park (%)

Animal	Aug	Sep	Oct	Nov	Dec	Average
1295G	39	44	36	23	48	**38**
2497G	26	33	37	29	40	**33**
2769G	37	35	37	40	37	**37**
4964G	35	34	35	35	39	**36**
5091G	31	39	7	32	36	**29**
6036G	32	33	31	37	38	**34**
8186G	18	22	32	33	32	**27**

Average	**31**	**34**	**31**	**33**	**39**	**34**

Daily distance travelled

The average daily distance travelled for sheep in Camden Park for the whole period of tracking was between 5.1 and 6.6 km, the group averaged 6.1km (Table 7). The maximum daily distance recorded was 13.3km, one sheep (7075S) had a relatively low maximum of 9.5km (Table 8). The minimum daily distance travelled for Camden Park sheep was between 1.1 and 2.6 km. This shows the sheep travelled at least 1 km per day (Table 9).

Table 7 Average distance travelled by Dorper sheep on Camden Park (metres)

Animal	Aug	Sep	Oct	Nov	Dec	Jan	Average
0059S	7,110	5,861	6,723	7,166	6,460	6,137	**6,576**
1591S	6,577	5,686	6,132	5,798	5,620	6,807	**6,103**
2883S	6,647	5,929	6,180	5,904	4,402	6,015	**5,846**
4352S	6,421	6,267	7,424	7,376	5,168	7,070	**6,621**
7075S	5,802	5,204	5,649	4,748	3,951	5,199	**5,092**
7824S	5,749	5,441	6,219	6,583	4,684	6,406	**5,847**
7826S	6,911	6,157	6,794	7,390	5,926	6,366	**6,591**
Average	**6,460**	**5,792**	**6,446**	**6,424**	**5,173**	**6,286**	**6,097**

Table 8 Maximum distance travelled by Dorper sheep on Camden Park (metres)

Animal	Aug	Sep	Oct	Nov	Dec	Jan	Average
0059S	9,645	10,026	11,389	12,070	9,900	12,333	**10,894**
1591S	10,145	9,456	10,682	9,960	7,984	13,305	**10,255**
2883S	9,252	9,557	8,079	10,559	7,017	10,354	**9,137**
4352S	8,390	11,333	13,056	12,840	9,646	13,264	**11,422**
7075S	7,926	8,860	8,040	9,534	7,716	8,725	**8,467**
7824S	8,658	8,895	8,212	10,085	9,420	11,485	**9,459**
7826S	9,621	12,949	11,962	11,209	8,903	12,131	**11,129**
Average	**9,091**	**10,154**	**10,203**	**10,894**	**8,655**	**11,657**	**10,109**

Table 9 Minimum distance travelled by Dorper sheep on Camden Park (metres)

Animal	Aug	Sep	Oct	Nov	Dec	Jan	Average
0059S	4,896	1,732	3,715	1,542	4,239	3,778	**3,317**
1591S	4,034	1,293	3,375	1,999	3,950	4,066	**3,119**
2883S	4,436	1,880	4,046	3,700	2,243	3,469	**3,296**
4352S	3,989	3,958	4,628	4,258	2,678	2,917	**3,738**
7075S	3,686	1,432	2,956	1,178	2,336	3,585	**2,529**
7824S	3,296	1,226	3,731	3,731	3,040	3,605	**3,105**
7826S	3,949	1,106	4,058	4,444	3,969	3,943	**3,578**
Average	**4,041**	**1,804**	**3,787**	**2,979**	**3,208**	**3,623**	**3,240**

The average daily distance travelled for goats in Camden Park ranged from 5.4 – 6.2 km with a group average of 5.7km (Table 7). The maximum daily distance travelled for goats varied by month and ranged between 6.5 and 12.1 km (Table 8), and the minimum was between 1.5 and 5.0 km (Table 9).

Table 10 Average distance travelled by Rangeland Goats on Camden Park (metres)

Animal	Aug	Sep	Oct	Nov	Dec	Average
1295G	5,319	6,260	6,566	5,921	5,430	**5,899**
2497G	4,675	5,631	6,425	5,254	6,596	**5,716**
2769G	6,097	5,887	6,551	7,103	5,280	**6,184**
4964G	5,336	5,727	5,602	4,937	5,389	**5,398**
5091G	4,949	6,001	6,148	5,710	5,001	**5,562**
6036G	5,029	5,915	5,653	4,903	5,663	**5,432**
8186G	5,812	5,674	6,971	5,417	5,224	**5,820**
Average	**5,317**	**5,871**	**6,274**	**5,607**	**5,512**	**5,716**

Table 11 Maximum distance travelled by Rangeland Goats on Camden Park (metres)

Animal	Aug	Sep	Oct	Nov	Dec	Average
1295G	7,508	10,530	8,716	9,366	7,412	**8,706**
2497G	6,963	7,550	9,517	8,756	8,163	**8,190**
2769G	7,684	9,761	8,808	12,144	6,553	**8,990**
4964G	6,991	7,283	9,222	7,710	5,816	**7,404**
5091G	6,491	7,936	9,221	9,018	5,871	**7,707**
6036G	7,306	8,298	9,161	7,666	6,836	**7,853**
8186G	9,351	8,417	10,432	9,529	6,892	**8,924**
Average	**7,470**	**8,539**	**9,297**	**9,170**	**6,792**	**8,254**

Table 12 Minimum distance travelled by Dorper Sheep on Camden Park (metres)

Animal	Aug	Sep	Oct	Nov	Dec	Average
1295G	2,793	4,587	3,061	2,354	4,879	**3,535**
2497G	1,584	3,450	4,093	3,631	5,062	**3,564**
2769G	3,953	3,625	4,047	4,223	4,430	**4,055**
4964G	2,539	4,017	3,207	2,682	4,864	**3,462**
5091G	3,170	3,472	1,051	3,594	3,173	**2,892**
6036G	1,844	4,148	3,240	2,934	4,656	**3,365**
8186G	1,658	2,296	4,011	3,205	3,822	**2,998**
Average	**2,506**	**3,657**	**3,244**	**3,232**	**4,412**	**3,410**

Diurnal activity patterns

The diurnal activity patterns of sheep (Figure 10) and goats (Figure 11) over the entire monitoring period are relatively similar. Both have a typical extensive grazing ruminant behaviour pattern of morning and evening high activity levels associated with grazing. Rest periods occur overnight and during the middle of the day.

