Use of GPS tracking collars and accelerometers for rangeland livestock production research[1]

Derek W. Bailey,*,[2] Mark G. Trotter,† Colt W. Knight,‡ and Milt G. Thomas§

*Animal and Range Sciences Department, New Mexico State University, Las Cruces, NM; †School of Medical and Applied Sciences, Central Queensland University, Rockhampton, QLD, Australia; ‡Cooperative Extension, University of Maine, Orono, ME; §Department of Animal Sciences, Colorado State University, Fort Collins, CO

ABSTRACT: Over the last 20 yr, global positioning system (**GPS**) collars have greatly enhanced livestock grazing behavior research. Practices designed to improve livestock grazing distribution can now be accurately and cost effectively monitored with GPS tracking. For example, cattle use of feed supplement placed in areas far from water and on steep slopes can be measured with GPS tracking and corresponding impacts on distribution patterns estimated. Ongoing research has identified genetic markers that are associated with cattle spatial movement patterns. If the results can be validated, genetic selection for grazing distribution may become feasible. Tracking collars have become easier to develop and construct, making them significantly less expensive, which will likely increase their use in livestock grazing management research. Some research questions can be designed so that dependent variables are measured by spatial movements of livestock, and in such cases, GPS tracking is a practical tool for conducting studies on extensive and rugged rangeland pastures. Similarly, accelerometers are changing our ability to monitor livestock behavior. Today, accelerometers are sensitive and can record movements at fine temporal scales for periods of weeks to months. The combination of GPS tracking and accelerometers appears to be useful tools for identifying changes in livestock behavior that are associated with livestock diseases and other welfare concerns. Recent technological advancements may make real-time or near real-time tracking on rangelands feasible and cost-effective. This would allow development of applications that could remotely monitor livestock well-being on extensive rangeland and notify ranchers when animals require treatment or other management.

Key words: behavior, geographical information system, global positioning system, motion sensing, well-being

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INTRODUCTION

Livestock management on rangelands presents different challenges than intensive livestock systems (Bailey, 2016). On rangelands, animals graze extensive and often rugged pastures. It is often a challenge to find all the livestock in a pasture, and normal management practices of checking water availability and animal well-being require additional labor compared with intensive systems.

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[2]Corresponding author: dwbailey@nmsu.edu

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Large pasture size and rugged terrain also make livestock research more difficult. Livestock movement patterns can be monitored on a 24-h basis with global positioning system (**GPS**) collars. Tracking data can be used to answer a wide variety of questions. Similarly, accelerometers can continuously monitor animal behaviors and activity patterns.

Currently, livestock motion and location data are usually stored on the sensor device (collar or ear tag) and cannot be economically accessed until the device is removed from the animal at the end of the monitoring period (weeks to months). However, technologies continue to evolve, and real-time or near real-time monitoring of location and animal motion data may be commercially available at an economically reasonable cost in the foreseeable future. It is likely that these new technologies will expand the use of GPS tracking and motion sensors in rangeland livestock management. The objectives of this article were to describe how GPS tracking and motion sensing have advanced our ability to conduct research and manage livestock on extensive and rugged rangelands and to discuss how these technologies may be used in the future.

BACKGROUND

Prior to GPS technologies, researchers followed cattle and sheep on horseback or on foot and periodically estimated and recorded their position (Herbel and Nelson, 1966; Roath and Krueger, 1982). This was especially difficult at night. The length of tracking was often only 1 or 2 d at a time, and location accuracy and the impact of the observer on the livestock were also issues. About 20 yr ago, GPS collars became commercially available and began to be used in livestock grazing research (Turner et al., 2000; Swain et al., 2011). The ability to accurately track livestock on a 24-h basis for weeks and months facilitated major advancements in livestock behavior and grazing management research and dramatically increased the number of studies evaluating distribution practices and livestock spatial movement patterns. The primary limitation to this technology was the cost of commercial GPS collars, which is currently $1,500 to $2,000 per collar (Anderson et al., 2013). With this cost, scientists often could not afford to track as many individual animals as they desired. Clark et al. (2006) developed a GPS collar that was less expensive (less than $1,000 USD) than commercial collars. Recently, low-cost GPS data loggers have been used to build tracking collars that cost between $150 to $300 (Allan et al., 2013; Knight, 2016). Studies using livestock tracking have increased as the cost of GPS collars have decreased.

