Pasture determinants of sheep grazing location in the Central Tablelands

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Contents

Abstract

The ability to obtain and analyse the spatio-temporal characteristics of both animals and pasture has been critical to our comprehension of the variability and drivers of pasture utilisation (Trotter *et al.*, 2010). The initiation, development and success of Global Navigation Satellite Systems (GNSS) has been universal across almost every aspects of agriculture including grazing systems. This study seeks to assess the drivers of sheep location by analysing the spatio-temporal characteristics of sheep behaviour in partnership with pasture species and biomass location and stocking rate, while quantifying these relationships using a model. Grazing trials were conducted between March and June of 2017 at the Orange Agricultural Institute (OAI). Pasture quality assessments as well as the technology and tools for evaluating spatial data were utilised. It was predicted that sheep location will not be predictable by species composition but by pasture biomass above all. The most significant driver of sheep location in this study was found to be that of sown perennial herbage mass. Native perennial pasture was also a reliable indicator for sheep locality. Analysis suggests no significant effect of stocking rate on animal location. The results of this study affect our understanding of paddock utilization. Analysis and interpretation proposes management strategies to combat poor pasture utilisation should be centered on pasture composition and not stocking rate.

1. Introduction

Continuing advancements in Global Navigation Satellite Systems (GNSS) have fostered an increase in front-line uptake and diversification of use. The initiation, development and success of the precision agriculture movement has been universal across almost every aspect of agriculture including grazing systems. Most notably, the devices have been utilised to combat production issues associated with variability across paddocks (Stafford, 2000). Spatial data acquisition and application has, however, seen a recent growth in livestock research and industries due to the miniaturisation, decreased cost, and robustness of units. This has led to greater use in the livestock sector and steadily increased our understanding of drivers of many aspects of animal production. The ability to obtain and analyse the spatio-temporal characteristics of both animals and pasture has been critical to our comprehension of the variability and drivers of pasture utilisation (Trotter *et al.*, 2010). Grazing is a product of the relationship and interaction between animals and the pasture, and the ability to qualify and quantify the location of plant species and biomass and the location of grazing has the potential to further our insight into paddock utilisation gaps in sheep enterprises (Thomas *et al.*, 2008; Taylor *et al.*, 2011; Ingram *et al.*, 2016).

The NSW Central Tablelands is a sub-region of both the Central-West and Lachlan Catchments. Classed as temperate, the sub-region receives between 600-900mm of rainfall per year, across its 450-1000m above sea level, undulating landscape (McCormick, 2014). The region boasts 5 million head of sheep, contributing $350 million dollars to the national economy (ABARES, 2017). Livestock grazing is the single largest land-use in the area, with beef cattle slightly outnumbering the previous dominant industry of sheep grazing for wool (McCormick, 2014) (Figure 1.).

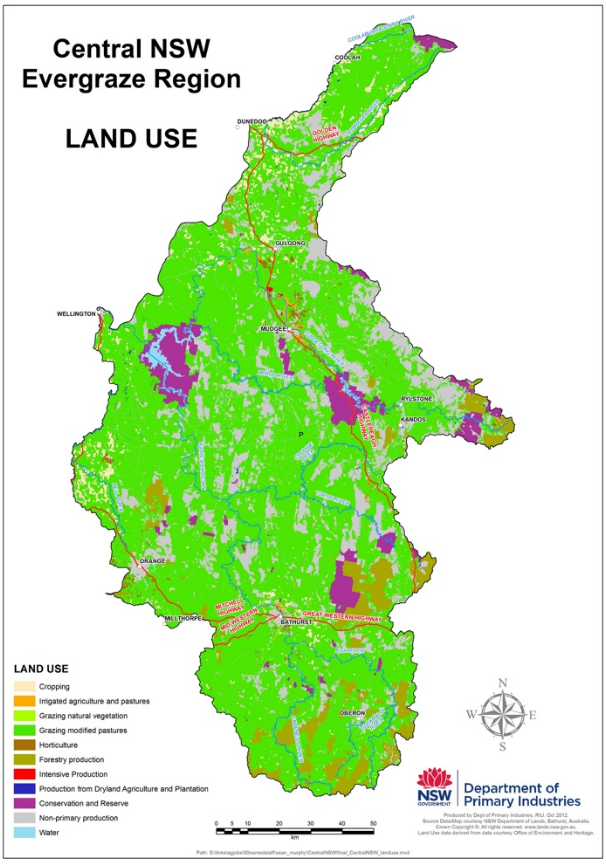

Figure 1: Land-use in the upper portion of the Central Tablelands, NSW (McCormick, 2014).

Having been extensively utilised for grazing, the Central Tablelands has seen some long-term deterioration and over-grazing of sown and native perennial pasture species which have been mostly attributed to declining prices and terms of trade, inducing a considerable reduction in carrying capacity over a 30 year period (Michalk *et al.*, 2003). Early pasture improvement management techniques have shifted the dominant occupation of many native species (Moore, 1970) and enabled the migration of exotic perennial species such as Phalaris (*Phalaris aquatica*), Cocksfoot (*Dactylis glomerata*) and Lucerne (*Medicago sativa*) (Campbell, 1974). Producers in the Central and Southern Tablelands between the period of 1968 and 1996 continually increased grazing pressure and eventually doubled the stocking rate (Holst *et al.*, 2006). In addition, the increasing acidification of soils from fertiliser applications, salinity from rising water tables, and soil compaction from grazing animals has intensified reduction in the occupancy and vigour of highly preferable perennial species and the promotion of larger proportions of undesirable annual grasses (Munnich *et al.*, 1991; SEAC, 1996; Kemp and Dowling, 2000). The availability of feed between late autumn and early winter in these systems is a known feed gap, where the reduced supply of adequate energy and nutrition creates an inherent decline in livestock performance, which without supplementary feeding, results in a decline in enterprise productivity and profitability (Michalk *et al.*, 2003).

For graziers to effectively manage nutrition, an understanding of the determinants of the intake at grazing and the dynamics between animal and vegetation is critical (Baumont *et al.*, 2004). Temperate pasture systems are often species diverse and inherently contain feeds of varying quality, quantity and nutrient concentration and thus sheep are able to actively select desired feeds (Parsons *et al.*, 1994). This selection results in a varied spatial distribution of a flock, including how far they walk and at what speed. The factors driving this selectivity have been hypothesised to be determined by the smell, taste and touch of a plant as a response to its age and greenness, even when feed is limited (Arnold *et al.*, 1980). Another early study has shown that sheep prefer to graze at a faster rate, where rate declines as tiller height increases, until height reaches a level where the pasture becomes a predatory vulnerability risk, and the area is avoided all together (Hodgson, 1982). Grazing is also experiential and thus sheep will base their grazing site based upon their knowledge of the location of preferred pasture and experiences of grazing in that area (Arnold, 1960) and will subsequently drive the decision-making factors of grazing selectivity and pasture utilisation.