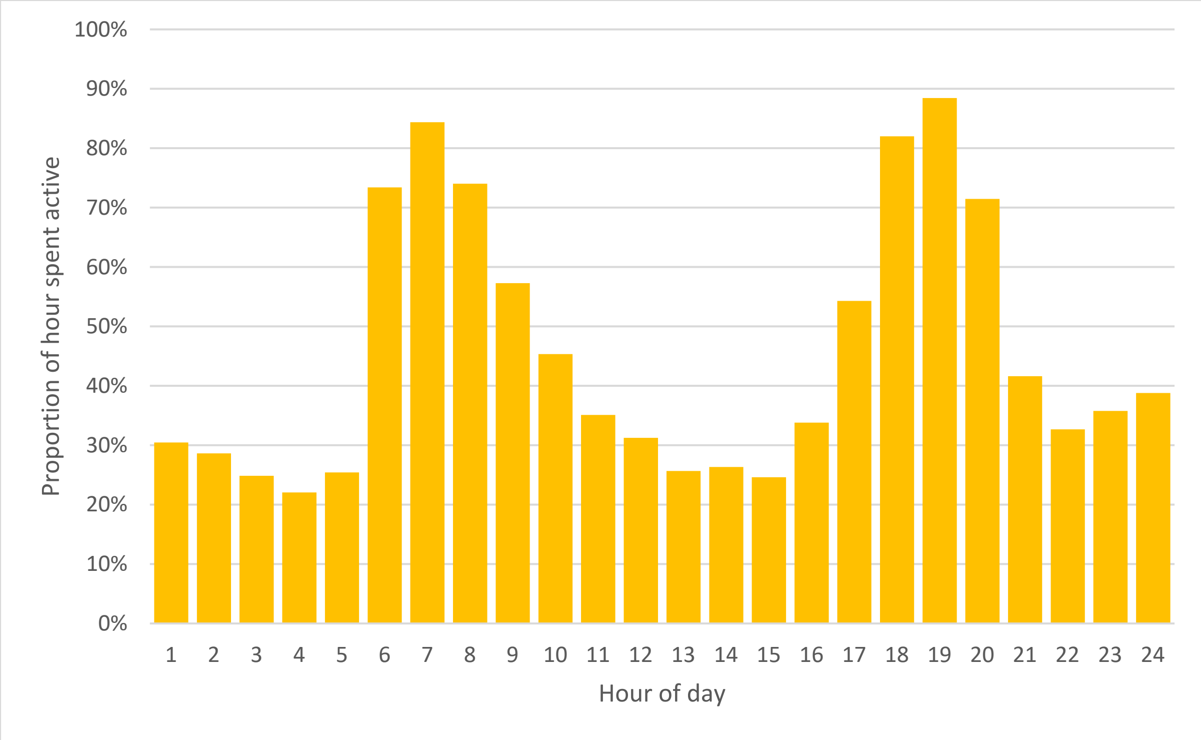


Figure 10 Diurnal activity pattern of Dorper sheep on Camden Park

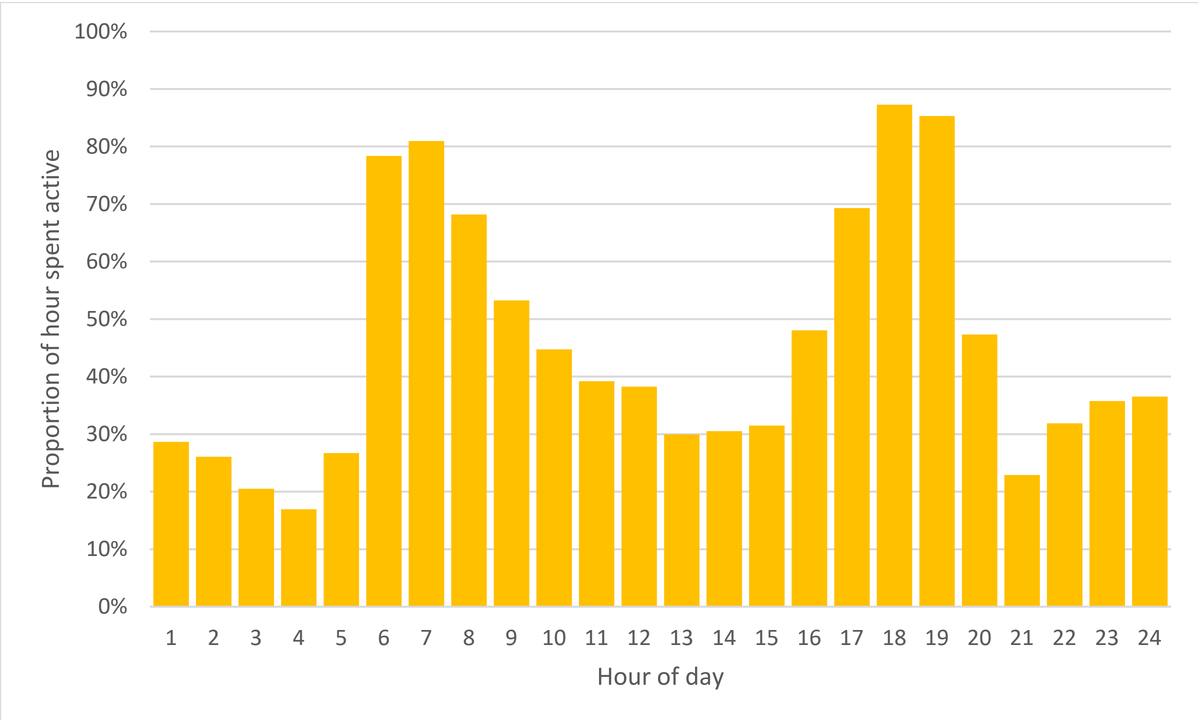


Figure 11 Diurnal activity pattern of Rangeland goats on Camden Park

Fairfield - Merino sheep

Time spent active

The speed of all Fairfield sheep were plotted against time and the active threshold was found to be 0.03 m/s, the same as Camden Park. Over the course of the 4 month study the sheep spent 44% of their time in an active state (Table 13). There were some days when the proportion of time spent in an active state fell to as low as an average of 13% (Table 15).

Table 13 Average time spent active by Merino ewes on Fairfield (%)

Animal	Dec	Jan	Feb	Mar	Average
11S	43	44	50	54	**48**
13S	37	37	43	42	**40**
15S	42	44	48	47	**45**
17S	45	41	47	52	**46**
18S	40	43	43	47	**43**
3S	40	43	46	46	**44**
4S	39	40	48	48	**44**
7S	36	43	47	48	**43**
Average	**40**	**42**	**47**	**48**	**44**

Table 14 Maximum time spent active by Merino ewes on Fairfield (%)

Animal	Dec	Jan	Feb	Mar	Average
11S	57	60	66	71	**63**
13S	58	51	60	58	**57**
15S	60	59	69	73	**65**
17S	55	54	69	70	**62**
18S	51	54	59	68	**58**
3S	51	56	69	65	**60**
4S	53	57	63	63	**59**
7S	51	67	68	66	**63**
Average	**55**	**57**	**65**	**67**	**61**

Table 15 Minimum time spent active by Merino ewes on Fairfield (%)

Animal	Dec	Jan	Feb	Mar	Average
11S	22	33	37	22	**29**
13S	16	26	23	13	**20**
15S	27	26	27	8	**22**
17S	31	27	35	17	**27**
18S	25	33	32	6	**24**
3S	19	32	27	4	**20**
4S	24	27	37	19	**27**
7S	23	26	28	14	**23**
Average	**24**	**29**	**31**	**13**	**24**

Daily distance travelled

The Fairfield sheep average daily distance travelled had a range of 5.9 – 8.9 km (Table 16). The maximum daily distance travelled ranged from 15.9 – 20.5 km (Table 17), well above the maximum range for Camden Park. Interestingly, the Fairfield sheep had a minimum daily distance travelled range of 0.4 – 1.1 km (Table 18), much lower than the Camden Park sheep.

Table 16 Average distance travelled by Merino ewes on Fairfield (metres)

Animal	Dec	Jan	Feb	Mar	Average
11S	7,908	7,504	9,378	10,907	**8,924**
13S	4,237	5,791	6,455	7,190	**5,918**
15S	8,771	8,305	9,828	10,097	**9,250**
17S	7,180	6,953	9,453	10,515	**8,525**
18S	7,601	7,363	8,741	8,871	**8,144**
3S	7,930	6,778	8,622	9,025	**8,089**
4S	8,892	6,710	7,875	8,288	**7,941**
7S	6,906	6,912	7,867	8,659	**7,586**
Average	**7,428**	**7,040**	**8,527**	**9,194**	**8,047**

Table 17 Maximum distance travelled by Merino Ewes on Fairfield

Animal	Dec	Jan	Feb	Mar	Average
11S	12,332	12,675	12,851	17,782	**13,910**
13S	11,281	11,666	12,871	16,510	**13,082**
15S	12,885	14,552	19,200	19,754	**16,598**
17S	13,087	11,808	19,006	20,400	**16,075**
18S	13,534	13,387	15,284	15,973	**14,544**
3S	13,266	11,598	16,601	20,508	**15,493**
4S	15,876	11,470	12,414	17,795	**14,389**
7S	14,859	11,900	12,049	16,315	**13,781**
Average	**13,390**	**12,382**	**15,034**	**18,130**	**14,734**

Table 18 Minimum distance travelled by Merino Ewes on Fairfield

Animal	Dec	Jan	Feb	Mar	Average
11S	965	3,951	5,401	1,367	**2,921**
13S	1,115	2,831	2,428	844	**1,805**
15S	1,587	2,738	6,060	510	**2,724**
17S	1,311	4,004	5,114	1,158	**2,897**
18S	984	3,946	4,791	421	**2,536**
3S	1,013	3,712	5,280	413	**2,604**
4S	1,105	3,532	3,928	905	**2,367**
7S	1,458	3,001	4,172	694	**2,331**
Average	**1,192**	**3,464**	**4,647**	**789**	**2,523**

Diurnal activity patterns

The Merino Ewes showed a typical crepuscule grazing pattern with two peak activity times associated with grazing and reduced activity overnight and during the middle of the day (Figure 12).

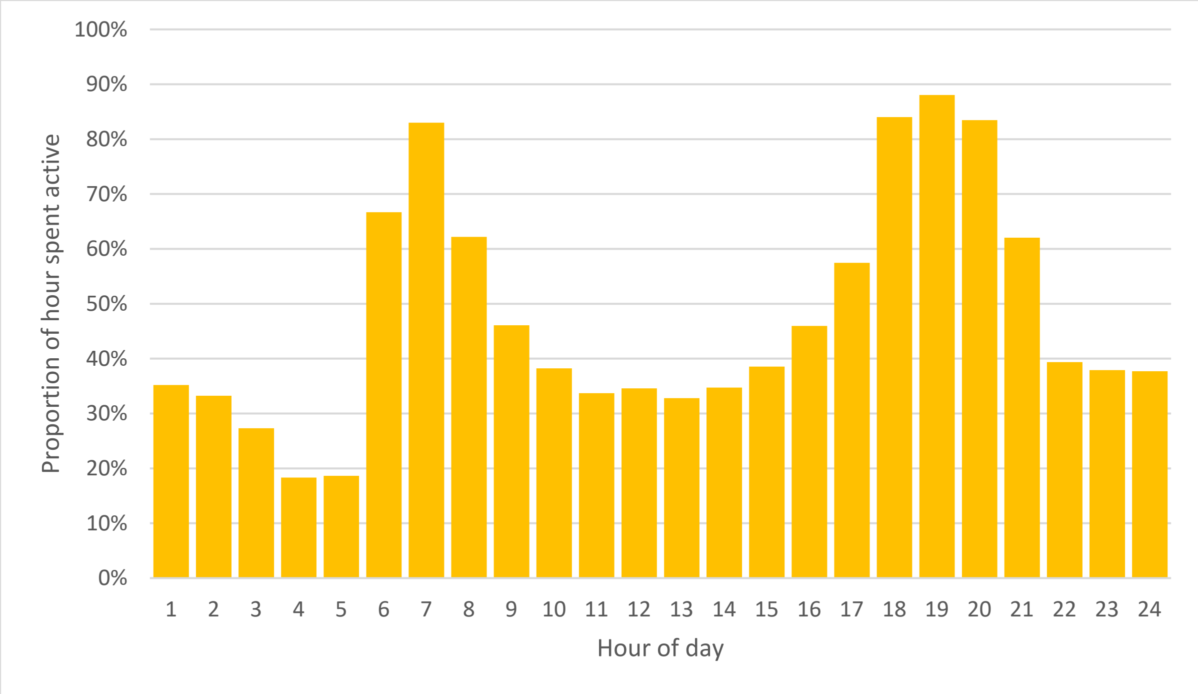


Figure 12 Diurnal activity pattern of Merino ewes on Fairfield

Rosebank - Merino Weaners

Time spent active

The Merino Weaners on Rosebank spent an average of 55% in an active state (Table 19). The maximum amount of time spent in an active state declined over time from an average of 76% in November to 64% in February (Table 20). The minimum time spent active was relatively high at an average of 42% (Table 21).