Accelerometers record movements and can be used to monitor activity. In the past, VibraCorders were used to determine cattle activity patterns on pasture. These devices could record the up and down movements of an animal's head for several days, which provided relatively good estimates of grazing and resting times (Stobbs, 1970). Commercially available tracking collars often included accelerometers along with the GPS receiver. The accelerometer recorded animal head movements, and researchers combined this motion sensor data with velocity between recorded locations to classify livestock behaviors, such as grazing, traveling, and resting (Ungar et al., 2005; Augustine and Derner, 2013). In the last few years, three-axis accelerometers have become commercially available and record movement at very fine temporal scales (e.g., 25 Hz). This fine-scale monitoring may allow scientists to detect subtle changes in livestock behavior (Barwick, 2017). Wildlife biologists have used three-axis accelerometers to identify body posture and a variety of behaviors from rhythmic patterns of movement, feeding, and social interactions (Shepard et al., 2008). Accelerometers allow biologists to monitor animal behavior in their natural habitat without the potential impacts from the presence of human observers (Brown et al., 2013).

MANAGEMENT OF GRAZING DISTRIBUTION

Livestock distribution is an economically relevant trait and one of the principles of grazing management (Vallentine, 2001). Most of the concerns associated with livestock grazing in the western United States are associated with uneven grazing distribution (Bailey, 2005). Cattle often avoid steep slopes and areas located far from water (Valentine, 1947; Mueggler, 1965). Conversely, livestock often congregate in riparian areas and gentle terrain near water (Bailey, 2004). The concentration of livestock grazing associated with uneven grazing distribution can reduce plant vigor, increase erosion, adversely affect wildlife habitat, and degrade riparian areas (Blackburn, 1983; Kauffman and Krueger, 1984). Increasing uniformity of grazing can also allow stocking levels to be sustainably increased or grazing periods lengthened, because areas extensive and rugged areas often have large areas that receive little, or no, grazing (Tanaka et al., 2007).

Almost all of the proposed tools to improve livestock grazing distribution were described over

60 yr ago by Williams (1954); however, our ability to test and refine these techniques was limited because of the difficulties and labor required to visually observe livestock grazing patterns. The advent of GPS tracking in the late 1990s allowed researchers to accurately monitor livestock grazing patterns for weeks to months and validate the effectiveness of techniques designed to improve distribution. For example, Ares (1953) and Martin and Ward (1973) used supplements to increase cattle use of areas away from water, but they were not able to measure how the supplements affected animal behavior. They relied on sampling forage utilization to evaluate the effectiveness of the distribution practice. Later, a series of studies showed that strategic placement of low-moisture blocks increased cattle use of areas within 600 m of placement sites and increased loafing near the supplement as well (Bailey et al., 2001; Bailey and Jensen, 2008; Bailey et al., 2008a). Although supplement intake could not be measured, the GPS collars also allowed researchers (Bailey et al., 2008a) to estimate the proportion of the tracked cows that visited supplement, 88%. Visits to supplement (location with 10 m of placement sites) should reflect the proportion of tracked cows that consumed low-moisture blocks, because the blocks were placed in areas with higher and steeper terrain.

Herding cattle was suggested as a tool to improve grazing distribution in the 1950s (Williams, 1954; Skovlin, 1957), but there were no quantitative studies documenting the effectiveness of this practice for over 50 yr. Anecdotal observations suggested that herding reduced cattle use of riparian areas (Butler, 2000), but Bailey et al. (2008b) demonstrated with GPS tracking that low-stress herding changed cattle behavior, decreased grazing use near riparian areas, and increased upland grazing. The GPS collars, digital elevation maps (**DEM**), and geographical information systems (**GISs**) were used to quantify the time cattle spent within 100 m of the stream, which was used as an indicator of riparian area occupation. Slope and elevation use were measured from DEM and cow tracking locations using GIS software. The combination of GPS tracking, DEM, and GIS software allows the rapid quantification of terrain use of livestock on rangelands.