Sheep are free-ranging group animals and as such, it is important to consider the social and environmental factors influencing behaviour. Social attachments and social organisation play key roles in how sheep utilise their environment (Dumont and Boissy, 2000) where preferences in feed and social interactions are usually the key factors determining the diet and site selections in a majority of domestic grazing herbivores (Bailey *et al.*, 1996). Sheep are flock animals, and will prefer to stay in larger groups when grazing even if this means ingesting plant species that are not preferable, based on the 'many eyes' hypothesis, where sheep feel less threatened and more comfortable when in numbers (Pulliam, 1973). Sheep will not break into smaller groups to access more preferred pasture species unless the flock size permits smaller but significant groups following (Dumont and Boissy. 2000). Flock dispersion would require sheep that are 'bold' and thus willing to separate from the larger flock in search for higher quality pasture (Michelena *et al.*, 2009). Within grassland systems it is suggested that sheep are willing to split into sub-groups as low as five animals in size but, critically this is dependent on forage availability (Squires, 1976). There is an inherent production impact of social bonds that exist within flocks. If sheep are constantly grazing with the larger mob, two issues may arise: Firstly, sheep may be ignoring higher quality feed in the paddock due to fear of group separation and predation, which can significantly reduce their grazing efficiency. Secondly, sheep may be overgrazing certain areas of the paddock, reducing its productivity over a long period of time in comparison to a situation where pasture is grazed evenly across a paddock.

Spatial foraging patterns can also be influenced by the location of resources such as shelter and water. In the Monaro of NSW, some of the most significant predictors of sheep location were distances from resources such as shade and water, more so than available biomass (Ingram *et al.*, 2016). In addition, external factors such as temperature increases, can prompt sheep to reduce their travelling distance from water, and decrease the overall flock spread (Thomas *et al.*, 2008). Similarly, a high sheep chill index (HSCI) was found to influence the utilisation of paddocks, where increases in precipitation, wind speed and decreased temperatures illustrated a closely confined distribution of a mob underneath trees, long grass and shelter (Taylor *et al.*, 2011). Inherently, there is a potential for producers to increase pasture utilisation and animal production by strategically planning the location of watering points and shelter within a paddock.

Studies relating to the behaviour and interactions of sheep with their environment can provide insights into the drivers of sheep location, including inferences as to drivers of forage selectivity. This study seeks to assess the drivers of sheep location by assessing the spatio-temporal characteristics of sheep behaviour in partnership with pasture species and biomass location and quantify this relationship using a model. Using predefined functional groups, a novel pasture assessments methodology as well as the technology and tools for evaluating spatial data, it is predicted that sheep location will not be predictable by species composition, but more so, by pasture biomass in general. This is based on evidence produced in a similar study, which found NDVI as the best predictor of sheep location (Edwards, 2014). With reference to production systems, a greater understanding of sheep grazing preferences may provide information relating to pasture management strategies. It is hoped this paper will also provide evidence of the viability of spatial technologies for use on farm, and prove they are valuable tools in tracking and managing livestock, atop of providing insights into pasture quality and quantity available for grazing.

2. Materials and Methods

2.1 Site description

Grazing trials were conducted between March and June of 2017 at the Orange Agricultural Institute (OAI) located near the New South Wales Central Tablelands town of Orange. The Bloomfield grazing site (694531E / 6310839N) is owned and operated by the NSW Department of Primary Industries (DPI). The area has been extensively used for grazing, pasture and soil trials, where commercial animals and management strategies have been incorporated. Climate and rainfall data records have been routinely measured and are available through the Bureau of Meteorology (BOM site 063294). The data collection site is situated approximately 0.5km from the grazing site. Average annual rainfall is 990mm. At 922m elevation, low ambient temperatures are characteristic of the tablelands (Figure 2), where high wind and sub-zero temperatures can be experienced, particularly between April and September. In 2017, temperatures were generally coherent to trend, however a slightly drier summer was ended by a late March to early April break, caused by a substantial rainfall event (Figure 2).

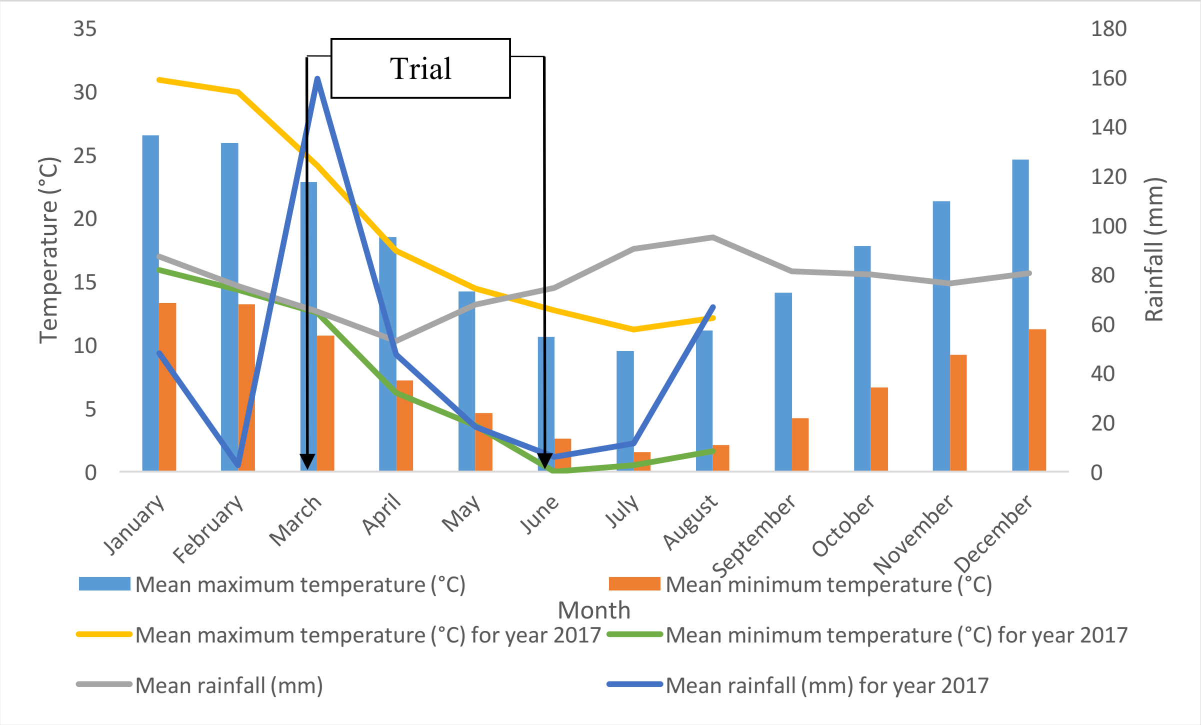

Figure 2: Long term climate and 2017 weather data for OAI (Bureau of Meteorology, 2017).

Ferrosols dominate the surrounding country of the Bloomfield site, where profiles often consist of neutral to acidic red earths with usually hard-setting loamy top soils and clayey subsoils, however, dependent on topography, alluvial and podzolic based soils can also be found (Garden *et al.*, 2001). Ferrosols are typically formed on basalts or other basic igneous rock and can be considered a highly productive soil when managed for chemical fertility, due to their developed structure and typically high organic matter content. Subsequently, they are often utilised for horticulture and improved pasture production (Sparrow *et al.*, 1999).

