Determining ‘wether’ social behaviour or pasture quality drives sheep grazing patterns using random forest modelling

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Abstract

Monitoring livestock providesvaluable insights into the spatial distribution, foraging patterns, and animal behaviour, which may lead to the improved management of livestock. This objective of study was to understand what variables were significant in determining where sheep spent the most time in paddocks of native (dominated by *Poa* spp., *Stipa* spp., and *Hordeum leporinum*), and improved (*Phalaris aquatica, Festuca* spp., and *Trifolium subterraneum*) pastures (~24 ha^{-1} in size). Castrated male sheep, wethers, were tracked using GPS collars on a property located in the Monaro region of Southern New South Wales, Australia. Trials were performed over four six-day periods in April, July, and November of 2014, and March in 2015. Thirty collars were randomly placed on 15 sheep in each pasture types. The GPS collars continuously recorded movements over the duration of each trial and were programmed to take five positional fixes over a minute. Data was analysed all together to understand various trends that may have occurred across the year, using random forest models (RFMs). Models were created for improved (IP) and native (NP) paddocks, producing R^2 values of 0.97 and 0.94. Regardless of the pasture type, near distance to water (NW) was important in predicting where animals were located within paddocks, despite its statistical insignificance. Sheep spent more time further away from water troughs (at least ~600 m). Additionally, NDVI was another important variable in predicting sheep location for IP and NP ($p < 0.01$). The data suggests that RFMs are able to predict where animals will likely spend time on a paddock at a large scale, with water troughs and pasture quality being two key drivers.

Introduction

Monitoring and tracking of livestock have been used in agriculture to provide valuable insight on spatial distribution, foraging patterns, and behaviours of animals, to better improve the management of sheep worldwide (Putfarken et al., 2008; Trotter et al., 2009; Anderson et al., 2012). Monitoring technologies that use the Global Navigation Satellite System (GNSS) allow the collection of uninterrupted data on animals over extensive systems, regardless of environmental conditions (Bowman et al., 2000). As these technologies are becoming more integrated into the farming managment, it reduces the need for labour intensive observational data, and allows insights on behaviours. Behavioural studies help improve the management of sheep, particularly with understanding what influences grazing distribution and what influences various behavioural attributes. Spatial distribution of a flock can be governed by many factors. For example, sheep may choose to graze an area of non-preferred species to stay close together (Dumont and Boissy, 2000; Sibbald and Hooper, 2004), and may only leave the main flock of sheep when herd sizes are larger (forming subgroups of up to five or six sheep (Squires, 1976), or if they are followed by several other animals (Michelena et al., 2009; Dumont and Boissy, 2000). The individual behaviours of sheep can also influence pasture use, as previous studies have identified ‘bold’ and ‘shy’ sheep, whereby the latter is more likely to consume poor quality forage and revisit areas already grazed (Michelena et al., 2009).

Sheep are known to selectively graze areas in paddocks, showing preference for certain plant species, and will revisit the same area repeatedly until feed is restricted or limited (Squires, 1976; Rutter, 2006; Putfarken et al., 2008). Sheep are also likely to begin grazing activity within the hour before daybreak, and in the late afternoon, a documented ruminant behaviour referred to as diurnal grazing (Lynch, 1974; Squires, 1976; Ferreira et al., 2013). The preferences of sheep for particular forages is well-documented with legumes preferred in the morning as hunger will motivate sheep to graze, despite grasses available having their lowest nutritional value in the morning (Rutter, 2006; Gregorini, 2012). Sheep will also graze grasses in the evening during a longer grazing window, filling the rumen to sustain the animals overnight (Rutter, 2006; Burritt et al., 2005; Gregorini, 2012). The objective of the study was to understand what variables were best for predicting where sheep spent time in paddocks of native and introduced pastures, at a large scale, using GPS data. It is assumed that animals will seek out areas of higher NDVI across both pasture types (introduced versus native). Pasture quality should also play a larger role in drivers of grazing behaviour than social/mob behaviours.