The combination of low-stress herding and strategic supplement placement has been used successfully to target cattle grazing in Arizona (Bruegger et al., 2016) and in New Mexico (Stephenson et al., 2016). In addition to increasing uniformity of forage use, targeted cattle grazing could be used to reduce fine fuel levels in designated areas and potentially reduce the risk and/or severity of wild fires (Varelas, 2012). Similar to other supplement and herding studies, tracking data, DEM, and GIS allowed Bruegger et al. (2016) and Stephenson et al. (2016) to quantify differences in terrain use between herded and supplemented cattle (treatment) and controls. Further meta-analysis allowed Stephenson et al. (2017) to examine factors that affected the efficacy of this practice. Intake of low-moisture block supplement was related to the time cattle spent in target areas. When cattle consumed recommended levels of low-moisture block, they spent 7.5 h/d more time near supplement locations than when intake was below recommended levels. Tracking data from GPS provide a wealth of information that can be used to answer a wide range of questions about rangeland livestock behavior.

A combination of technologies may allow rangeland livestock producers to select cattle for improved grazing distribution. As discussed earlier, GPS tracking provides data that can be used to develop grazing distribution traits. GIS software readily calculates the average slope and elevation use of tracked cows from DEM. It also can be used to develop metrics based on the distance cattle travel from water. These distribution metrics can be considered as “hard to measure traits” because of the cost of GPS tracking collars and complexity cattle movement patterns on rangelands. The BovineSNPHD (~77,000 single-nucleotide polymorphism [SNP] genotypes) beadchip from Illumina (San Diego, CA) and other genomic technologies provide a new approach to examine the genotypic and phenotypic relationship of complex traits like grazing distribution. Eggen (2012) suggested that genomic selection is a promising approach to improve complex traits that are difficult to measure. Using BovineSNPHD genotypes, Bailey et al. (2015) reported that genetic markers on chromosomes 4, 8, 17, and 29 were related to indices of terrain use. A single marker or SNP explained up to 24% of the variation in a terrain index, while a combination of five SNPs explained up to 36% of the variation. Not only does this research demonstrate that terrain use is heritable, but it shows the potential to use genomic selection to improve cattle grazing distribution. A DNA test costing roughly $30 to $50 USD could be used to rank bulls in their ability to sire daughters that are more willing to travel away from water and use rugged terrain. The reduction in cost of GPS collars will allow more cattle to be tracked and enhance this research.

Individual animal variation in movement patterns continues to be a rich area of future grazing behavior research (Searle et al., 2010). Bailey et al. (2004) showed differences in terrain use of hill climbing and bottom dwelling cows. Lunt (2013) found that terrain use of cows was relatively repeatable across weeks. Intraclass correlations of elevation use were 0.61 and 0.71 for two ranches, but correlations for slope use were lower, 0.30 and 0.29. Subsequent analyses by the authors of tracking data from other ranches showed more variabilities with intraclass correlations of weekly elevation and slope use varying from 0.00 to 0.60. This suggests that consistency of movement patterns may vary across herds and varying terrain and vegetation. Searle et al. (2010) suggested that behavioral syndromes might be a method to identify individuals with favorable behavioral patterns. Wesley et al. (2012) separated cows into two behavioral syndromes based on supplement consumptions rates and then evaluated their grazing patterns with GPS tracking. Cows that consumed supplement more slowly spent more time at water and had less dispersed grazing patterns than cows that consumed supplement quickly. Individual animal variation in behavior can occur as single response or in multiple contexts (MacKay and Haskell, 2015). Spatial movement patterns and terrain use are multidimensional, and the individual responses need much more study because livestock respond to the cumulative impact of slope, horizontal and vertical distance to water, and vegetation characteristics in complex ways with varying tradeoffs between travel effort and available forage nutrients (Senft et al., 1987; Bailey et al., 1996; Bailey, 2005; Launchbaugh and Howery, 2005).

