Classifying livestock grazing behavior with the use of a low cost GPS and accelerometer

Jameson Brennan, Kenneth Olson, Patricia Johnson, Janna Block, and Chris Schauer

Objective

The ability to remotely track livestock through the use of GPS technology has tremendous potential to study livestock use patterns on the landscape. The use of high frequency accelerometers may give researchers and managers the ability to accurately partition GPS points into differing behaviors, giving further insight into livestock grazing selection, pasture use, and changes in forage preference through time. The objectives of this study were to 1) develop a classification algorithm to discriminate between graze and non-graze behaviors using a combination of metrics derived from a high frequency accelerometer motion sensor and a GPS data logger and 2) assess the accuracy of the classification algorithm using model error rates and expectant livestock behavior patterns.

Study Description

A study was conducted in 2016-2018 at the Cottonwood field station in South Dakota, to test the effectiveness of predicting livestock behavior through the use of a low cost homemade GPS collar outfitted with a high frequency 3-axis accelerometer to determine head position. GPS devices were set to record a fix at 1 minute intervals. Accelerometers were programmed to record X, Y, and Z position at 12 Hz (12 records per second). The accelerometer data was aggregated to 1 second intervals initially, and mean, minimum, maximum, and standard deviation of X, Y, and Z axis were calculated between the start and stop time of each GPS fix. Further data was extracted from the GPS device to include rate of travel and stationary point identification to aid in classification. Direct visual observations were recorded each summer to classify data into grazing or non-grazing behaviors. A yearly random forest models and a global (all data) model was fit to the data, and out of bag error rates used to assess misclassification rates, and predict behavior of unobserved data.

Take home points

Overall misclassification rate was low (11.2%), and similar error rates were observed over years and within the test datasets, suggesting stability in the models. A secondary model validation approach was used by calculating daily grazing time and diurnal grazing patterns. Time spent grazing ranged from 8.67-10.49 hours daily, and timing of grazing tended to be heaviest during morning and evening hours, both of which are expected from yearling steers grazing native pasture in the summer. Results indicate that model predictions are aligned with expected livestock grazing behavior adding further validity to the method. These results show great

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Abstract
The ability to remotely track livestock through the use of GPS technology has tremendous potential to study livestock use patterns on the landscape. The use of high frequency accelerometers may give researchers and managers the ability to accurately partition GPS points into differing behaviors, giving further insight into livestock grazing selection, pasture use, and changes in forage preference through time. A study was conducted in 2016-2018 at the Cottonwood Research Facility in South West South Dakota, to test the effectiveness of predicting livestock behavior through the use of a low cost homemade GPS collar outfitted with a high frequency 3-axis accelerometer to determine head position. GPS devices were set to record a fix at 1 minute intervals. Accelerometers were programmed to record X, Y, and Z position at 12 Hz (12 records per second). The accelerometer data was aggregated to 1 second intervals initially, and mean, minimum, maximum, and standard deviation of X, Y, and Z axis were calculated between the start and stop time of each GPS fix. Further data was extracted from the GPS device to include rate of travel and stationary point identification to aid in classification. Direct visual observations were recorded each summer to classify data into graze and non-graze behaviors. A random forest model was fitted to the data, and out of bag error rates used to assess misclassification rates, and predict behavior of unobserved data. Overall misclassification rate was low (11.2%). Time spent grazing ranged from 8.67-10.49 hours daily, and timing of grazing tended to be heaviest during morning and evening hours, both of which are expected from yearling steers grazing native pasture in the summer. These results show great promise in accurately identifying livestock grazing locations, which could benefit for researchers and land managers monitoring rangeland use.

Introduction
The use of GPS tracking to monitor free ranging livestock movement and use patterns has been well established (Anderson et al. 2012). For example, previous research has demonstrated the use to GPS technology to study: strategies to improve livestock distribution through placement of low moisture blocks and salt (Bailey et al. 2008), the relation of forage nitrogen content to livestock distribution (Zengeya et al. 2013), and the influence of cattle genetics on animal distribution in terms of distance to water and elevation (Bailey et al. 2010). While most of the past research utilizing GPS tracking of cattle has looked to describe questions of livestock distribution, fewer studies have aimed to describe factors that drive livestock grazing behavior. This has been in part due to lack of technology to discriminate between graze and non-graze behaviors accurately.