2.2 Paddocks

Three replicate paddocks for each stocking treatment, High and Low (see following paragraph) for a total of six paddocks (approx. 0.6ha in size) were used in this study. Aligned in an east-west direction, the sites sat on a gentle slope above a creek. Replicate paddocks of each treatment were partnered beside each other. All paddocks were managed under an improved pasture system. Each of the six paddocks had a similar plant diversity and quantity of feed on offer at the onset. Phalaris (*Phalaris aquatica* L.), Tall Fescue (*Festuca arundinacea* Shreb.) and Cocksfoot *(Dactylis glomerata* L.) dominated the pasture system, with some obvious clover strikes between May and June. Superphosphate is applied to the paddocks every three years and clover seed was broadcast in 2016. Each of the paddocks contained a continual feed water trough, shaded area and designated hand feeding trough. In replicate one, paddock two (HSR), a small walk-over-weigh (WoW) area (~5m^2) was present. In the third replicate, paddocks contained some small trees inside the paddock and shading from a large tree on the outside perimeter. Both of these paddocks also contained a small rock outcrop. Resources including WoW, watering, feeding and shading areas were logged using a GPS unit (Garmin etrex 30, Garmin Ltd, Kansas, USA) and the most significant were mapped (Figure 3).

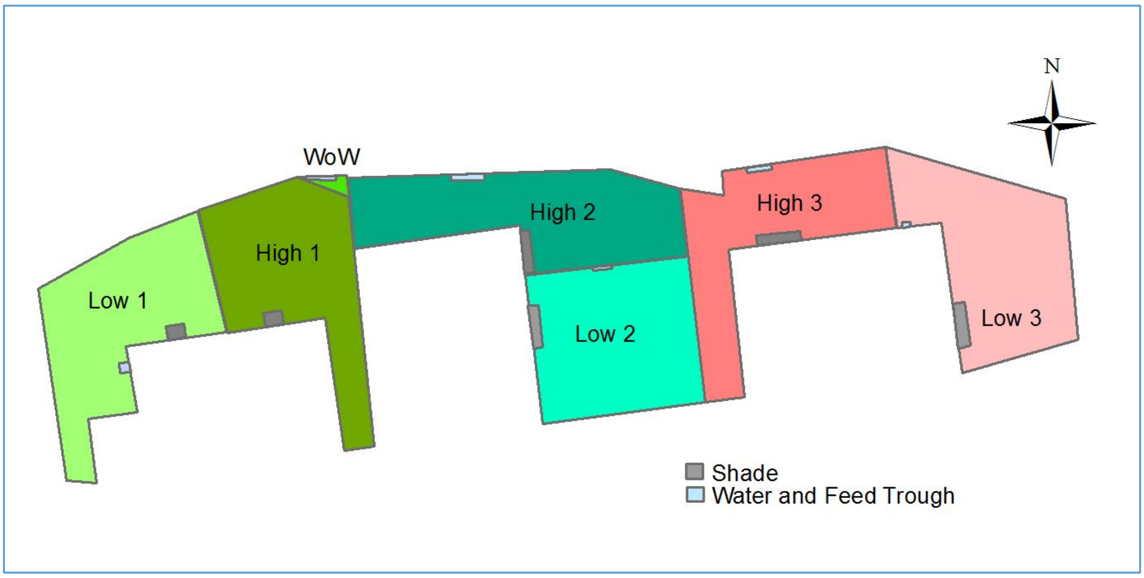

Figure 3: Map of paddocks and features with allocated treatment and replication number.

2.3 Livestock and grazing

For this grazing trial, 25 four year old Merino wethers were sourced from a DPI flock. The trial and use of animals was approved by The University of Sydney Ethics Committee (2016/1098) as well as the Department of Primary Industries Ethics Committee (ORA 11/14/014). For the high stocking rate treatment, 15 wethers were randomly selected and then five animals were randomly allocated to each replicate paddock. Similarly the low stocking rate used nine animals, with three sheep being randomly allocated to each of the three replicate paddocks in this treatment. Initial wether weights ranged from 56kg to 76kg, averaging 67kg and a body condition score (BCS) of 3. Based on weight and maintenance requirements animals were estimated to have a dry sheep equivalent (DSE) requirement of 2.6. Subsequently stocking rates for low and high treatments were 8 and 13 DSE, respectively. Both low and high treatments were continuously grazed for the entirety of the grazing trial. Animals had been shorn in the previous December, checked routinely, weighed, drenched, crutched and wigged in June. The trial accounted for commercial animal management practices and thus, sheep were fed between 250g and 750g oats/head as supplementary feed on 13 separate days in March as pasture growth was not sufficient to maintain their body weight.

2.4 GPS collar configuration and fitting

Store-on board animal tracking collars, UNETracker II (Trotter *et al.*, 2010) were utilised for this trial. Collars were randomly deployed onto two randomly selected sheep (out of three sheep/paddock) in each low stocking rate treatment, and three sheep (out of five sheep/paddock) in the high stocking rate treatments. The overall weight of the collars (0.3kg) is less than 1% of the sheep weights and are thus unlikely to have an effect on the bite rate, circadian rhythm and live weight after the first 16 hours (Hulbert *et al.*, 1998) and a previous study (Fogarty *et al.*, 2015) showed no significant variation in accuracy between collars. Fixing accuracy is expected to be within 4.14m, where 99.9% and 97.3% of entries fall within 20m and 10m, respectively (Trotter *et al.*, 2009; Trotter *et al.*, 2010). Collars were configured to take one fix every 15 minutes between 7 March and 22 June.

2.5 Pasture measurements

Pasture composition and sampling was performed at three intervals, prior, during and conclusion of trial. The BOTANAL method (Jones and Hargreaves, 1979) was used and utilises a calibrated visual assessment for quantity and quality of pasture. The method involved pasture composition surveys across 90 fixed sites, with 15 in each treatment (Figure 4). At each point, green and dead pasture was surveyed and ranked in two quadrats, based on estimated percentage species composition, from primary (~70%), secondary (~21%) and tertiary (~9%) as well as green or dead dry matter (DM) tonnes per hectare. Each quadrat was also estimated for litter (t/ha) and ground cover (%). Pasture cuts were performed on each of the 90 sites for calibration, allowing a prediction of tonnes per hectare for individual species to be calculated. The measurement of pasture composition and quantity relies on the experience of the collector, due to the preciseness of species taxonomy and DM estimations. Studies comparing the traditional methods of estimating plant biomass, the BOTANAL method was identified as the most appropriate for heterogeneous pasture systems (Redjadj, 2012). Pasture growth rates are consistently variable and a late autumn flush may have escaped examination. The location of pasture surveys and calibration cuts was logged using a handheld GPS device (Garmin etrex 30, Garmin Ltd, Kansas, USA). Pasture species were assigned into one of six functional groups; native perennials, sown perennials, other perennials, annual grasses, legumes and weeds. Interpolated weekly tonnage of each plant functional group at each fixed point was calculated based on prior, initial and final BOTANAL dry weight measurements using a linear model of growth or decline. Weekly predictions were krigged using VESPER (Whelan *et al.*, 2001) in order to extrapolate functional groups biomass across each paddock. Some variability in fitness of variogram modelling was observed during this process. Krigged data was finally processed in ArcGIS (v. 10.1 ESRI, CA, USA) to produce a point map of each plant functional group location and biomass, fitted to an assigned 5x5m grid cell. Final mapping of functional groups was assessed on accuracy with visual observations.