Table 19 Average time spent active by Merino Weaners on Rosebank

Animal	Nov	Dec	Jan	Feb	Average
1744S	62	55	49	54	**55**
1757S	67	56	51	51	**56**
1781S	59	54	53	58	**56**
1784S	65	49	46	55	**54**
Average	**63**	**54**	**50**	**54**	**55**

Table 20 Maximum time spent active by Merino Weaners on Rosebank

Animal	Nov	Dec	Jan	Feb	Average
1744S	78	76	66	67	**72**
1757S	80	73	67	61	**70**
1781S	70	84	68	65	**72**
1784S	75	63	65	63	**67**
Average	**76**	**74**	**67**	**64**	**70**

Table 21 Minimum time spent active by Merino Weaners on Rosebank

Animal	Nov	Dec	Jan	Feb	Average
1744S	46	42	34	40	**40**
1757S	59	38	35	38	**43**
1781S	49	39	40	53	**45**
1784S	52	35	31	41	**40**
Average	**51**	**38**	**35**	**43**	**42**

Daily distance walked

The average daily distance travelled for Rosebank sheep ranged from 7.5 km to 8.3 km. The maximum daily distance travelled was between 10.7km and 12.9km (Table 23). The minimum daily distance travelled for all sheep at the start of the monitoring period was 7.0km (November) but dropped in subsequent months (Table 24).

Table 22 Average distance travelled by Merino Weaners on Rosebank (metres)

Animal	Nov	Dec	Jan	Feb	Average
1744S	8,505	7,524	7,549	8,336	7,978
1757S	10,652	7,273	7,874	7,482	8,320
1781S	9,319	7,537	7,749	8,650	8,314
1784S	9,117	6,758	6,697	7,381	7,488
Average	9,398	7,273	7,467	7,962	8,025

Table 23 Maximum distance travelled by Merino Weaners on Rosebank (metres)

Animal	Nov	Dec	Jan	Feb	Average
1744S	9,584	12,357	10,594	11,474	11,002
1757S	16,133	12,371	11,793	11,131	12,857
1781S	13,129	12,549	12,636	12,945	12,815
1784S	12,015	10,139	10,827	9,970	10,738
Average	12,715	11,854	11,462	11,380	11,853

Table 24 Minimum distance travelled by Merino Weaners on Rosebank (metres)

Animal	Nov	Dec	Jan	Feb	Average
1744S	7,225	3,797	2,730	4,347	4,525
1757S	7,933	4,038	4,017	4,442	5,108
1781S	6,553	3,575	4,500	4,565	4,798
1784S	6,254	3,021	2,947	4,362	4,146
Average	6,991	3,608	3,548	4,429	4,644

Diurnal activity patterns

The diurnal activity of the Merino Weaners on Rosebank showed a typical pattern for grazing ruminants (Figure 13). It should be noted that the lowest levels of activity are still quite high (30-40%) suggesting that these sheep did not completely reduce their activity overnight as would be typical of grazing ruminants.

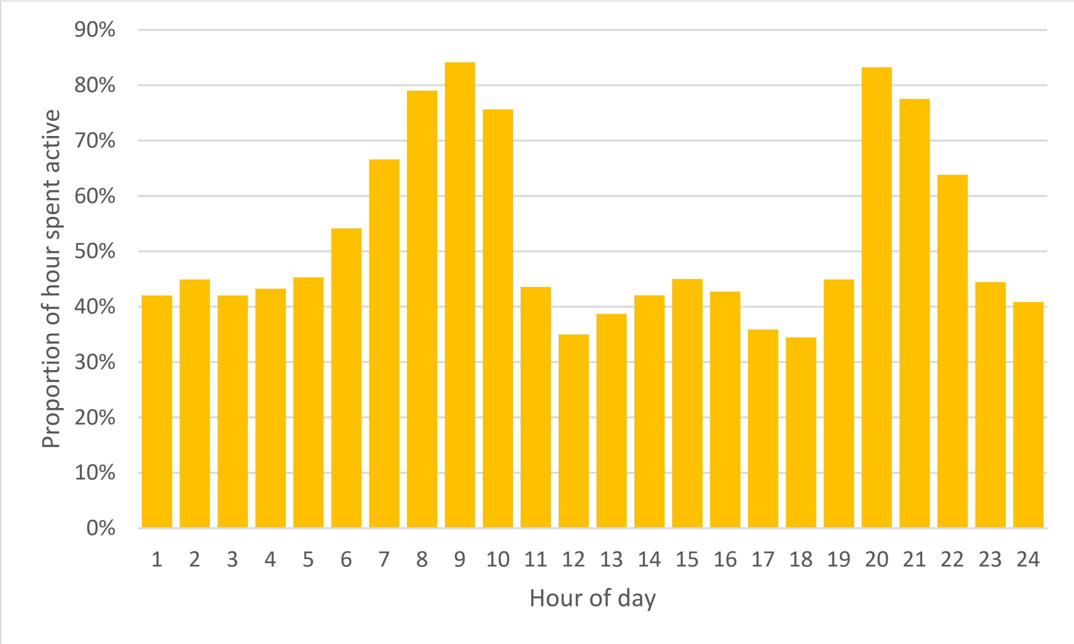


Figure 13 Diurnal activity pattern of Merino Weaners on Rosebank

Comparison across sites

A simple comparison of key behavioural data from all sites provides some interesting insights. The sheep and goats on Camden Park travelled almost 2km per day less than the sheep on Fairfield and Rosebank (Figure 14). This may be due to the available feed on Camden Park and the relatively lower stocking rate. The smaller paddock size of Rosebank might have been expected to provide a lower distance travelled however this was not the case. This may in part be due to the type of animal with weaner sheep expected to travel more in search of their mothers. This increased activity was observed in the first month (travel distance over 9km) however the daily distance travelled remained above 7km for the following months. One of the key differences noted between the different animal groups was the increased activity reported for the Rosebank Merino Weaners (Figure 15). These sheep spent over 10% more time in an active state than the other groups. One possible reason for this is the low levels of social cohesion that these weaner sheep may be experiencing. The establishment of social structures amongst this newly developed flock of sheep may have meant that they spent more time moving around. The very high amount of time spent active in the first month (63%) would likely be a result of this however the prolonged elevated levels may be due to other causes. It is worth noting that although the Fairfield sheep travelled a relatively large distance, they did this with a relatively normal time spent active.

The diurnal activity of the Camden Park Sheep and Goats and the Fairfield Ewes was almost identical (Figure 16). However, the pattern expressed by the Rosebank Weaners was both elevated and offset compared to these other animals. An explanation for this trend is still being explored.

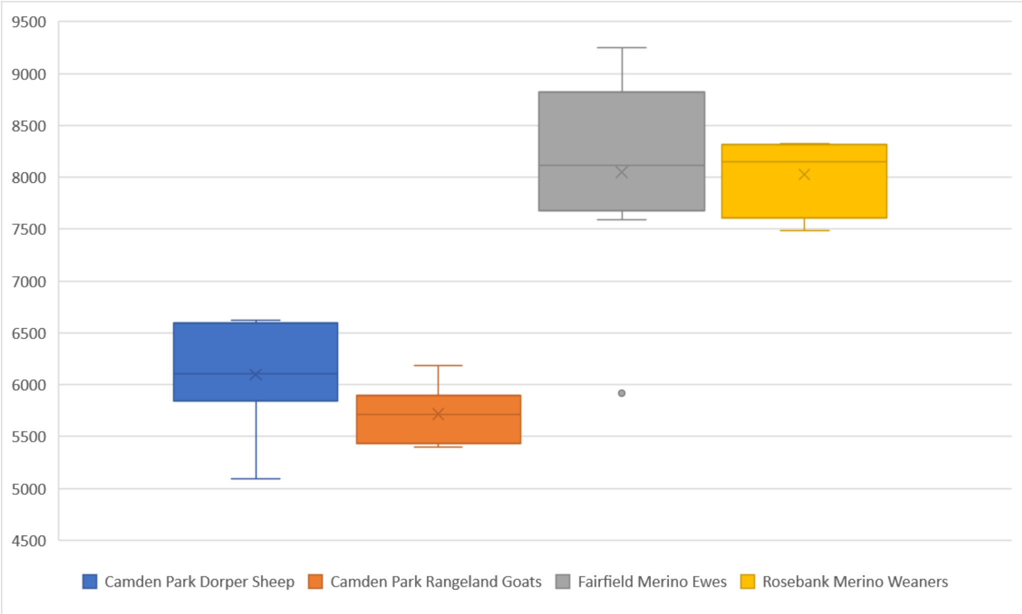


Figure 14 A comparison (quartile plot) of the average daily distance travelled for all animals across all deployments. Block shows 50% of data line within block shows median, whiskers outer 25% of data and dots represent outliers.

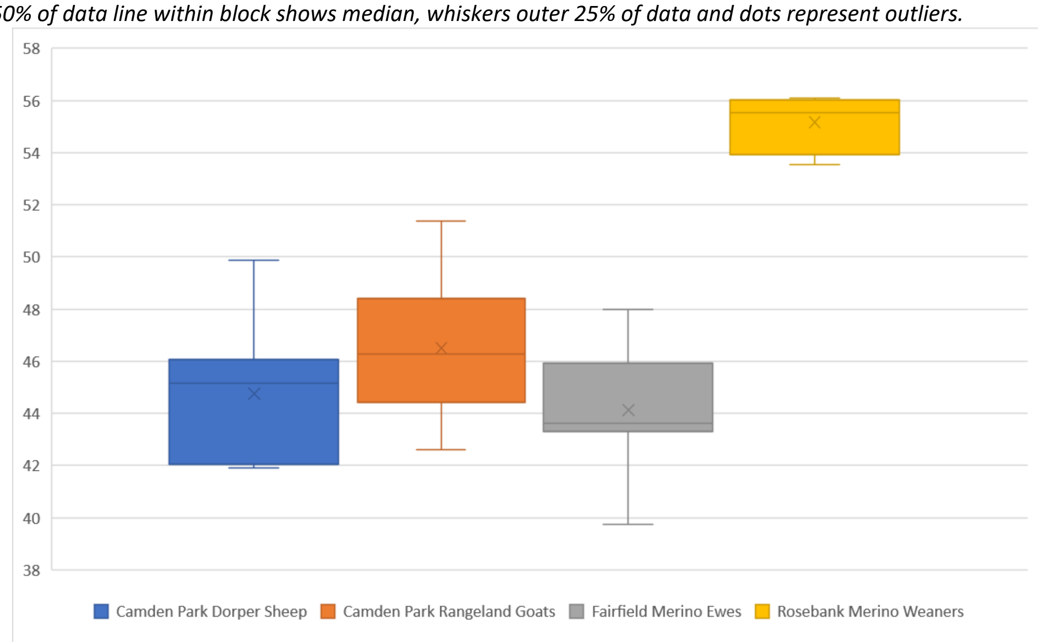


Figure 15 A comparison (quartile plot) of the average time spent active for all animals across all deployments. Block shows 50% of data line within block shows median, whiskers outer 25% of data and dots represent outliers.