Quantifying cattle grazing behavior and locations of free ranging animals can be difficult, as animals often graze rugged remote rangelands for extended periods of time. Furthermore, the relatively high cost of commercially available livestock tracking devices is often cost prohibitive for both researchers and producers alike, and may lack the temporal precision necessary to accurately predict behavior. Previous research has demonstrated the utility of adapting low-cost GPS data loggers for tracking cattle (Knight et al. 2018, McGranahan et al. 2018). In addition, accelerometer technology has garnered considerable interest in monitoring animals' behavior for the purpose of detecting estrus, early diagnosing of animal sickness, and monitoring daily activity patterns (Richeson et al. 2018). Though previous research combining GPS and accelerometer data has demonstrated the ability of these technologies to accurately predict livestock behavior, study lengths are often limited to a few days, and have yet to be tested on season long livestock grazing (Gonzalez et al. 2015, Mansbridge et al. 2018).

The use of high frequency accelerometers has great potential to discriminate between livestock behaviors, and when combined with GPS technology can improve our understanding of foraging patterns of free ranging animals. The objective of this study was to develop a low cost (~$230) GPS and accelerometer livestock collar to monitor and predict season long livestock grazing behavior. Goals of this research are to 1) develop a classification algorithm to discriminate between graze and non-graze behaviors using a combination of metrics derived from a high frequency accelerometer motion sensor and a GPS data logger and 2) assess the accuracy of the classification algorithm using model error rates and expectant livestock behavior patterns.

Experimental Procedures

Study Site. Research for this study occurred at the Cottonwood Field Station, which is located in the Northern Great Plains mixed-grass prairie. Topography of the station is gently sloping with long, rolling hills and relatively flat topped ridges. Climate of the station is characterized as continental and semiarid with hot summers and cold winters.

GPS Collar. Data collection occurred over a three year period from 2016 to 2018. Yearling steers grazed four good to excellent range condition pastures from May to August in 2016 and 2018, and from May to July in 2017. The shorter grazing season in 2017 corresponded with a drought year. The research project was overlaid on an existing long-term grazing study on the South Dakota State University Cottonwood Field Station (Dunn et al. 2010). Five steers within each pasture were outfitted with GPS collars. The livestock tracking collars used in the study contained a GPS data logging device and a high frequency accelerometer. The iGotU GT-120 GPS logger (Mobile Action Technology, New Taipei City, Taiwan) as described by Knight et al. (2018) was used to measure animal location. The GPS logger was programmed to collect a fix (latitude/longitude) at 1 minute intervals. Average time to acquire a fix was 1 minute and 22 seconds. A 3-axis X16 mini accelerometer manufactured by Gulf Coast Concepts, LLC was used to measure livestock movement (Gulf Coast Data Concepts, LLC, Waveland, MS). Accelerometers measure acceleration forces in three directions: X, Y, and Z. Accelerometers were programmed to collect data at 12 Hz (corresponding to approximately 12 records per second, or 1,036,800 data points/day). Both the GPS logger and accelerometer were outfitted with a 5200 mAh lithium ion battery to extend data collection in the field. Animals were gathered into corrals once during the grazing season (after approximately 45 days) to download data and charge batteries.

Data Processing. Accelerometer and GPS data was merged using a two-step approach in Python. In the first step, accelerometer data was aggregated to 1 second intervals to reduce data size. Data metrics from the accelerometer included the X, Y, and Z axes, and additional calculations of movement intensity (MI = SQRT ($X^2 + Y^2 + Z^2$) and signal amplitude (SMA= ABS(X) + ABS(Y) + ABS(Z)). For each one second interval, mean, maximum, minimum, and standard error were calculated for X, Y, Z, MI, and SMA measurements. In the second step, accelerometer data was merged with the GPS data by identifying all 1 second time stamps that fell between successive GPS fixes, and calculating the average of the accelerometer variables for that time period.

Three additional metrics were calculated from the GPS fix locations to aid in behavior classification, these included the rate of travel between successive fixes (m/min), a count variable, and a sum variable. Count and sum variables were calculated using a moving window algorithm to loop through GPS data. For every GPS fix, a subset window of 10 fixes prior and 10 fixes after was created, corresponding to roughly a 30 minute time window (21 fixes per window). The total number of points within a 10m radius was calculated for each fix in the window. The count variable was calculated by the number of points within a 10m radius of the fix of interest (max value = 20), the sum variable was calculated by summing the number of fixes within a 10m radius for all points in the window and assigning that to the fix of interest (max=400).

Field observations. Direct visual observations in the field were recorded to link accelerometer and GPS data to livestock behavior. During field observation days, an animal within a pasture was selected at random for observation. Animal ID and animal behavior was recorded to the nearest minute. Changes in behavior were recorded if an activity lasted more than one minute. For analysis, all behaviors were grouped into two categories, graze or non-graze behaviors. Observed behavior was then assigned to the corresponding date time stamp for that animal's GPS collar. The total number of observations by year were 3340 for 2016, 1093 for 2017, and 828 for 2018, with a combined total of 5261 observations over three years. A total of 45 individual animals were observed over the three year period.