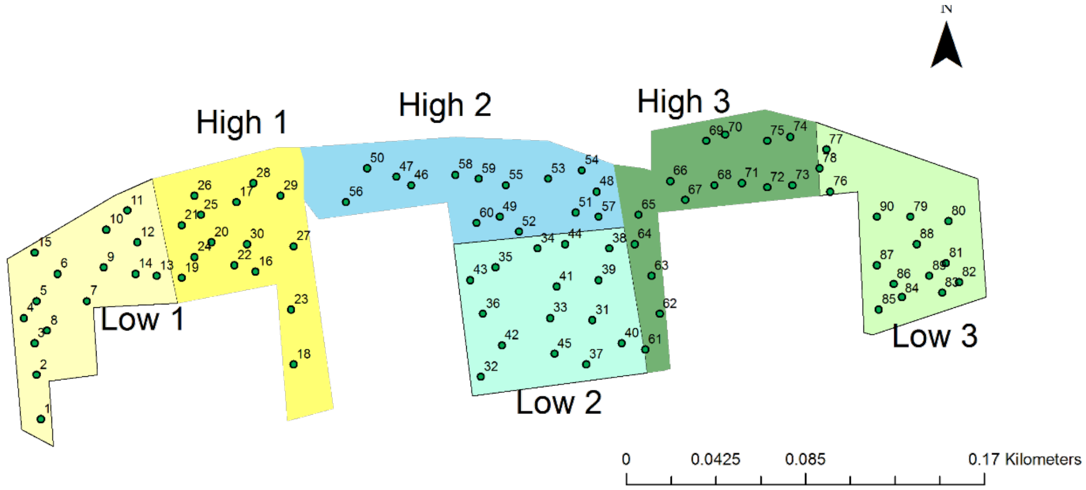

Figure 4. BOTANAL survey and sampling sites across all treatments.

2.6 GPS data

All collars were removed from animals at the conclusion of the trial. GPS data from each animal collar was downloaded to an MS Excel spreadsheet. Coordinate points for each fix were converted from degrees, minutes, seconds (DMS) to Universal Transverse Mercator (UTM). Coordinate fixes prior to 2/04/17 were adjusted to account for daylight savings. Any fix that acquired less than three satellites was removed. Horizontal dilution of precision (HDOP) limit was determined to be five, where all points greater than five were removed. Assuming a straight line of migration, the distance travelled and animal speed was determined as:

Distance between two fixes/Time between the two fixes

The analysis used for attaining distances travelled presumes that within the time frame of each fix, an animal travelled in a straight line. Speed data was based upon this distance calculation and thus some underestimation, of distance travelled and speed, is probable. Individual animal data was stacked with its respective treatment and replicate and imported to ArcGIS (v. 10.1 ESRI, CA, USA). Animal fixes that lay outside the assigned paddock boundary were clipped and layered over the trial map. Similar to the pasture mapping, a 5x5m grid was placed over the paddock and livestock residency index (LRI) was calculated (number of fixes falling within each cell).

2.7 Statistical analysis

Each 5x5m grid cell was assigned its appropriate stocking rate, dependent on where the cell fell across the paddocks. For each cell and for each week, a yield value for each functional group was assigned based on previous krigging. Each cell also contained a value for the amount of times a sheep collar fixed within that cell for that week.

Random Forest modelling has become a highly utilised tool in remote sensing and spatial mapping studies, as a method of predicting and accounting for the impact of a range of variables in relation to another (Wiesmeier *et al.*, 2011; Allen *et al.*, 2013). The model used incorporated functional group biomass: native perennial, sown perennial, other perennial, annual grass, legume, and weeds, as well as total dry matter, stocking rate, trial week and paddock. By randomly taking 100 arbitrary GPS samples and running them against two-thirds of the predictors at random, and repeating 500 times, the model will produce an average predictability (Breiman, 2001) of each variable as a determinant of the GPS location. As such the model determines the extent that plant functional group, environmental or social factor is best to predict where a sheep will be located in a paddock and thus, what is most likely driving the sheep location. The increase in mean square error (MSE) provides an estimate of the relative importance of each variable used in the model in decreasing importance of prediction (i.e., the higher the % MSE, the more important a variable is in predicting the LRI of each cell). The out-of-bag estimate of the variance of the overall model is also determined (analogous to r^2 in linear regression model). Analyses were determined using "RandomForest" in R (R Development Core Team, 2014).

Botanal data for the three sampling periods (January, February and May) was analysed using a linear mixed model. Repeated measures analysis was undertaken with a linear mixed effects model using 'lme' in the package, 'nlme' (Pinheiro *et al.*, 2009) in R (R Development Core Team, 2014). Stocking rate (High or Low) and Time (January, February and May) were the fixed factors and sampling points as a random factor. To account for repeated sampling, a continuous AR1 correlation structure was used if analyses for temporal correlation indicated that it was warranted. A p-value of 0.05 was used for all analyses.

3. Results

3.1 Livestock Residency Index

Livestock recorded fixes (per 5m²) were mapped for the length of the trial (Figure 5). All grid cells recorded at least one fix with exception of eight, all of which were located in the north-west corner of replicate 2, LSR. The highest areas of fixes appeared around adjoining fence lines, where sheep appeared to congregate (Figure 5). No correlation between high-fix areas and resource location appear. The number of fixes in a single grid reached a maximum of 1170. All paddocks, particularly replicate 2 LSR, appeared to have areas of avoidance, despite higher biomass (see below).

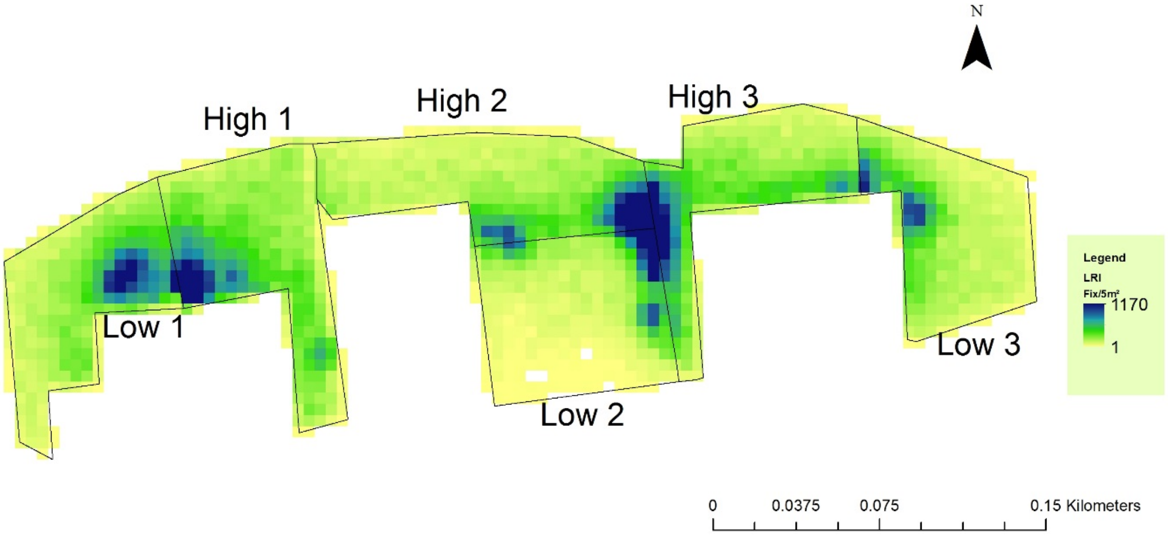

Figure 5. Map of Livestock Residency Index (LRI) indicating areas of high concentrations of fixes (blue) to areas of low/no fixes (yellow/white).