OTHER USES OF GPS TRACKING AND ACCELEROMETERS

For livestock, most uses of GPS tracking and accelerometers have been to monitor and quantify grazing behavior (Anderson et al., 2013). However, this technology can be used to help answer other livestock husbandry and land management issues. Animal behavior patterns can be monitored using GPS and accelerometers both independently and in combination (Ungar et al., 2005; Augustine and Derner, 2013). Differences in overall activity patterns such as the proportion of time spent grazing, resting, or walking can be quantified and used to compare treatments. For example, cows were more active and spent less time resting when supplement and salt were available on Montana foothill rangeland compared with salt alone (Bailey et al., 2008a). In addition, GPS tracking can be used to quantify the distance animals travel each day and correspondingly be used to help estimate energy expenditure (Brosh et al., 2006). To accurately estimate distance traveled using GPS collars, positions recorded when the animal is resting and inactive must be removed because GPS error can artificially increase the cumulative distance between positions by roughly 15% (Ganskopp and Johnson, 2007). In addition, the sampling interval during tracking affects the estimate of distance traveled by livestock. As the time interval between recorded positions increases, the estimate of distance traveled per day decreases (Johnson and Ganskopp, 2008). The optimal interval between recorded positions is a balance between battery life of the GPS tracking collar and accuracy of the movement path. When positions are recorded more frequently, the movement path is recorded more accurately but the time period that animals tracked decreases. Thus, the objectives of the research and the quality of the battery determine the livestock location sampling intervals.

Static acceleration can be used to remotely measure body posture (Shepard et al., 2008). Augustine and Derner (2013) used the head-down posture detected by accelerometers to help identify when cattle were grazing. Posture is also very useful in wildlife studies. For example, if penguins are upright for long periods, they must be on land (Shepard et al., 2008). Dynamic acceleration is also used to estimate changes in behavior patterns (Brown et al., 2013), but another potential use of accelerometers is to estimate energy expenditure. Halsey et al. (2011) demonstrated that overall dynamic body acceleration can be used as a proxy for energy expenditure for a wide variety of species, especially if it combined with heart rate monitoring.

An important factor in using accelerometers to determine animal activity is the positioning of the device and calibrating sensor data to observed behaviors (Ungar et al., 2005). When accelerometers are mounted to collars, there can be substantial differences among animals (Bailey et al., 2008a). Visual observations are needed to develop relationships between acceleration signals and behavior (Ungar et al., 2005; Augustine and Derner, 2013; Barwick, 2017). Attaching accelerometers in ear tags can be a superior approach to collars, because it is easier to maintain the sensor in the same anatomical location on the animal. Ear tag accelerometers may be able to sense a wider array of animal movements than collars (Barwick, 2017).

POTENTIAL OF REAL-TIME TRACKING AND MOTION SENSING

Real-time or near real-time animal tracking is currently available, but the cost of the equipment is currently prohibitive for livestock producers and most livestock research projects. Tracking data can be recovered from collars in the field using radio modem technology, Argos satellites, mobile telephone systems, and satellite phone systems (Tomkiewicz et al., 2010). These systems are usually significantly more expensive than "store onboard" systems. The global system for mobile communications (**GSM**) was successfully used to track moose in Europe (Dettki et al., 2004). However, GSM cannot be reliably used in many portions of the western United States and in Australia, because mobile phone coverage is limited (Tomkiewicz et al., 2010). Recent advances and efforts by universities and commercial enterprises suggest that practical and cost-effective systems may be available for rangeland livestock producers in the near future and potentially allow ranchers to monitor livestock remotely in real or near real time.

The most obvious benefit of real-time tracking is the ability to readily find your livestock in extensive and rugged rangeland pastures. A majority of the time required to gather cattle and move them to corrals for husbandry practices, such as branding or weaning, is to simply find the animals. The time required for locating animals is one of the major reasons that helicopters are used to herd cattle in Australia. Labor is expensive and limited in Australia, and it is often more cost-effective to hire a helicopter than to have employees spend time searching for cattle by horseback or motorized vehicle.

Real-time tracking could also be used to reduce the incidence of stock theft. Movement patterns associated with being gathered and moved could be used to detect unauthorized herding and potential stock theft. When cattle are herded, the tracking pattern is more linear and less sinuous than free-ranging movement patterns (Figure 1). A monitoring system could alert managers when tracking data indicate livestock are being herded. If the herding was not authorized, the system alert could potentially allow managers to respond before the animals left the property.