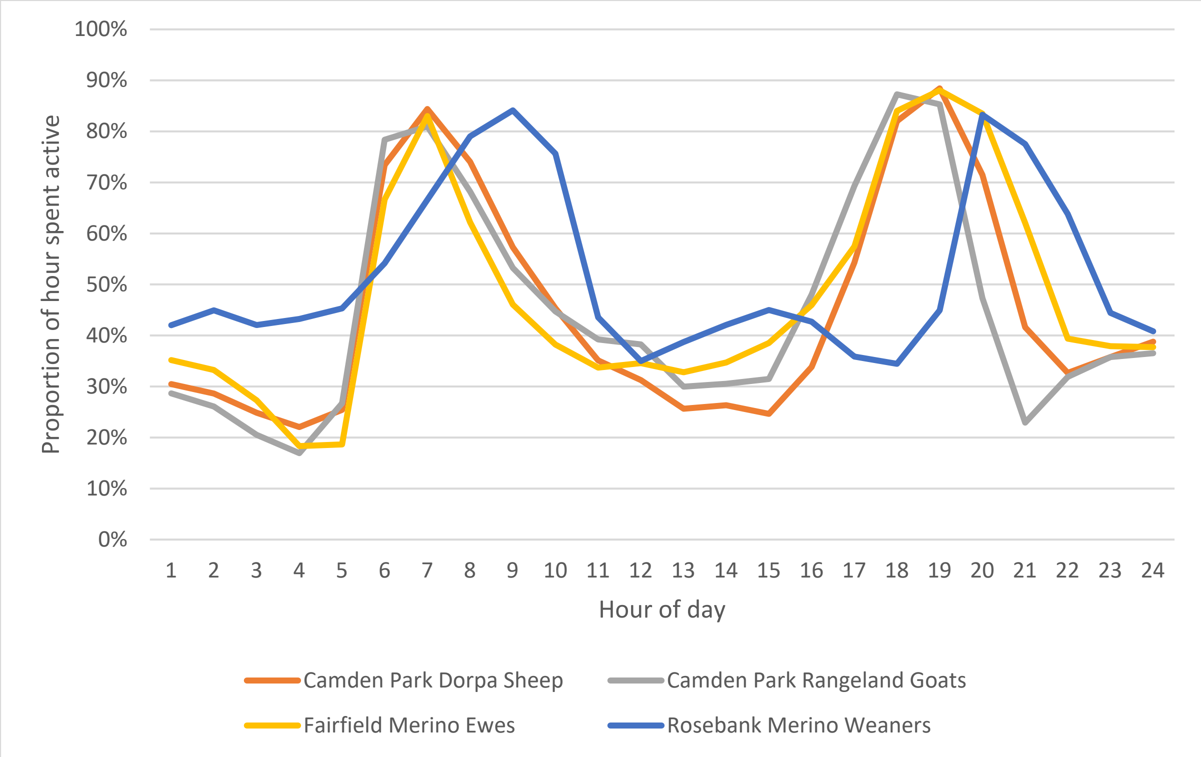


Figure 16 Diurnal behaviour of all groups of animals.

5.2.3 Spatial grazing distribution

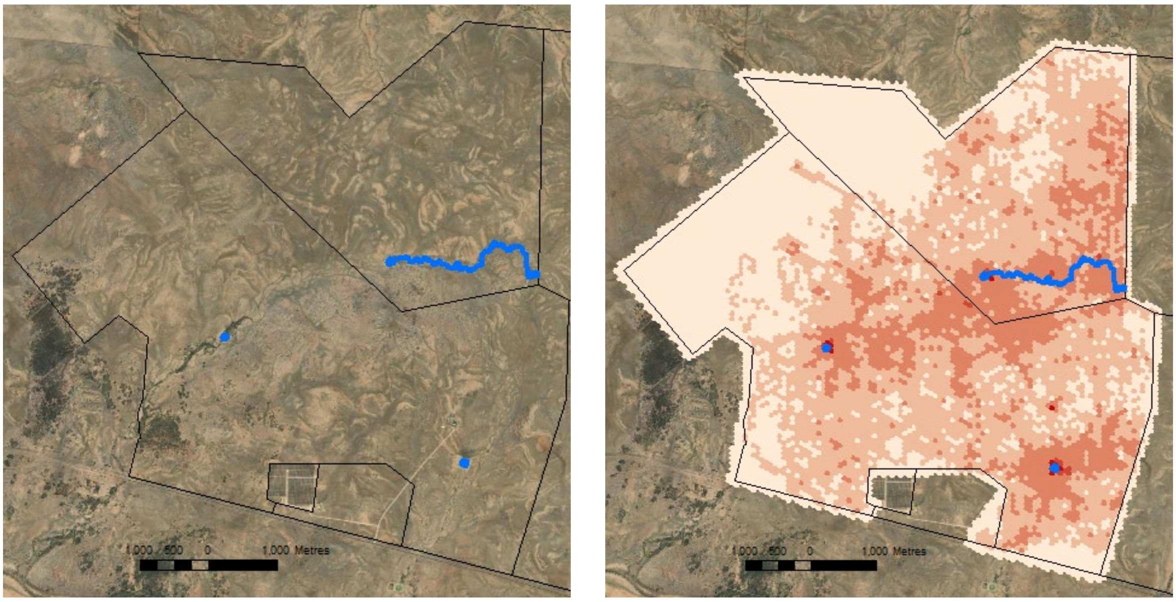
Spatial grazing distribution maps were developed by isolating the active data points (>0.03m/s) and then counting these within a hexagonal grid. This provides a relative density map to enable exploration of the trends in spatial landscape utilisation by animals.

Camden Park - Dorper sheep & Rangeland goats

The grazing density maps for sheep and goats reveal a strong tendency for both types of animals to graze more heavily around water points (Figure 17 and Figure 18). Large areas of the paddocks available to these animals remain completely unutilised, particularly the North-western corner. The relatively lower stocking rates of this paddocks will almost certainly have impacted on this landscape utilisation with animals not having to walk further to find available feed. The Dorper sheep appear to have a slightly larger total area utilised compared to the rangeland goats. However, an inspection of the individual animal maps provided in Figure 6 and Figure 7 would suggest that whilst individual sheep have a similarly large spatial grazing distribution individual goats have more intensive grazing distribution ranges. The integration of the multiple (and different) spatial grazing distribution ranges of the goats sums to a similar grazing distribution range as was reported for the Dorper sheep.

The focus section shown in Figure 18 demonstrates the link between land type, water and sheep grazing distribution. There are clear patterns of association between the grazing density highlighted in the black oval and landform represented underneath. Further research including land-type assessment is required to explore these trends in more detail.

The focus section in Figure 20 shows the preferential use of two features by the rangeland goats. The first is the waterway and the second is a patch of Gidgee scrub.

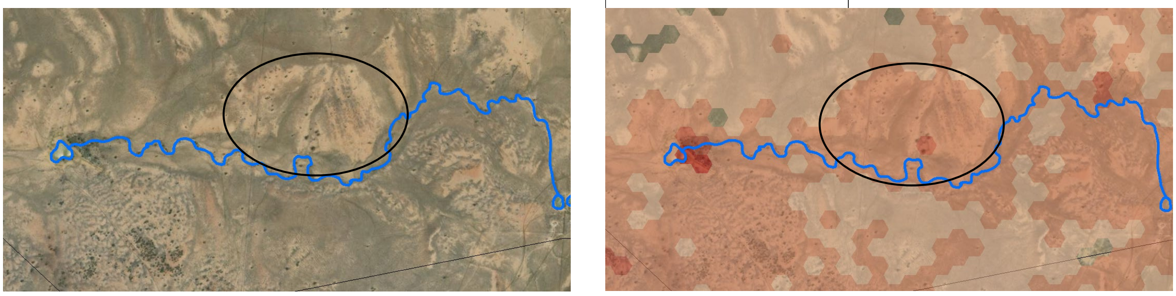


(A)

(B)

Figure 17 Base map of Camden Park for reference (A) and Spatial Grazing Distribution Map (B) for Dorper Sheep. Point count represents the number of active points reported for each hexagon.