3.2 Indices of activity

3.2.1 Distance travelled

There were significant differences (*P=<0.001*; refer to Appendix 8.1.1) in the average distance per hour that sheep travelled between the high stocking rate (13 DSE/Ha) and the low stocking rate (8 DSE/Ha). Animals in the higher stocking rate travelled consistently further in the paddocks throughout the day and sheep distances generally increased as the day progressed in both stocking rates (Figure 6). On average, sheep in low stocking rate treatments were travelling 1,930m/day, while sheep in high stocking rate were travelling 1,973m/day, with high stocking rate sheep travelling 1.8m/hour more than low stocking rate.

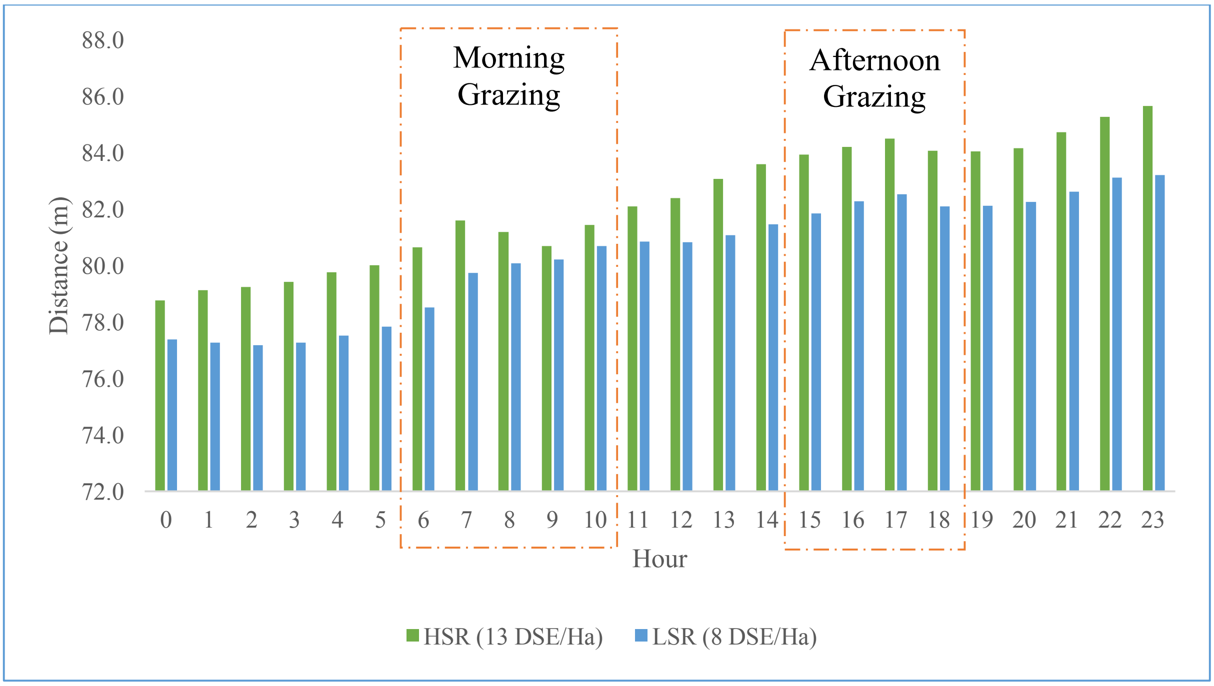

Figure 6. Distance travelled for sheep in high and low stocking rate treatments. Based on highest rate of increase in distance, morning and afternoon peak grazing periods were determined and are indicated in dotted rectangles.

3.2.2 Speed of movement

The average speed of movement for sheep between high and low treatments was significantly different (*P=<0.001*) (refer to Appendix 8.1.2) and increased steadily throughout the day (Figure 7). Similar to distance travelled, animals in the higher stocking rates travelled, on average, at faster speeds per hour, than that of the high stocking rate (Figure 7).

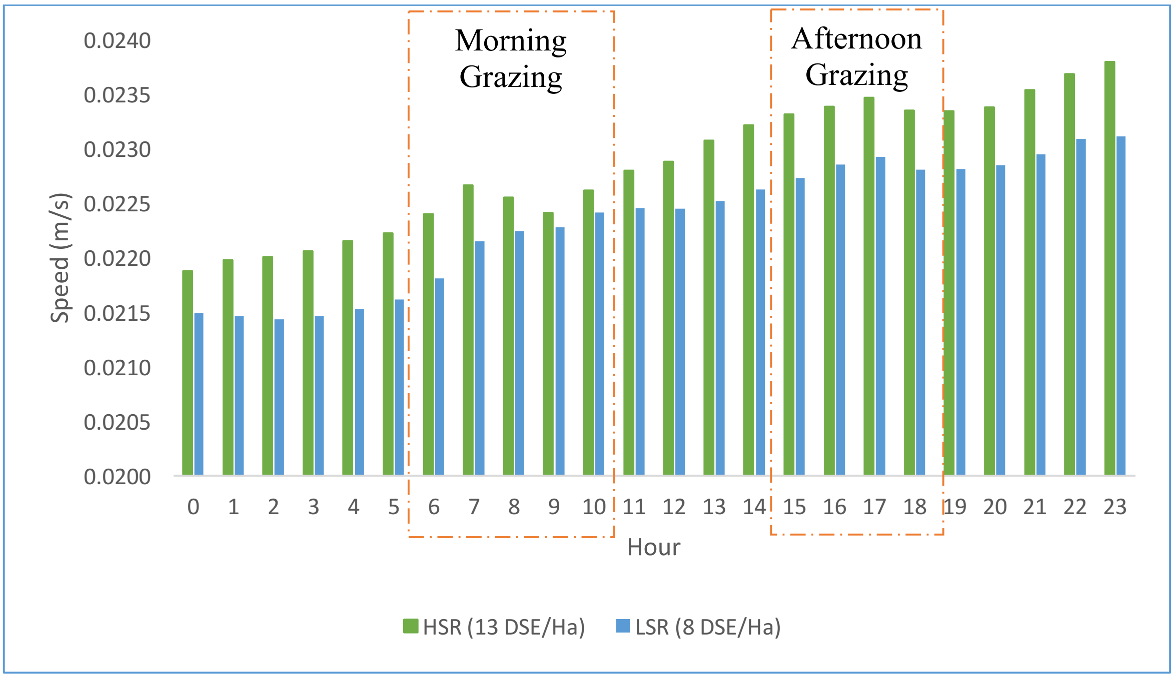

Figure 7. Speed of movement for sheep in high and low stocking rate treatments. Based on highest rate of increase in speed, morning and afternoon peak grazing periods were determined and are indicated in dotted rectangles.

3.3 Random Forest Modelling

Overall the out-of-bag (variability explained) estimate of the random forest model was 61.3% and the concordance correlation coefficient was 0.74 (Figure 8). Random Forest modelling analysis found sown perennial pasture quantity to be the highest accuracy predictor of sheep location with a mean square error (MSE) of 44.22% followed by native perennial at 41.32% (Figure 9). Annual grasses, weeds, other perennials, legumes and total DM were of similar importance in the model. Paddock, stocking rate and week were indicated to not be great predictors of sheep location, with the lowest level of impact on location.