Statistical analysis. The random forest algorithm (RF) was used to classify behavior as either graze or non-graze. The random forest models were built using 10,000 decision trees. Yearly models were constructed for 2016, 2017, and 2018 as well as a combined global model that included all data. Livestock behavior ('G' or 'NG') was the response variable and all metrics derived from the accelerometer and GPS device were the predictors (23 total). To test the accuracy of each model, a validation set approach was used by splitting each dataset into an 80%/20% train/test dataset. Following the model testing and validation stage, a final RF model was constructed using all available data. The final RF model was used to predict animal behavior for all un-observed observations for the GPS collared steers. As a secondary assessment of model accuracy, predictions were then used to calculate daily time spent grazing, and to generate histograms of number of graze fixes per hour of day for each animal.

Results and Discussion

Results from the yearly and global RF models can be seen in Table 1. For all models, training (out of bag (OOB)) error rates and test set error rates were similar. Similarity in model accuracy between the train and test datasets indicates that the RF models are not overfitting or under fitting in any year. Overall 2017 had the lowest error rates compared to the 2016 and 2018 RF models. The final RF model fit using all available data had a training (OOB) error rate of 11.7% (88.3% accuracy), and is consistent with test error rates for the global model (Table 1). OOB accuracy in random forest models is considered an unbiased estimate of the overall classification accuracy (Breiman 2001). Higher accuracy rates (>90%) for classifying cattle and sheep behavior with accelerometers have been reported using a variety of classification algorithms (Dutta et al. 2015, Gonzalez et al. 2015, Tamura et al. 2019).

Lower classification accuracy rates in our study compared to previous work may be due to differences both the duration of the trials and scale of paddocks allowed to graze. For instance, Tamura et al. (2019) reported an accuracy of 99% in classifying dairy cattle behavior from accelerometers, however cattle behavior was only observed over a 6 hour period in free stall barns in this study. Dutta et al. (2015) monitored dairy cattle grazing perennial ryegrass pastures over a 9 day period and Gonzalez et al. (2015) monitored yearling steers grazing a 15 ha paddock over a 10 day period. Within our study, observations were recorded over several months during a 3 year period utilizing 3 different herds of yearling steers continuously grazing heterogeneous rangelands. Lower accuracy rates in our models compared to previous research may be due to greater variability in behavior due to observing cattle under more natural conditions.

To estimate daily grazing time and diurnal grazing patterns, the global RF model was used to predict behavior for all unobserved GPS/accelerometer data. Results in table 2 show average daily grazing time by pasture (averaged across all individual animals) and year followed by standard errors. Average daily grazing time ranged from 8.67-10.49 hours per day. In his review of the literature, Kilgour et al. (2012) found that cattle spend between 6.8 and 13 hours grazing per day depending of forage quality and quantity. Given that steers in this study were grazing good to excellent quality range at moderate stocking rates, average daily time spent grazing is consistent with expected time. Low standard error rates and consistency across pastures and years demonstrates stability in global RF model predictions when applied across individual animals over time. As a secondary method of model verification, histograms were generated for each collared steer to show the distribution of grazing points by hour of day for the duration of collar deployment. Example plots in figure 1 show peaks in livestock grazing behavior at sunrise (~0500) and sunset (~2000) with intermittent grazing throughout the day and little to no grazing during night time hours. Similar diurnal grazing patterns have been observed by Zemo and Klemmedson (1970) who reported two major periods of grazing associated with daybreak and late afternoon/evening. Likewise, Sneva (1970) reported two maor grazing periods from 0500 to 0700 and 1700 to 2000, with intermitten grazing in between. These results are consistent with diurnal grazing patterns observed in our study. Previous research classifying livestock behavior with accelerometers tends to focus on model parameterization and error rates. Less focus has been placed on assessing whether model predictions accurately reflect expected livestock behavior.

Implications

The results of this study demonstrate that a low cost GPS/accelerometer collar can be used to accurately monitor season long livestock grazing behavior, and that model predictions align with expected livestock grazing behavior. Further research is needed to determine the stability of model predictions between different classes of animals (e.g. Cow-Calf pairs) or under varying landscape conditions. Though the focus of this study was to differentiate between graze and non-graze GPS locations to better understand forage selection on the landscape, this technology can potentially be used to answer a number of questions relating to livestock production, performance, and behavior.

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Table 1: Error rates from classifying behavior as either graze or non-graze utilizing the random forest algorithm. Out of bag (OOB) error rates and training error rates reported from the model, while validation error rates were determined by reserving 20% of the dataset for testing. The global model combines data from all years.