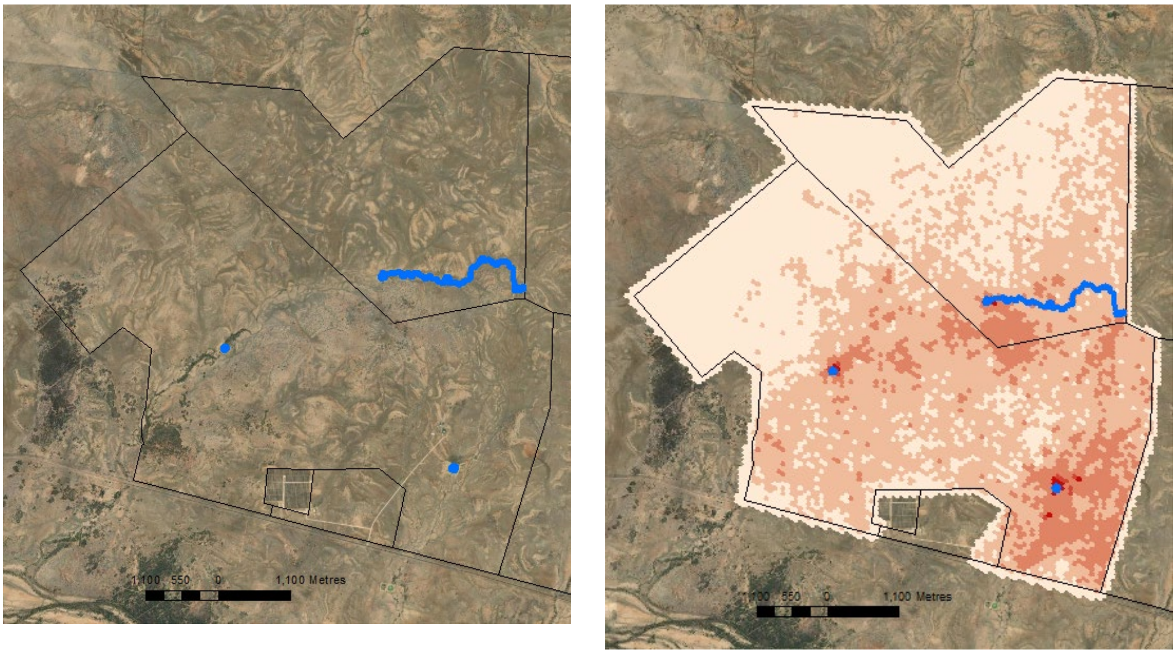
Point Count



(A)

(B)

Figure 18 Base map of Camden Park for reference (A) and Spatial Grazing Distribution Map of selected area (B) for Dorper Sheep. Point count represents the number of active points reported for each hexagon.

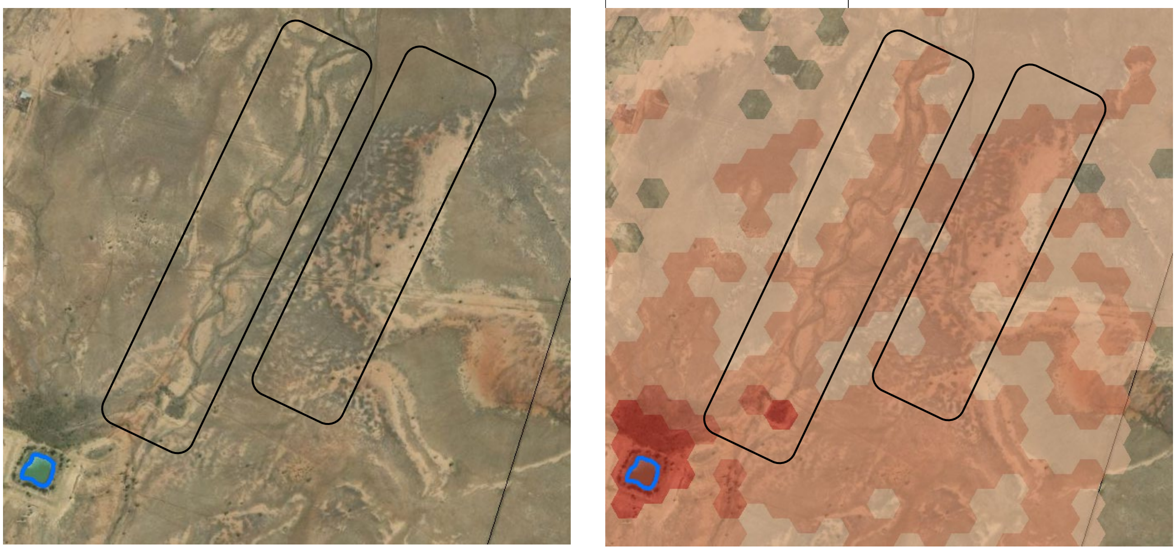


(A)

(B)

Figure 19 Base map of Camden Park for reference (A) and Spatial Grazing Distribution Map (B) for Rangeland goats. Point count represents the number of active points reported for each hexagon.

Point Count



(A)

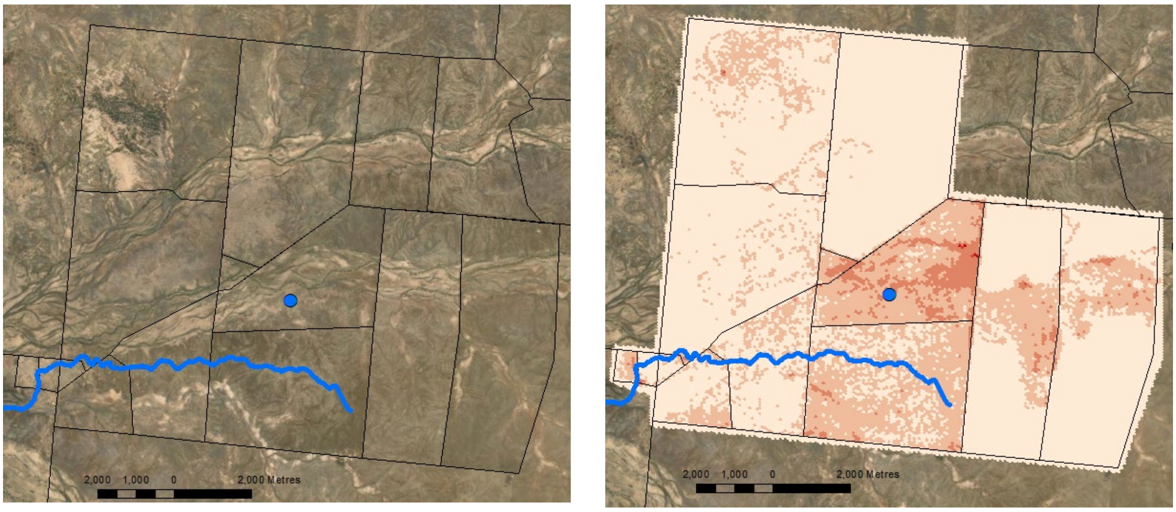
(B)

Figure 20 Base map of Camden Park for reference (A) and Spatial Grazing Distribution Map of selected area (B) for Rangeland goats. Point count represents the number of active points reported for each hexagon

Fairfield - Merino sheep

The spatial grazing distribution maps for Fairfield Merino ewes reveals a number of trends in landscape utilisation (Figure 21). For the initial part of the deployment the sheep were isolated to the central paddock (paddock with single water point) before being provided access to the paddock below this (with bore drain). There was almost complete utilisation of the first paddock, however some areas of this field received higher grazing density. This can be seen in the central western edge of this field which is highlighted in Figure 22. This area was identified as a scald by the property manager is was known to be a sight which the sheep frequent. The impact of this high density grazing on sustainability indicators such as ground cover remains to be explored.

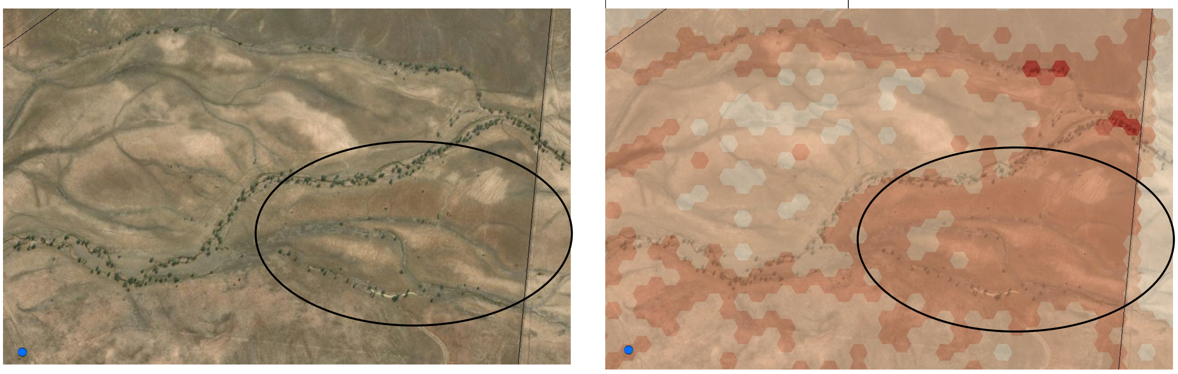
The utilisation of the two paddocks on the far eastern side of the property (actually neighbouring property fields) was only enabled when floods washed away the boundary fences. There are clear spatial preferences for landscape utilisation in these fields, some of which will be due to the flood water themselves providing increased feed growth in the channel areas.



(A) (B)

Figure 21 Base map of Fairfield for reference (A) and Spatial Grazing Distribution Map (B) for Merino Sheep. Point count represents the number of active points reported for each hexagon.

Point Count

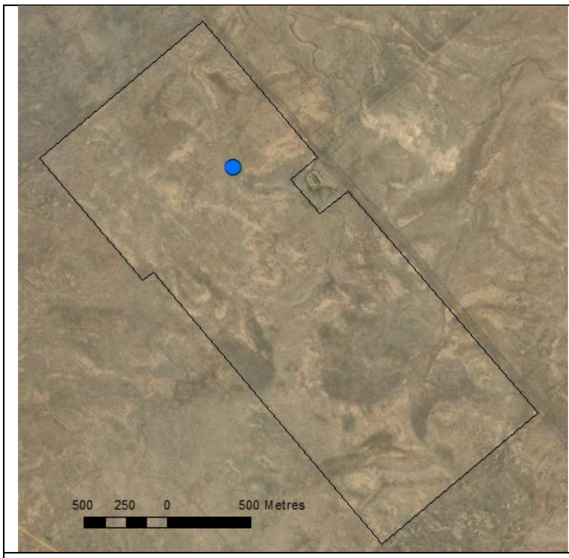


(A) (B)

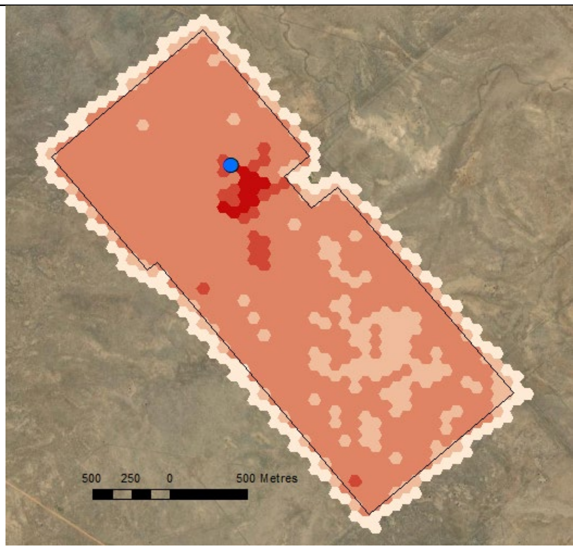
Figure 22 Base map of Fairfield for reference (A) and Spatial Grazing Distribution Map of selected area (B) for Merino Ewes. Point count represents the number of active points reported for each hexagon.