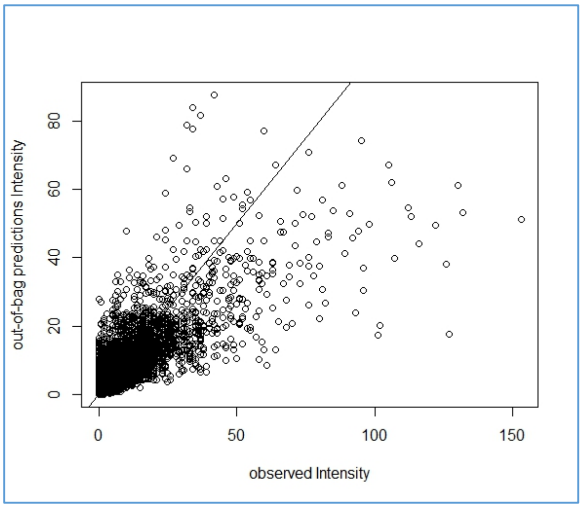

Figure 8. Running unbiased estimate of the classification error as samples are added to the model

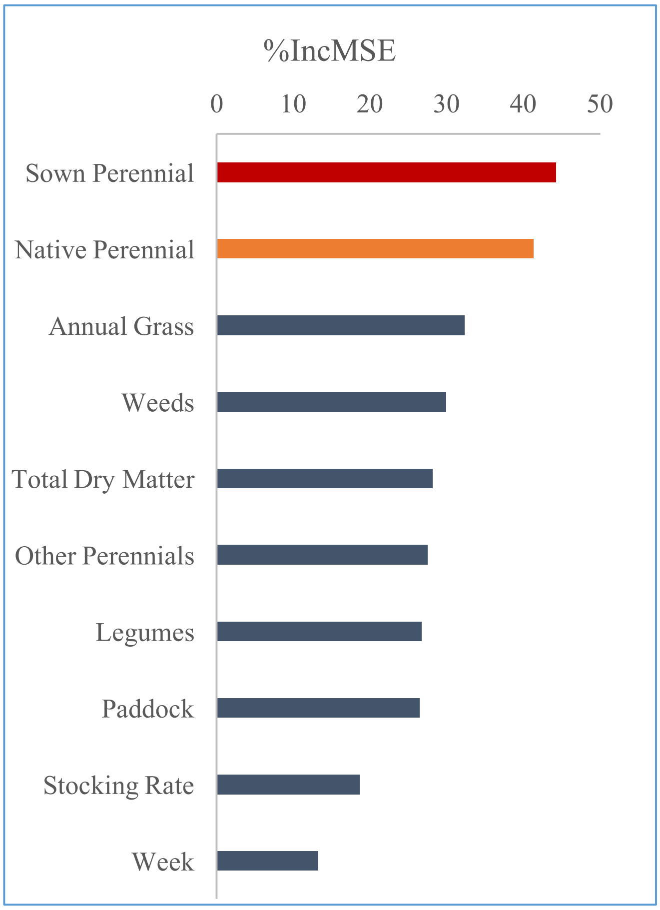

Figure 9. Random Forest model for both high and low stocking rates.

3.4 Pasture Drivers

3.4.1 Sown perennial

Pasture yield maps and Livestock Residency Index (LRI) data illustrate congregation and residency of sheep over areas of higher sown perennial biomass (Figure 10). Average yields range from 0.2 to 2.9tonnes/Ha. No significance was found between functional group and paddocks (*P= 0.32*) (refer to Appendix 8.2). Residency is based on total count of fixes within each 5x5m grid cell, while biomass is based on average yield of sown perennials across all weeks of the trial.

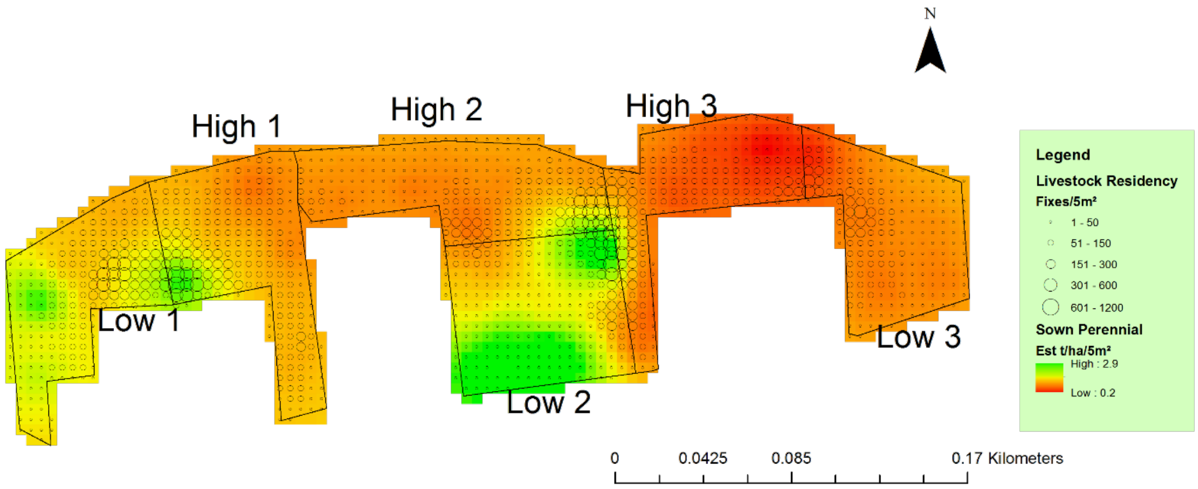

Figure 10. Livestock residency index map, illustrating location of GPS fix points and average yield of sown perennial species, per 5m^2 grid cell.

3.4.2 Native perennial

Pasture yield maps and GPS count was mapped based on the secondary predictor of location, native perennial (Figure 9). Mapping illustrates the livestock residency of animals over areas of higher native perennial species biomass (Figure 11). Average yields were far less for native perennial, ranging from 0.001 to 0.005t/Ha. No significance was found between native perennial and paddock (*P=0.979*) (refer to Appendix 8.2).

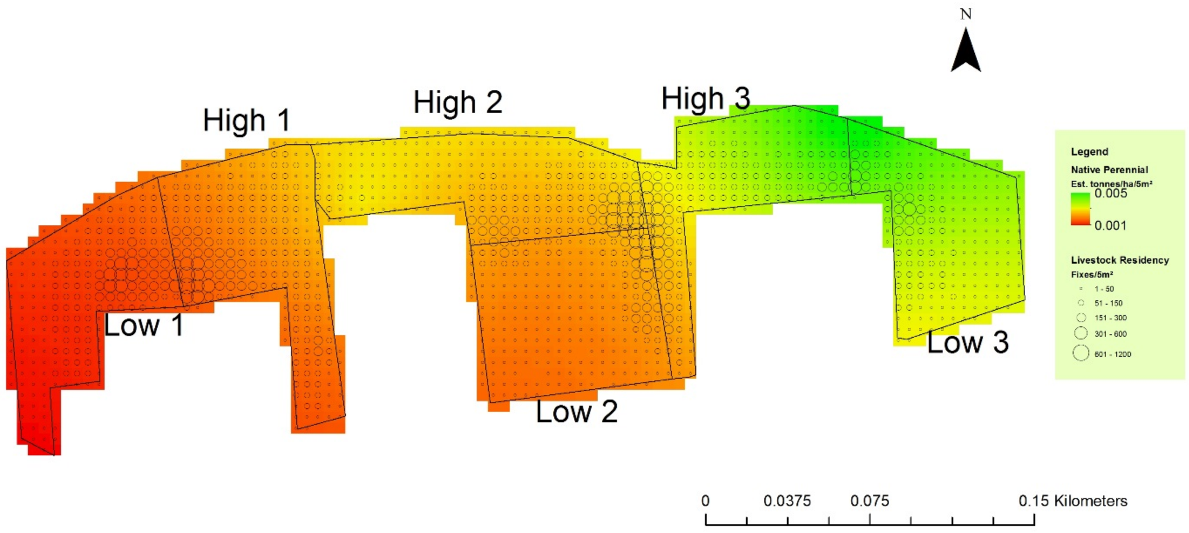

Figure 11. Livestock Residency Index map, illustrating location of GPS fix points and average yield of native perennial species, per 5m^2 grid cell.