Methods

This research was performed on a Merino wool based enterprise, 'Coolringdon', in the Monaro region of southern New South Wales, Australia. Research was conducted over four six-day periods in April July, and November of 2014, and March of 2015. The Monaro region is characterised by low ambient temperatures, high wind chill, and severe frosts which are common from April to September. Two paddocks were chosen that were within close (~100 m) proximity of each other but were comprised of different pasture species. The "Native" paddock (NP) (21.3 ha^{-1}) was comprised of the low quality native species; *Poa* spp. and *Stipa* spp., along with barley grass (*Hordeum leporinum*). The "Improved" Paddock (IP) (26.6 ha^{-1}) was comprised of improved pasture, primarily phalaris (Phalaris aquatica), fescue (*Festuca* spp.), and subterannean-clover (*Trifolium subterraneum*). Unlike the NP which had trees distributed across the northern end of the paddock, IP had relatively sparse shade coverage. Both paddocks had a water trough available (south-western corner NP, north-western corner IP), and were sampled for their normalised difference vegetation index (NDVI) using a vehicle mounted CropCircle ACS-470 system (Holland Scientific, Lincoln, NE USA) 1-2 days prior to the initiation of each trial, on approximately 40 m transects across the paddocks. Data were stored on a logger before being processed using VESPER (Whelan et al., 2001) to produce an interpolated 5 x 5 m gridded NDVI map, for use in ArcGIS (v. 10.5 ESRI, CA, USA). Fifty 3-year-old wethers (castrated male sheep) were used (approved by the University of Sydney Ethics Committee, 2014/570) and randomly allocated into each paddock in flocks of 25. In the mob of 25 sheep present in each paddock, 15 sheep were randomly allocated a gps collar (UNETracker II; Trotter et al., 2010) to record their location in the paddock during each trial, with the remaining 10 sheep being used as buffers. GPS collars were programmed to sleep for four minutes and then take five positional fixes over a minute at 0, 15, 30, 45, and 60 seconds before returning back to sleep mode for 4 minutes, etc., and any fix that took longer than 16 seconds to log was removed.

Data processing undertaken in ArcGIS included calculating the near distance to various features such as trees (NT), water troughs (NW), and fence lines (NF), extracting elevation (E) and aspect (AS), data for each animal (A), and extracting the normalised difference vegetation index (NDVI) values, as a measure of pasture quality (Ryan et al., 2012). Data were then joined to a weather dataset which included features such as temperature (T), and rainfall (R) that was recorded from the closest Bureau of Meteorology automated weather station (Cooma Airport, 2014/15), and was used with other data to calculate sheep wind chill (SCI). Sheep location was based on a livestock residency index (LRI), a count of the number of times an animals spent in a given pixel per hour, calculated for each individual animal, normalised by the total observations made over the course of trial. The LRI was calculated for each treatment (n = 15 collared animals; 'treatment replicate LRI') and thus was used as the target variable for all RFM created. Random forest models (RFM) were used in this study to explain sheep location, as it has been a useful tool for remote sensing and spatial mapping studies in agricultural research (Wiesmeier et al., 2011), and details of how RFM processes data and produces outputs have been outlined in previous studies (Oliveira et al., 2012; Naghibi and Pourghasemi, 2015; Akter et al., 2021). To take into account spatial autocorrelation in successive GPS data, eastings (EA) and northings (NO), were also included in the models to attempt to reduce the potential for biased random forest models produced. These models internally separate data for validation and training to form an out of bag subset (OOB), analogous to a cross validation, which aids in prevent overfitting by use of bootstrap sampling. Mean squared error (MSE) and the OOB R^2 values were used to evaluate the prediction error of the RFM, and its overall fit.