Rosebank – Merino weaners

The spatial grazing map for Rosebank shows utilisation of most of the paddock area with increased activity around the water point (Figure 23). Some of this activity will simply be active states captured as the animals walked directly to water. There is one area of lower utilisation in the southern area of the paddock (Figure 24). The manager has advised that this area is a scald and is only usually grazed after rainfall generates the growth of forbs.



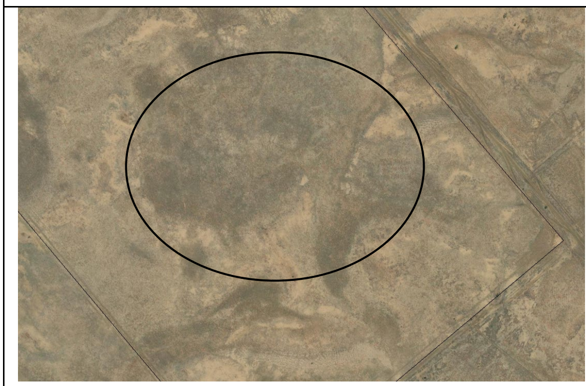
(A)



(B)

Figure 23 Base map of Rosebank for reference (A) and Spatial Grazing Distribution Map (B) for Merino Weaners. Point count represents the number of active points reported for each hexagon.

Point Count



(A)

(B)

Figure 24 Base map of Rosebank for reference (A) and Spatial Grazing Distribution Map of selected area (B) for Merino weaners. Point count represents the number of active points reported for each hexagon.

5.2.4 Distance to water

Camden Park - Dorper sheep & Rangeland goats

The average distance to water for sheep in Camden Park ranged from 0.5 – 0.7 km (Table 25), while the goat average distance to water ranged from 0.4 – 0.8 km (Table 26). The maximum distance to water for sheep on Camden Park was 2.8 – 3.2 km (Table 27), and the goat max distance to water ranged from 2.3 – 4.0 km (Table 28). This data does not show evidence of sheep requiring closer proximity to water than goats, or vice versa (Figure 25 and Figure 26). However, there is a noteworthy trend with the average distance to water for rangeland goats decreasing over the season whilst the sheep values fluctuate (Figure 25). Further research is required to understand this trend.

Table 25 Average distance from water for Dorper sheep on Camden Park across months (metres)

Animal	August	September	October	November	December	January	Average
0059S	767	438	655	827	936	1,022	**774**
1591S	726	482	619	689	782	1,028	**721**
2883S	743	521	632	655	241	445	**540**
4352S	844	571	625	713	355	877	**664**
7075S	705	426	643	566	286	582	**535**
7824S	750	489	703	707	363	879	**648**
7826S	914	512	655	758	766	1,035	**773**
Average	**778**	**491**	**648**	**702**	**533**	**838**	**665**

Table 26 Average distance from water for Rangeland goats on Camden Park across months (metres)

	August	September	October	November	December	Average
1295G	572	588	679	641	320	**560**
2497G	750	541	500	490	421	**540**
2769G	1,112	690	653	963	942	**872**
4964G	769	552	515	424	352	**523**
5091G	823	617	601	471	343	**571**
6036G	728	545	527	446	500	**549**
8186G	1,100	968	664	433	337	**700**
Average	**836**	**643**	**591**	**553**	**459**	**514**

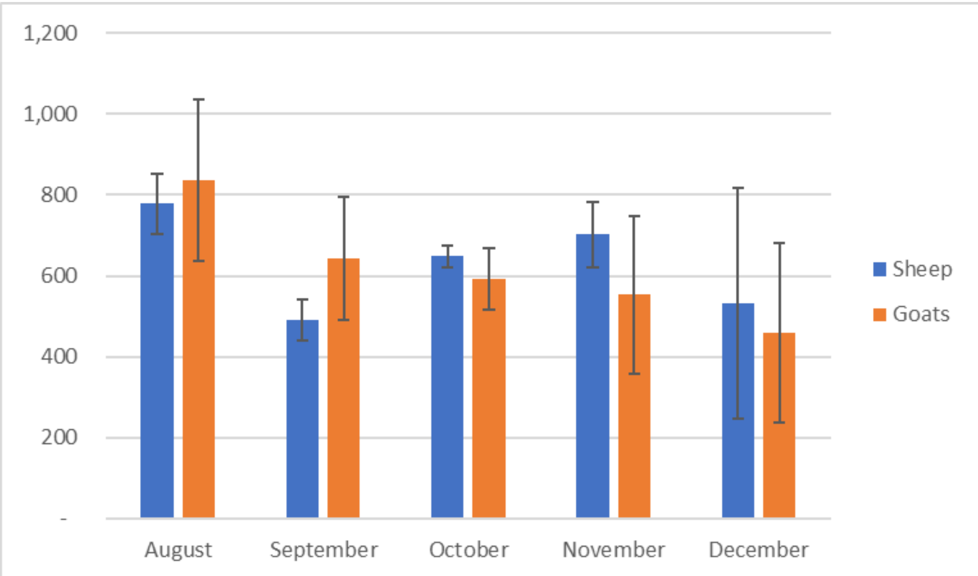


Figure 25 Comparison of Dorper Sheep and Rangeland Goat average distance to water from August to December

Table 27 Maximum distance from water for Dorper Sheep on Camden Park across months (metres)

Animal	August	September	October	November	December	January	Average
0059S	2,755	1,810	2,800	2,504	2,153	3,072	**2,516**

1591S	2,787	1,933	2,810	1,876	2,090	3,083	**2,430**
2883S	2,831	2,160	2,477	1,758	1,118	2,067	**2,069**
4352S	2,126	2,000	2,810	2,479	2,106	3,082	**2,434**
7075S	2,394	1,763	2,789	1,628	1,403	3,216	**2,199**
7824S	2,486	1,930	2,781	2,482	2,082	3,070	**2,472**
7826S	2,738	2,139	2,784	2,486	2,206	3,079	**2,572**
Average	**2,588**	**1,962**	**2,750**	**2,173**	**1,880**	**2,953**	**2,384**

Table 28 Maximum distance from water for Rangeland Goats on Camden Park across months (metres)

Animal	August	September	October	November	December	Average
1295G	1,991	2,008	2,800	2,489	1,953	**2,248**
2497G	1,686	1,609	2,372	1,525	2,624	**1,963**
2769G	2,074	2,004	2,813	2,493	2,166	**2,310**
4964G	1,672	1,619	2,364	1,607	1,669	**1,786**
5091G	1,679	1,693	2,335	1,617	1,925	**1,850**
6036G	1,676	1,633	2,366	1,615	1,664	**1,791**
8186G	2,452	2,078	2,218	1,842	2,368	**2,192**
Average	**1,890**	**1,806**	**2,467**	**1,884**	**2,053**	**2,020**

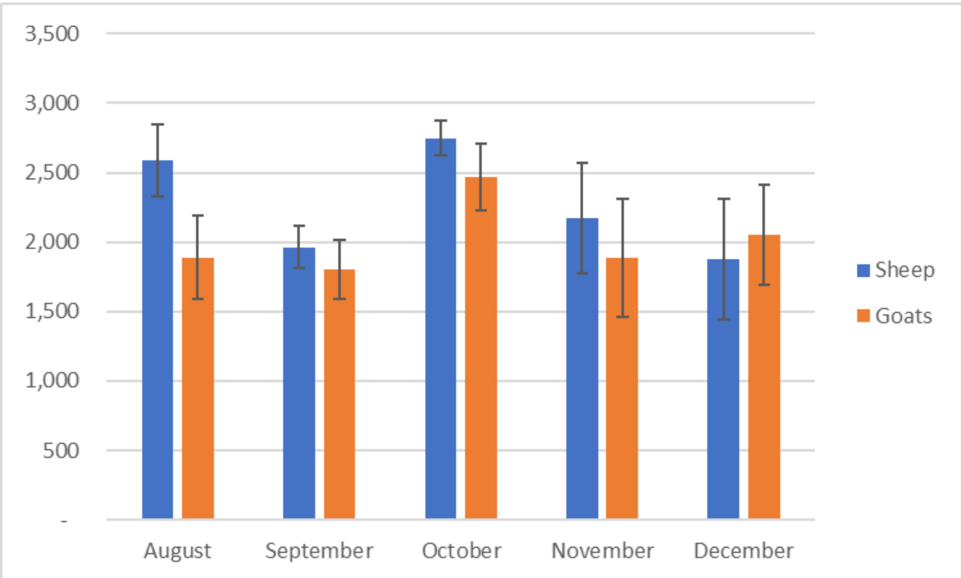


Figure 26 Comparison of Dorper sheep and Rangeland goat maximum distance to water from August to December

Fairfield - Merino sheep

A large storm came through Longreach at the beginning of January that caused floods and filled previously dry streams. Thus, it was hard to definitively determine the location of water sources for distance to water analysis. The floods also created property damage that left several fences easily penetrable. The Fairfield sheep were able to cross these broken fences into the neighbour's property. Even though the GPS collars have data from December 2020 to March 2021, we only assessed distance to water prior to the storm. Distance to water was measured from 16 December 2020 to 4 January 2021 (a much shorter period than for the other properties). The average distance to water for Fairfield sheep was between 0.9 km and 1.8 km with an average of 1.3

km (Table 29). The maximum distance to water ranged from 1.9 km to 2.5 km and an average of 2.3km (Table 30).