3.5 Liveweight

While there was no significant weight change in animals between the start (March) and the conclusion of the trial (June) (*$P=0.06$)* (refer to Appendix 8.3) or within stocking rates (Low: *$P = 0.337$*, High: *$P = 0.092$)* (refer to Appendix 8.3), animals increased in weight from an average of 67.1kg, to 70.5kg.

4. Discussion

4.1 Distances travelled and speed

Average distances travelled and speeds were greater in the higher stocking rate of 13 DSE/Ha, consistently throughout the day. Speed is a product of distance and time, and therefore their correlation is expected. Greater distances and speeds for the high stocking rate could be explained by an animal's desire to consume feeds of differing palatability and digestibility. Due to the process of 'gut-fill' a sheep has only a limited amount of forage intake before it must ruminate. As this is a limiting factor in the process of grazing, its selection of appropriate dry-matter is critical in ensuring adequate nutrition and energy intake. Particularly in heterogeneous pasture systems, plants vary in quality based on species, age, season and location amongst many other factors (Lambert and Litherland, 2000). Therefore increases in speed and distance can be attributed to an animal's drive to find and graze desired herbage. Increased speed and distance in animals in the high stocking rate suggest that one of two things may be occurring. The first scenario is that sheep under the high treatment will inherently have less feed-on-offer due to a higher number of animals, a greater amount of total energy required and thus an increased removal of herbage mass daily from the paddock. Limited forage will require animals to travel longer distances and at greater speeds to locate and ingest plant material (Garcia *et al.*, 2003). The other possibility is that ruminants in lower stocking rates are more inclined to spend more time grazing one area, than constantly travel for available feed (Garcia *et al.*, 2003, 2005). While grazing periods can be inferred from the speeds and distance results (Figure 5, 6), a diurnal grazing pattern is not as obviously evident as illustrated in previous studies (Edwards, 2014). Increased activity (i.e. speed and distance) of a ruminant is usually indicative of the highest energy expenditure activity - grazing. This generally occurs just prior to daybreak and is followed by a period of rumination, before returning to grazing in the afternoon before sunset (Ferreira *et al.*, 2013). Diurnal grazing patterns are however, subject to the environment, animal husbandry and grazing management, where increases in forage, temperature and shortening of day length can cause a merge in grazing events across the day (Gregorini, 2012). As distinct grazing events are not as readily apparent in this trial, it may be that cooler temperatures, and shortening days may have 'flattened out' the two distinct grazing periods that are commonly observed in livestock over the course of the day (Gregorini, 2012) as stressors associated with heat and available daylight hours are not limiting on grazing behaviour. It has been shown that sheep in rectangle paddocks in comparison with square paddocks will spend twice as much time walking and exploring than the latter (Sevi *et al.*, 2001) and as such, it is reasonable to assume that natural sheep behaviour, even in these low numbers, may have been affected, simply by the varying formations of the paddocks.

4.2 Modelling drivers of sheep location

The most significant driver of sheep location in this study was that of sown perennial pasture herbage mass. Native perennial pasture was also suggested to be a reliable indicator for sheep locality. Inherently, the model suggests that a greater sown and native perennial biomass results in a higher likelihood of an animal being present in a given area of the paddock. The modelling also suggests that when all variables are accounted, animal location could be predicted to an accuracy of 74%. The model is able to predict location, ergo the probability that the relationship between where the animal is, the pasture functional group and the act of grazing can be inferred. The best explanation of sheep location being predictable based on the presence and mass of a pasture functional group is the idea of grazing selectivity.

The considerable variation in the species composition, quality and nutrient status of temperate grasslands fosters a grazing animal's selectivity for feed (Edwards *et al.*, 1994). If selectivity is playing a role in the results of this study, this would indicate that sheep under these trial conditions are preferentially grazing the sown perennial and native perennial grasses, above legumes, annual grasses, other perennial grasses and weeds. This is a justified response and must be based on the animal's experience of smell, touch, taste, nutritive value and fill effect of grazing on plants of those functional groups (Baumont *et al.*, 2004). One of the factors contributing to the sensory attraction of forage species to sheep is the greenness and digestibility of the plant. In a study assessing the agronomic potential of native perennial species, Fescue, Phalaris and Danthonia species recorded the highest organic matter digestibility (OMD), particularly for autumn and early winter months, where it exceeded legumes (Garden *et al.*, 2005). Fescue and Phalaris preference would most likely be attributed to active C3 autumn growth, while Danthonia may have had higher selection potential earlier in the trial (early autumn) towards the end of its C4 summer growth.

There was no significant effect of stocking rate on location. Pasture utilisation is determined by a number of factors, notably animal selectivity, and animal dispersion across the paddock. While animals in the higher stocking rate did travel significantly longer distances and at greater speeds, their location around their paddocks was equally as variable as the low stocking rate. Previous studies suggest that higher stocking rate systems would encourage greater paddock utilisation, where animals would more evenly spread themselves across the entirety of the paddock in comparison with a low stocking rate (Ash and Smith, 1996). Differing results may be explained by two possibilities. One, trial paddocks are of small enough size that mobs are forced to spread grazing evenly, despite stocking rate. The second, and more plausible explanation, is supported by the Random Forest model. Paddock utilisation is affected less by higher concentrations of animals, and more so about the spread and location of plant species.

4.3 Animal selectivity

While selectivity in this study cannot be explicitly identified, conjecture based on location of animal and pasture functional group is a reasonable indication of grazing preferences. The native perennial composition of the pastures was far less than that of sown and was comprised of Danthonia (*Austrodanthonia spp.*), Lovegrass (*Eragrostis brownie*) and Native Summer Grass (*Digitaria spp.*).

4.3.1 Cocksfoot, Phalaris and Fescue

Sown perennial pastures were primarily composed of the C3 grasses (in order of yield) Cocksfoot (*Dactylis glomerata*), Phalaris (*Phalaris aquatic*) and Tall Fescue (*Festuca arundinacea*). During this trial, cooling autumn temperatures and a large rain event would have instigated increased vegetative growth rates of temperate perennial grasses, where digestibility and palatability would have been highest, in comparison to annual grasses and legumes which would have senesced or lignified over the summer period. Cocksfoot, Fescue and Phalaris pastures can reach 67%, 76% and 78% digestibility in this time, respectively (Archer and Robinson, 1988). The proposed selectivity for the sown perennials is consistent with studies observing the grazing behaviour of sheep in relation to different grass lines, where animal preference for temperate-introduced grasses was substantial in comparison to natives and C4 species (Garden *et al.*, 2005). Studies into species preference are varied. One study over a five day period of May in Flaxley, South Australia, examined the consumption of 25 different introduced and native grass species, where 96% of all Cocksfoot was consumed, the highest portion above all others (Garden *et al.*, 2005). As a significant factor of selection is centered on sensory signals (i.e. smell, taste and touch), which in particular for temperate perennial species can fluctuate dramatically with changes in dry-matter content, an animal may preference differently, depending on time of year and growth stage (Scott and Provenza, 1998).