Another potential use of real-time tracking is monitoring livestock breeding programs. For example, the location of bulls could be tracked to ensure that they remained in their assigned pastures, and a remote monitoring system could notify managers that breeding bulls had traveled away from their selected herds and pastures. This technology would improve the accuracy and efficacy of planned mating systems based on natural service and multiple breeding pastures. Also, real-time tracking could monitor cattle in extensive rugged pastures and notify managers if cows were grazing in areas without bulls during the breeding season. In extensive and rugged pastures, bulls and cows may become isolated during the breeding season, which can potentially reduce pregnancy rates. Another potential use of real-time tracking is estrus detection. The combination of tracking and accelerometer monitor might be able to detect when cows grazing rangelands come into estrus.

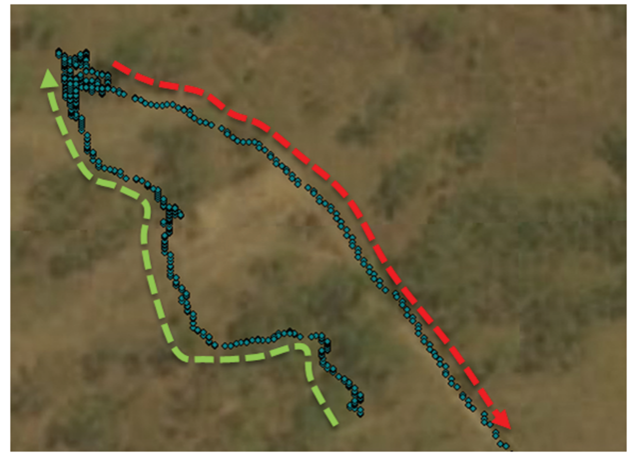

Figure 1. Movement pattern of a free-ranging heifer (green line) during grazing and resting. Later the heifer was herded to water (red line). Note: the movement path of the heifer during herding was more linear that when it was free ranging.

Monitoring livestock welfare is different on rangelands than in intensive systems (Bailey, 2016). Animals are often not seen by managers and/or staff for days or even weeks. Correspondingly, animals that become ill may often are not treated as quickly as those raised in intensive systems. If real-time tracking and animal sensing can be used to detect disease and other welfare concerns remotely, this technology could be used to inform management that treatment or other management actions are needed. For example, real-time tracking could be used to determine whether water was available in extensive pastures. Livestock would remain near water tanks longer than normal if the water system failed, and a monitoring system could notify managers. Measuring and reporting water flow rates and water levels in drinkers is an alternative approach for monitoring livestock watering facilities, which would complement a real-time livestock tracking system.

Although much more research is needed, there are some studies that demonstrate the potential for GPS tracking and accelerometers to detect animal well-being concerns. Dobos et al. (2014) were able to detect when ewes lambed using GPS tracking. Preliminary analyses of a study conducted by the authors and David Scobie and colleagues at AgResearch in New Zealand showed that perennial grass staggers can potentially be detected remotely. Sheep grazing in a perennial ryegrass pasture (4350 ± 63 m/d) moved slower (P = 0.04) than sheep in a control pasture (4727 ± 56 m/d). Accelerometers showed clear changes in behavior of affected sheep from the beginning to the end of the study. Accelerometers may be useful for remotely detecting the onset of perennial ryegrass staggers.

In the near future, commercially available technologies may be able to provide accelerometer data to livestock producers on a real-time or near real-time basis. Recent research demonstrated how accelerometers can be used to detect livestock diseases and welfare concerns. Using a three-axis accelerometer, Barwick (2017) was able to readily detect lameness in sheep. Analyses being conducted by the authors showed that accelerometers may also be useful for detecting disease incidence. As part of a separate study, two of eight heifers being monitored with accelerometers became ill with bovine ephemeral sickness (3-d sickness). Along with high fever, cattle with 3-d sickness dramatically reduced feed intake, become sore, and were depressed. The ill heifers were first observed about noon when they were usually checked visually. Activity during the early morning, a normal grazing period, clearly dropped the day before the clinical signs of the illness were observed by the herdsman (Figure 2). Additional research and analyses are needed to determine whether accelerometers can consistently detect the onset of disease before clinical signs can be observed.