Table 29 Average distance from water for Merino ewes on Fairfield across months (metres)

Animal	Dec	Jan	Average
11S	1,159	1,296	1,228
13S	1,317	1,798	1,557
15S	1,084	1,262	1,173
17S	909	1,346	1,127
18S	912	1,021	966
3S	1,067	1,709	1,388
4S	1,056	1,336	1,196
6S	986	1,820	1,403
7S	890	936	913
8S	1,005	1,833	1,419
Average	1,038	1,436	1,237

Table 30 Maximum distance from water for Merino Ewes on Fairfield across months (metres)

Animal	Dec	Jan	Average
11S	2,500	2,405	2,452
13S	2,147	2,164	2,155
15S	2,475	2,390	2,433
17S	2,060	2,293	2,176
18S	1,970	2,409	2,190
3S	2,484	2,411	2,447
4S	2,538	2,373	2,456
6S	2,336	2,406	2,371
7S	2,059	2,375	2,217
8S	2,330	2,436	2,383
Average	2,290	2,366	2,328

Rosebank - Merino sheep (weaners)

The average distance to water for the Rosebank sheep ranged from 0.48 km to 0.82 km with an average of 0.62 km (Table 31). The maximum distance to water was between 2.2 km and 2.4 km with an average of 2.4km (Table 32). There was no difference between average or maximum distance to water across months.

Table 31 Average distance from water for Merino weaners on Rosebank across months (metres)

Animal	Nov	Dec	Jan	Feb	Average
1744	629	571	484	824	**627**
1757	702	661	537	594	**624**
1781	694	673	497	793	**664**
1784	690	596	503	539	**582**

Average	**679**	**625**	**505**	**688**	**624**

Table 32 Maximum distance from water for Merino weaners on Rosebank across months (metres)

Animal	Nov	Dec	Jan	Feb	Average
1744	2,418	2,399	2,391	2,412	**2,405**
1757	2,268	2,428	2,427	2,408	**2,383**
1781	2,316	2,426	2,396	2,430	**2,392**
1784	2,394	2,412	2,435	2,411	**2,413**
Average	**2,349**	**2,416**	**2,412**	**2,415**	**2,398**

A comparison across all properties

The average distance to water for all properties showed some variation with the Fairfield Ewes reporting almost double all other sites (Table 33). Interestingly the maximum distance for all sights was very similar ranging from 2.1km to 2.4km. Although further research is required this would suggest that the maximum distance these small ruminants are prepared to walk from water in this environment does not exceed 2.4km.

Table 33 Average statistics for distance to water for all deployments

Property/animal group	Average distance to water (metres)	Average maximum distance to water (metres)
Camden Park Dorper Sheep	665	2,384
Camden Park Rangeland Goats	514	2,192
Fairfield Merino Ewes	1,237	2,328
Rosebank Merino Weaners	624	2,398

5.2.5 The impact of weather and thermal stress on resource utilisation

One of the key questions of interest that evolved during this project was understanding how animal use key resources under different environmental conditions. Of particular interest was the relationship between water point utilisation and ambient temperature. Increasing incidence of thermal stress events is thought to be an emerging issue for the livestock industry and an understanding of how heat stress might interact with animal behaviour could improve production and animal welfare outcomes. An analysis of the relationship between temperature and distance to water was undertaken for two of the properties (Camden park and Fairfield).

Camden Park Dorper sheep & Rangeland goats.

There was evidence of a significant relationship between average distance to water and maximum temperature for sheep in Camden Park ($p = 0.03$). As maximum temperature increased by 1 degree, distance to water decreased by 6.28 metres. In addition, maximum distance to water of the Camden Park sheep was shown to be significantly related to minimum temperature ($p = 0.02$). A visual assessment of the data shows that sheep are limited in their distance from water under more extreme temperatures (Figure 27 and Figure 28). Higher maximum and minimum temperatures appear to impose limitation on the average distance animals will be found from water although these results need to be treated with some caution as the incidence of very hot days (min temp exceeding 30c) was limited.

There was no evidence of a significant relationship between daily distance travelled and temperature for the sheep in Camden Park. However, Figure 29 shows that as temperature rises the average daily distance travelled decreases, as seen from late November to mid January. During the last week of January 2020, a storm rolled through Longreach, Queensland. The temperature went from 39◦C down to 27◦C and back up again over the course of seven days. The drop in temperature initially caused a spike in average daily distance travelled by the sheep, and then as the temperature dropped further the activity dropped as well (Figure 29). Between the 24th and 28th of January there was 70mm of rainfall, with 29mm of that occurring on the 27th. The drastic drop in average daily distance travelled occurred on the 27th, the day of the lowest maximum temperature in January and of the most rainfall.

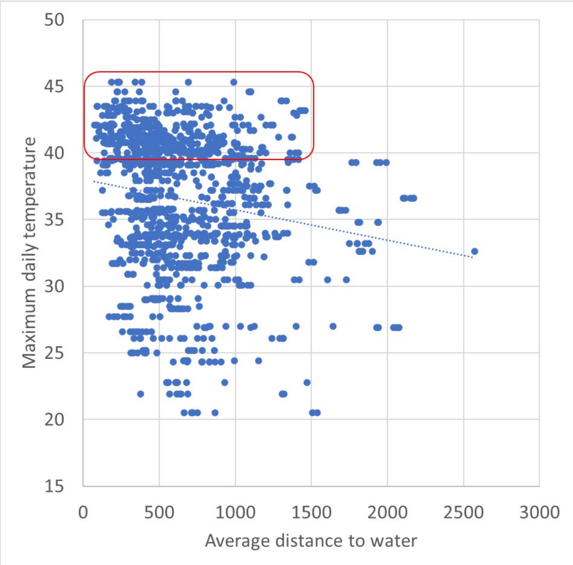


Figure 27 Relationship between average distance to water and maximum daily temperature (each point = 1 sheep day). Note that no sheep averaged more than 1500m from water on days exceeding 40c (highlighted by the red line).

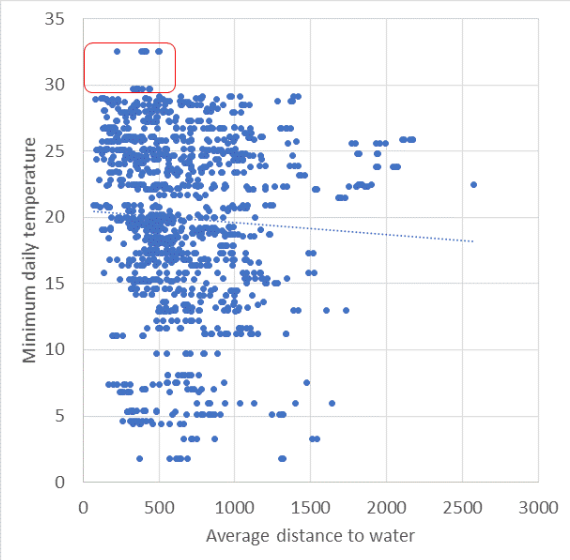


Figure 28 Relationship between average distance to water and minimum daily temperature (each point = 1 sheep day). Note that no sheep averaged more than 500m on days where the minimum temp exceeded 30c (highlighted by the red line)

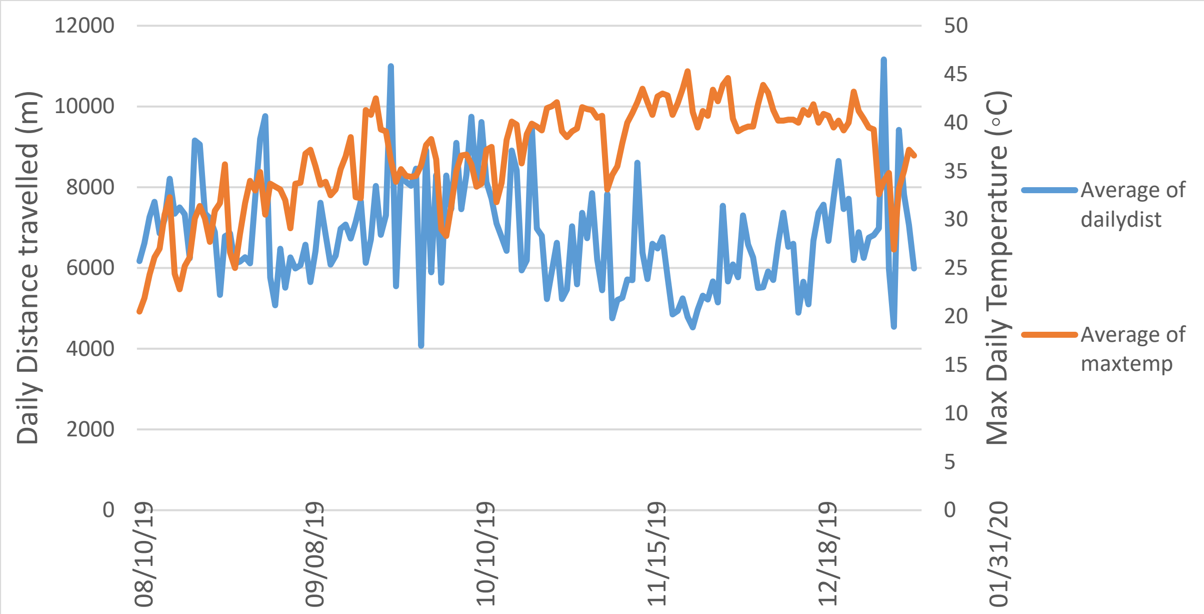


Figure 29 Average daily distance travelled for all Camden Park sheep.