4.3.2 Wallaby Grass, Lovegrass and Native Summer Grass

Much like the sown perennial species, sheep preference for native perennials, such as Wallaby Grass, Lovegrass and Native Summer Grass is based on Random Forest modelling and can suggest these species are driving location. Particularly when feed was limited in the early autumn, it is plausible to assume that native perennials were higher quantity and reasonably palatable foliage, when annuals and introduced perennials were inadequate. Lack of sufficient rain events prior to April would support the persistence of green growth during drier conditions in comparison to other pasture species, particularly for summer dominant Wallaby Grass, Lovegrass and Native Summer Grass (Breakwell, 1923; Archer and Robinson, 1988). While these C4 species will often provide adequate grazing material during hotter and drier conditions, and can tolerate reasonable heavy grazing, these species inherently lack adequate growth and reproductive vigour in winter conditions (Garden *et al.*, 2005) and henceforth, a similar criticism to grazing preferences for sown perennials can be made, when seasonality is a plausible effector.

5. Conclusion

Perennial pastures, both sown and perennial, are significant drivers for sheep location, regardless of stocking rate. Clearly sheep location is determined by many factors, however there can be little argument that the presence of a given plant species will play a major role (either negatively or positively) in determining where an animal spends time in a paddock. Using Random Forest modelling the herbage mass of sown and native perennial plants are identified as the best predictors of animal location and infer a degree of forage selectivity. Sown and native perennials are at their higher digestibility and palatability during the autumn months in comparison with other perennials, legumes and annual grasses, therefore, it is highly likely that the above statement is true. High digestibility and robustness of sown and native perennial pastures, respectively, not only provide the nutrition required for maintenance and growth year-round, but evidently please the sensory systems of sheep, and will preference over many other plant functional groups. More direct effects of the results presented, suggest that pasture systems should see a greater shift away from predominantly winter annuals, particularly in a variable climate. No other studies have looked at location differences or drivers in relation to stocking rate. This study provides evidence that the drivers of location are not affected by stocking rate.

This study also supports some changes to management strategies, as a means of achieving some of the potential rewards of perennial grass species. As highlighted earlier, heavy stocking rates, soil acidification and rising salinity have seen not only declines in perennial abundance and quantity, but a loss of production capacity as a result. By assisting in the reversal of these land changes, increased productivity is possible by the re-colonisation of perennial species, as would be predicted based on historical data. Future studies should be undertaken to confirm selection, and extended across all seasons. This would further support the results, or provide alternate factors driving location and selection.

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8. Appendix

8.1 Indices of Activity

8.1.1 Distance

Two-sample t-test

Variates: Distance_13_DSE_Ha, Distance_8_DSE_Ha.

Test for equality of sample variances

Test statistic F = 1.37 on 23 and 23 d.f.

Probability (under null hypothesis of equal variances) = 0.45

Summary

```
                                                         Standard   Standard error
Sample               Size      Mean      Variance       deviation          of mean
Distance_13_DSE_Ha     24     94.84         2.730           1.652           0.3372
Distance_8_DSE_Ha      24     96.72         3.743           1.935           0.3949

Difference of means:               -1.877
Standard error of difference:       0.519
```

95% confidence interval for difference in means: (-2.922, -0.8314)

Test of null hypothesis that mean of Distance_13_DSE_Ha is equal to mean of Distance_8_DSE_Ha

Test statistic t = -3.61 on 46 d.f.

Probability < 0.001

8.1.2 Speed

Two-sample t-test

Variates: Speed_13_DSE_Ha, Speed_8_DSE_Ha.

Test for equality of sample variances

Test statistic F = 1.37 on 23 and 23 d.f.

Probability (under null hypothesis of equal variances) = 0.45

Summary

```
                                                                   Standard       Standard error
Sample                  Size          Mean        Variance        deviation              of mean
Speed_13_DSE_Ha           24       0.02634    0.0000002106        0.0004589            0.0000937
Speed_8_DSE_Ha            24       0.02687    0.0000002888        0.0005374            0.0001097

Difference of means:               -0.000521
Standard error of difference:       0.000144

95% confidence interval for difference in means: (-0.0008117, -0.0002309)
```

Test of null hypothesis that mean of Speed_13_DSE_Ha is equal to mean of Speed_8_DSE_Ha

Test statistic t = -3.61 on 46 d.f.

Probability < 0.001

8.2 BOTANAL

P-values for BOTANAL functional groups

	Sown PG	Native PG	Other PG	Legume	Weed	Green DM	Dead DM
Trtmt	0.3200	0.9788	0.5448	0.6596	0.9372	0.2261	0.2852
Month	<0.0001	0.1802	0.0006	<0.0001	0.0096	<0.0001	<0.0001
Trt x Month	0.1234	0.6687	0.2357	0.4774	0.9579	0.4774	0.1152

8.3 Liveweight

Test of null hypothesis that mean of March_Weight is equal to mean of June_Weight

Test statistic t = -1.93 on 46 d.f.

Probability = 0.060

```
  22  DESCRIBE [SELECTION=nobs,nmv,mean,median,min,max,q1,q3] June_Weight,March_Weight
```

Summary statistics for June_Weight

```
      Number of observations =   24
    Number of missing values =   0
                        Mean =   70.52
                      Median =   70.5
```

Minimum = 57.5
Maximum = 83
Lower quartile = 66.25
Upper quartile = 74

Summary statistics for March_Weight

Number of observations = 24
Number of missing values = 0
Mean = 67.10
Median = 67.25
Minimum = 56.5
Maximum = 76.5
Lower quartile = 62.5
Upper quartile = 71

By Stocking Rate

Two-sample t-test

Variates: March_Weight, June_Weight.

Test for equality of sample variances

Test statistic F = 1.25 on 14 and 14 d.f.

Probability (under null hypothesis of equal variances) = 0.68

Summary

Sample	Size	Mean	Variance	Standard deviation	Standard error of mean
March_Weight	15	67.43	31.89	5.647	1.458
June_Weight	15	69.57	39.78	6.307	1.629

Difference of means: -2.133
Standard error of difference: 2.186

95% confidence interval for difference in means: (-6.611, 2.344)

Test of null hypothesis that mean of March_Weight is equal to mean of June_Weight

Test statistic t = -0.98 on 28 d.f.

Probability = 0.337

Two-sample t-test

Variates: March_Weight, June_Weight.

Test for equality of sample variances

Test statistic F = 1.35 on 8 and 8 d.f.

Probability (under null hypothesis of equal variances) = 0.68

Summary

```
                                                     Standard    Standard error
Sample           Size      Mean      Variance       deviation           of mean
March_Weight        9     66.56         36.78           6.064             2.021
June_Weight         9     72.11         49.67           7.048             2.349

Difference of means:                -5.556
Standard error of difference:        3.099
```

95% confidence interval for difference in means: (-12.13, 1.015)

Test of null hypothesis that mean of March_Weight is equal to mean of June_Weight

Test statistic t = -1.79 on 16 d.f.

Probability = 0.092