Year	OOB Error Rate (%)	Validation Set Error Rate (%)
2016	11.9	11.5
2017	4.9	6.4
2018	13.9	14.4
Global	11	11.2

Table 2: Average daily grazing time (hours) followed by standard errors. Yearling steers outfitted with GPS/accelerometer collars in four pastures grazed summer range from 2016-2018. Daily grazing time was calculated for each collared steer, and averaged for each pasture and year.

Pasture	2016	2017	2018
2	9.74 ± 0.05	10.49 ± 0.07	8.84 ± 0.06
3	8.74 ± 0.06	9.71 ± 0.1	8.92 ± 0.09
5	9.68 ± 0.05	8.72 ± 0.14	8.67 ± 0.154
6	9.31 ± 0.05	9.47 ± 0.1	9.08 ± 0.17

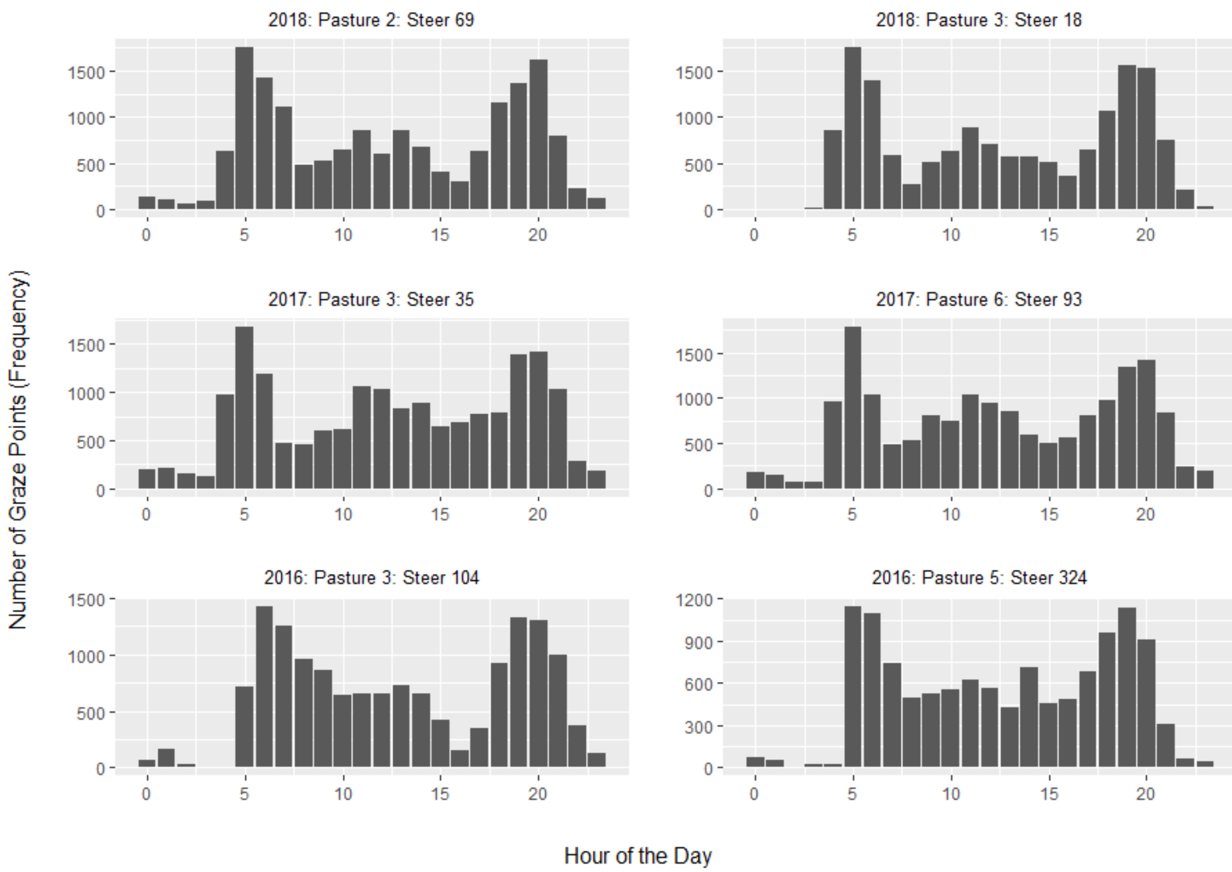

Figure 1. An example of diurnal grazing patterns from six steers outfitted with GPS/ accelerometer collars. Histograms were generated by counting the number of graze points for each hour of the day (0-23) over the duration of collar deployment (~6 weeks).

promise in accurately identifying livestock grazing locations, which could benefit for researchers and land managers monitoring rangeland use.

Keywords: accelerometers, GPS, livestock grazing