We found a significant positive relationship between minimum temperature and daily distance travelled for goats in Camden Park (p = 0.02). The average distance to water of the goats in Camden Park significantly interacted with temperature, as both maximum and minimum temperature increased, the average distance to water decreased by a measure of 15-20 meters per degree (p = < 0.0001). We saw the same trend with maximum distance to water and maximum temperature (p = < 0.0001). In a similar result as was revealed in the sheep data there does appear to be a cap on the distance goats will be found from water on extremely hot days (Figure 30 & Figure 31).

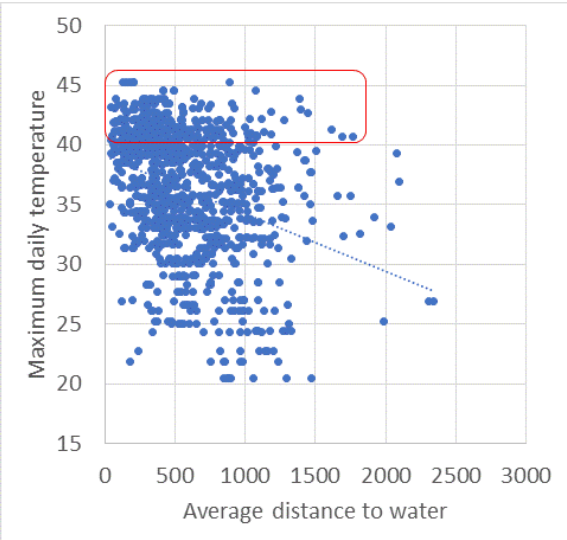


Figure 30 Relationship between average distance to water and maximum daily temperature (each point = 1 goat day). Note that only 3 goats averaged more than 1500m from water on days exceeding 40c (highlighted by the red line).

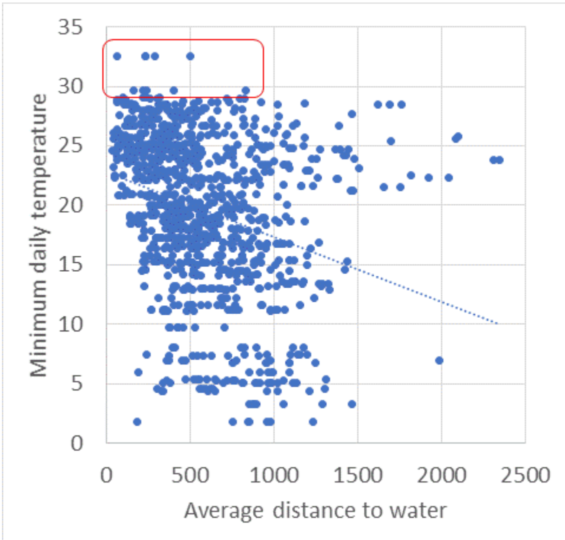


Figure 31 Relationship between average distance to water an minimum daily temperature (each point = 1 goat day). Note that only 1 goat averaged more than 500m from water on days where the minimum temp exceeded 30c (highlighted by the red line)

Fairfield - Merino sheep

Average distance to water was found to be significantly related to maximum temperature for Fairfield sheep (p = 0.012). As maximum temperature increased by 1 degree, the average distance to water decreased by 16.6 meters. We did not find a significant relationship between daily distance travelled and temperature.

6. Summary of project termination

The project has been terminated early due to constraints around undertaking field work using visiting researchers from New Mexico State University (NMSU). Due to COVID related restrictions we have been unable to arrange for the Masters Student (Caroline Wade) and Professor Derek Bailey to travel to Australia and cannot be guaranteed that this can be achieved before completion of the project. The original objective was to have this team (alongside researchers from CQU and Qld Department of Agriculture and Fisheries) undertake a substantial body of field research gathering base line landscape survey data along with implementing interventions to be evaluated in the second year. As the field work cannot be resourced within the current project and as the Masters student program cannot be delayed beyond the 2 year time frame it became necessary to terminate the project. The Masters student will continue to undertake data analysis and complete her research training program at NMSU. Where possible resources from within CQU and NMSU will be directed towards having the student visit the region should travel restrictions ultimately be lifted.

7. Conclusion

Although this project has been cut short it has begun to explore several key issues and provided many interesting outcomes that warrant further investigation.

The review of literature completed within this project highlighted how little research has examined spatial utilisation of extensive landscapes by small ruminants, especially compared to cattle. This lack of published material around interventions to optimise landscape utilisation makes it difficult to provide robust industry relevant guidelines for land managers. Further formal research in many areas is warranted but the synthesis of current industry management practises that influence grazing distribution through producer survey is recommended and could provide valuable insights.

The GPS tracking of sheep and goats within this project has provided key insights into how these animals use the landscape and the limitations that key resources place on this. It is well recognised that grazing animal distribution is impacted by the location of water and this has been confirmed in this study. However, grazing distribution is also impact by a variety of other factors with the preference for certain locations across a paddock obvious amongst the small ruminants in this study. Some of this variation in spatial landscape utilisation can be explained by differences in the feed-base while some variability remains unexplained and warrants further investigation. One of the key drivers of landscape utilisation that we began to explore in this project was the influence of temperature. In this project high temperatures, particularly high minimum temperatures were clearly impacting the distribution of small ruminants. This has important implications for landscape management. As the incidence of thermal stress events increases grazing distribution will likely become more concentrated around water sources.

7.1 Key findings

- The review of literature highlighted how little information is available regarding spatial landscape utilisation by small ruminants compared to cattle. Further research is warranted to catalogue industry knowledge and practices around managing sheep and goats in the rangelands.
- The average daily distance travelled by small ruminants across all sites varied between 5.7km (Camden Park Rangeland Goats) to 8.1 km (Fairfield Merino Ewes). However, there was a large amount of variation between individual animals and across seasons.
- The maximum distance travelled across all sites ranged from 6.5 (Camden Park goats) km to as much as 20.5km (Fairfield ewes). These excessive distances travelled have not been widely reported before and represent a significant energy expenditure by individual animals which might be having a profound impact on productivity.
- Where sheep and goats were monitored in a co-grazing situation (Camden Park) the goats appeared to have a smaller range over which they operated and reported a lower daily distance travelled (~0.5km less than sheep). While the sheep and goats in their entirety used a similar total range individual goats operated in more discrete areas while the sheep ranged more broadly.
- The maximum distance to water reported across all sites was approximately 2.5km. This is consistent with industry knowledge, however animals were on average more likely to be within 500m – 1.2km of water. Industry recommendations in southern Australia suggest that water points should be as close as 500m however there appears to be little knowledge around this topic for rangeland environments.
- Increasing temperatures had a significant impact on the distance animals were found from water. Not surprisingly as temperatures increased animals were found closer to water although the effect was only marginal, for every 1 degree increase in temperature, distance to water decreased by 5-20 metres. This statistic may be hiding a more profound effect of grazing distribution restrictions under extreme thermal stress events which requires further investigation.
- Producers can gain important insights into livestock landscape interactions when provided with objective data from GPS tracking technology. These insights, when provided for the specific country and livestock they manage will likely enable considerable local optimisation of many interventions such as fencing and water point placement.

7.2 Benefits to industry

It is difficult to extrapolate the findings from this study to make general recommendations across the entire industry. The unique features of each property and animal type that was monitored in this project means that the observations may not necessarily be directly transferable to other properties with different landscape characteristics.

Despite this, some interesting insights have been made and can be used by producers to assess their own operation. The fact that few animals grazed beyond 2.5 km from a water source confirms the information currently being provided to the industry. However, given that most animals preferred to be within 500m of a water point suggests that a more intensive distribution of water points should be considered by producers seeking to optimise landscape utilisation. Again, this cannot be made as a general recommendation but will provide producers seeking to develop country with infrastructure some guidance in their thinking.

One of the key benefits to industry is the value of the objective GPS tracking data to producers. For some producers involved it revealed genuinely unknown trends in spatial landscape utilisation. As we sat with producers and worked through the results we were often met with exclamations of surprise that certain areas of a paddock where either used or not used by the sheep and goats. Although it is currently not possible for producers to generate this data outside of a research project, there are many commercial technology developers seeking to provide GPS tracking as a day-to-day management tool. The development and economical provision of this service will undoubtedly have a profound effect on enabling producers to gain deep insights into their livestock landscape interactions and subsequently implement management strategies to improve production and efficiency. The key to this will be the development of affordable systems that can be reliably deployed on small ruminants as most development is focussed on cattle at this stage.

8. Future research and recommendations

This project has highlighted a number of areas of future research that could prove valuable to the industry.

Continued investigation into the spatial landscape utilisation of small ruminants in rangelands is warranted. Although this project has been terminated early, the research in this area will continue to be supported through the Masters student at NMSU and will involve more properties. However, there is a need to gain a broader understanding of how these animals utilise the landscape across a wider diversity of operations in the rangelands as each property has many unique features. The understanding of how animals use water resources and other features (particularly shade and shelter) across more sites will allow more solid recommendations to be developed to assist producers in designing infrastructure development programs.

One of the key outcomes of this project was the tendency for temperature to affect animal spatial landscape behaviour. There were clear relationships between temperature and the distance livestock travelled from water, however, only a limited amount of data to explore genuine thermal stress events was collected. There is an increasing interest within the industry in understanding how heat stress events might impact on productivity and sustainability on rangeland ruminant production systems. Further research into monitoring sheep and goat behaviour under genuine thermal stress events and the evaluation of management interventions that might ameliorate the effects of these climate extremes will be necessary.

Another key area that could see significant benefit to the industry is the development of real-time commercially affordable GPS tracking systems for small ruminants. These systems are being developed but much of the focus is around larger systems appropriate for cattle only. There may be ways in which this technology could be rapidly adapted for use on small ruminants and this warrants investigation. The benefits that these systems might provide to producers in terms of the data they provide also needs to be quantified.

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