Results and Discussion

Models were run for both IP and NP individually, where IP produced the highest R^2 value of 0.97 (0.00000238 MSE), whilst NP had the lowest at 0.94 R^2 (0.00000324 MSE). For all models, A was not a significant variable ($p > 0.01$), suggesting that in this herd size, individual animal behaviour was not important in predicting location and so too, social behaviours were not likely to be driving where wethers spent time in the paddocks. The most significant factors for predicting LRI, as determined by their importance value were also ranked for each treatment, were consistent for both treatments with EA, NO and NW taking the three top positions. Unsurprisingly, EA and NO were ranked in the top three variables, likely due to temporal correlation between points (Perotto-Baldivieso et al., 2022) and were both significant ($p < 0.01$) for the IP, but not for the NP, as NO was not significant. Additionally, despite its statistical insignificance ($p > 0.01$) for each of the paddocks, NW is an important predictor whereby data produced suggested that animals were often at least 600 m away from watering points, and had the highest residency at 800 m away from the water trough. Aside from potential correlation between sheep and water location, importance of NW could be due to there only being one water trough for the whole paddock in the southwest (NP) and north-western (IP) corners in each treatment. As such, the high importance of NW could be due to the positioning within the landscape, as they were long and thin paddocks, and simply put, high residency occurred when wethers were on the complete opposite end of the paddock. It has been stated in literature that position of water can have an impact on paddock utilisation, grazing, and distribution, suggesting that with efficient placement of water troughs, pastures can be used more thoroughly (Squires, 1976; Murthy et al., 2005; Putfarken et al., 2008). These results are also consistent with literature that suggests that on large pastures, livestock will head to water less often and spend more time away from them (Hart et al., 1993).

The succeeding variables of importance to the top three include T, NDVI, and E for the IP, and T, SCI, and NDVI for the NP. Weather based variables, T and SCI, were significant and important for both paddocks, likely due to the range of weather events that occurred during the study period. As highlighted in previous studies, poor weather such as high winds and rain (Donnelly, 1984) can influence heat loss from animals and will therefore influence where they may be located, depending on the presence and utilisation of these shelters (i.e., trees, shrubs, structures). Although not significant the importance of E in the IP is likely due to the instinctive nature of sheep to camp and graze on higher grounds, as predicted LRI was highest when elevation was at 970 m above sea level (asl) for the IP and which was a known camp location. Animal movement is also influenced by factors such as topography (elevation and aspect), and the need to have good visibility (Kie et al., 2005; Dickson and Beier, 2007; Patterson et al., 2009; Humphries et al., 2010). Landscape position is known to have the greatest influence on pasture availability, and ground cover production zones (Badgery, 2017). As there was a positive correlation between NDVI and elevation in both the IP and NP, it can be suggested that areas in paddocks at a higher elevation, had moderate to high NDVI values and so too, residency by animals. Additionally, NDVI was highly variable in the IP in contrast to the NP, as NP had more consistent 'green' pasture throughout the duration of the study, and IP varied greatly across the different seasons. This was highly apparent during March, where the paddock had much lower NDVI values (~0.19) in contrast to the NP which had significantly more areas of greener pasture (between ~0.22 to ~0.28). This effect may have influenced the higher importance level of NDVI in IP models, in contrast to NP where NDVI was only significant in the model, but not one of the topmost important variables. Though evidently animals in NP were often in high NDVI areas during grazing, the supposition that NDVI values would be sought out more in the NP than the IP was false, based on both the significance and level of importance of NDVI in IP, compared to NP.

Conclusions and/or Implications

Regardless of the pasture type, near distance to water (NW) was an important variable in predicting where animals were located within each paddock, likely due to collinearity within the data. However, variables such as NDVI, T, SCI, and E, were valuable in predicting where animals were located in both paddocks. Data suggests that RFMs are able to predict where animals are located within a paddock on a large scale, with NDVI being a key driver in each paddock. Weather variables (T, SCI) also impact location within the paddock due to both shelter location and utilisation. Results such as these provide insights on behaviour based distribution of livestock on pastures, and the ability to use predictive models to replicate animal behaviours. Overall, this gives the ability to constantly improve and shape the sustainable management of sheep.

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