On extensive rangeland systems, the ability to detect illness and other livestock welfare concerns remotely brings up a critical issue that has not previously been addressed. If we can detect a single ill animal on an extensive pasture, can we economically afford to find the animal and herd it to corrals and a squeeze chute for treatment? Also, can we ethically ignore an ill animal if it is uneconomical to find and treat it on extensive or rugged rangeland pastures? The development of new technologies will necessitate livestock managers and scientists

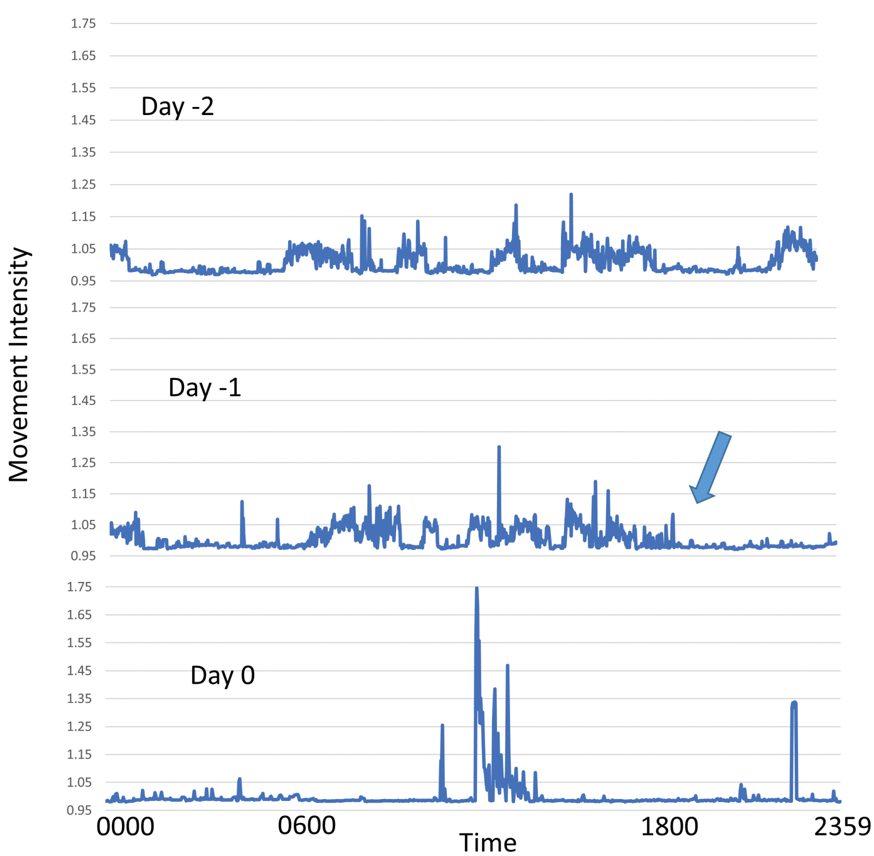

Figure 2. Activity of a heifer over 24-h periods the day it is was visually detected as ill from 3-d sickness (day 0) and the 2 days before it was the sickness was detected (day −1 and day −2). An accelerometer placed on a collar monitored motion in three axes, which was converted to movement intensity (Zhang and Sawchuk, 2011). A blue arrow indicates where there was a behavioral change from normal activity patterns to less active and ill.

studying behavior and welfare to address such issues.

CONCLUSIONS

The advent GPS tracking has greatly enhanced research and development of tools to improve distribution and uniformity of grazing by livestock by allowing them to quantitatively measure changes in movements. Genomic technologies combined with GPS tracking and GIS allow researchers the ability to conduct genotype to phenotype association studies of grazing distribution traits and potentially use genomic selection to improve cattle use of steep slopes and areas far from water.

Development of real-time and near real-time monitoring of GPS tracking and motion sensing may allow producers to remotely monitor livestock behavior and well-being on extensive rangeland pastures in the near future. Ongoing research suggests that GPS tracking and accelerometer motion sensing can identify livestock illness and other welfare concerns. Preliminary results are promising, but much more research is needed to determine whether GPS tracking and motion sensing can remotely detect disease and welfare concerns remotely and potentially before clinical signs can be observed.

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