Calculating Foraging Area Using Global Navigation Satellite System (GNSS) Technology

By Dean M. Anderson, Rick E. Estell, and T. Scott Schrader

On the Ground

- Optimum forage utilization on animal-dominated landscapes can only occur when stocking rate (SR) and stocking density (SD) are considered and managed simultaneously.
- Landscapes with foraging animals contain vegetation ranging from unused to over-used even under a proper SR.
- The global navigation satellite system (GNSS) technology has catapulted our understanding of spatial–temporal management of free-ranging livestock into a 24/7 opportunity.
- Location-specific data will improve management of stocked landscapes, both ecologically and economically.
- GNSS data from instrumented animals provides an opportunity to understand when and where a landscape is used to improve animal distribution.
- A proper SR and management of animal distribution (i.e., SD) will facilitate adaptive management of animal dominated landscapes.

Keywords: tracking livestock, animal behavior, GPS, plant–animal interface, adaptive management, preweaning, and postweaning.

Rangelands 36(6):31–35
doi: 10.2111/Rangelands-D-14-00022.1

Stocking rate (SR) has been defined as "The relationship between the number of animals and the total area of the land in one or more units utilized over a specified time."[1] The relationship between vegetation and foraging animals within the United States is usually expressed as the number of animals or their normalized equivalent (e.g., metabolic body mass; weight), often expressed in terms of animal unit months (AUM)[1] per unit area or its reciprocal. The definition of stocking density (SD) refers to "the instantaneous measurement of the animal-to-land area relationship."[1] The literature is replete with research, reviews, and textbooks that point out the importance of SR[2,3] as the fundamental tenet of grazing livestock management. However, even with a proper SR, landscapes evaluated over extended periods of time seldom show uniformity in forage use because animals do not distribute themselves evenly during foraging[4]; this produces the key signature of animal dominated landscapes—areas of use and nonuse.[5,6]

Current SR calculations assume all forage in a paddock will be used at some time and in some amount if stocked with the proper number of animals. In reality, this supposition is not usually true.[4] Nonuniformly used rangelands[5] produce many challenges, not the least being a lower carrying capacity that translates into reduced financial returns. Because topography and distance to water[6] are critical in influencing how landscapes are used by livestock, these factors are key considerations when determining SR. Between 1926 and 2009, 68 different factors were identified and many have been managed or employed singly or in combination to attempt and improve animal distribution.[7] Before the advent of the global navigation satellite system (GNSS), of which the global positioning system (GPS) is one of several satellite systems available worldwide, research on the spatial–temporal use of landscapes was largely limited to observations during daylight hours. Proposed high-tech[8] livestock management strategies that embrace 21st century technologies have the potential to improve livestock distribution on animal dominated landscapes managed under a proper SR. We now have the ability to accurately monitor the spatio-temporal behavior of free-ranging animals on a 24/7 basis.[9] This ability allows an accurate assignment of behaviors to different parts of the landscape and identification of unused areas of a landscape at various scales[6] at which management can be applied.

Using GNSS to Track Livestock Distribution: An Example

GNSS data can be used to determine the uniformity of livestock distribution on a landscape based on locations of particular behaviors. A 433-ha brush infested paddock (14A) located on the Jornada Experimental Range (JER) was established in 1989. This paddock has received between 0 AUM and 74 AUM of use per year during the last 25 years under seasonal suitability[10] management. Location of four different cows (two cows per year) were recorded every second using GPS devices worn by each cow.[11] Between 26 March and 6 April 2009, 30 cows were periodically observed during daylight hours, and in 2011, three of the same cows plus nine different cows were observed between 10 and 21 March 2011.

During observation periods, cow behaviors were classified into three categories, i.e., foraging, walking, and stationary. Beginning and ending times of each behavior were recorded and merged with the corresponding GPS data. These categorized data were then used to classify GPS data recorded when observers were not present by assigning a range in rate of travel (m/second) to each behavior. The data sets of each of the four cows used in this example were $\geq$90% complete.[11] During the two periods over two 11-day intervals, the four instrumented cows gave birth giving a precalving as well as a postcalving interval in which stationary, foraging, and walking behaviors were observed and recorded (Fig. 1).

Recorded foraging and walking behaviors were converted to area by assuming a 0.5 m distance on either side of the head was impacted by the cow. Thus, multiplying total distance (m) traveled by 1 m produces the area (m^2) in which foraging or walking occurred. Each of these areas represents a subset of the paddock (Table 1). The total area in which the herd impacted the paddock can be calculated by determining the mean area occupied by the two instrumented cows for each activity and multiplying by the number of cows in the paddock.

To calculate the area occupied by a stationary or lying cow requires further assumptions. Standing dairy cows require between 1.4 m^2 and 1.6 m^2 per cow,[12] depending on group size, whereas lying dairy cows need 2.9 m^2 to 3.3 m^2 per cow.[13,14] In this example, we assume that each time one of our cows was stationary, she influenced 3.1 m^2 of space. Multiplying this number by the number of cows in the herd provides an estimate of area over which stationary animals have an impact, although it does not reduce the area if specific areas are used multiple times during the sampling period (Table 1). Location of cow inactivity can be determined by calculating a center point of a polygon that encloses the outermost perimeter of stationary animals (Fig. 2). No attempt was made to determine if each location was used multiple times during periods of inactivity. The focus of this research was to determine what percent of the entire paddock received impact from the cattle rather than how much of a particular activity (i.e., foraging, walking, or inactivity).

This example suggests that, based on the numbers of cows used to stock this paddock in 2009 and 2011, between 58% and 91% of the paddock was not used during the 11 days that data were collected, and the use that did occur was not uniformly distributed over the landscape (Table 1; Figs. 1 and 2). Because these data represent only 11 consecutive days within a year, extrapolating long-term animal impact on this paddock using a simple mathematical relationship would be inappropriate because of changes in the nutritional needs and preferences of the animals, coupled with changes in the quantity and quality of the standing crop, along with abiotic weather factors that affect foraging and use patterns. These two relatively small groups of cows were judged to be acting as a cohesive group during both years and their behaviors appeared to be synchronized, probably as a result of social facilitation.[15,16] However, it is not possible from these data to accurately indicate what percent of a cow herd would need to be instrumented to accurately predict the behavior of the entire group. In addition to numbers of cows forming a group, their genetics, physiology and disposition, landscape topography, weather, and phonological stage of plants would be just some of the variables that would dictate what percent of a group of

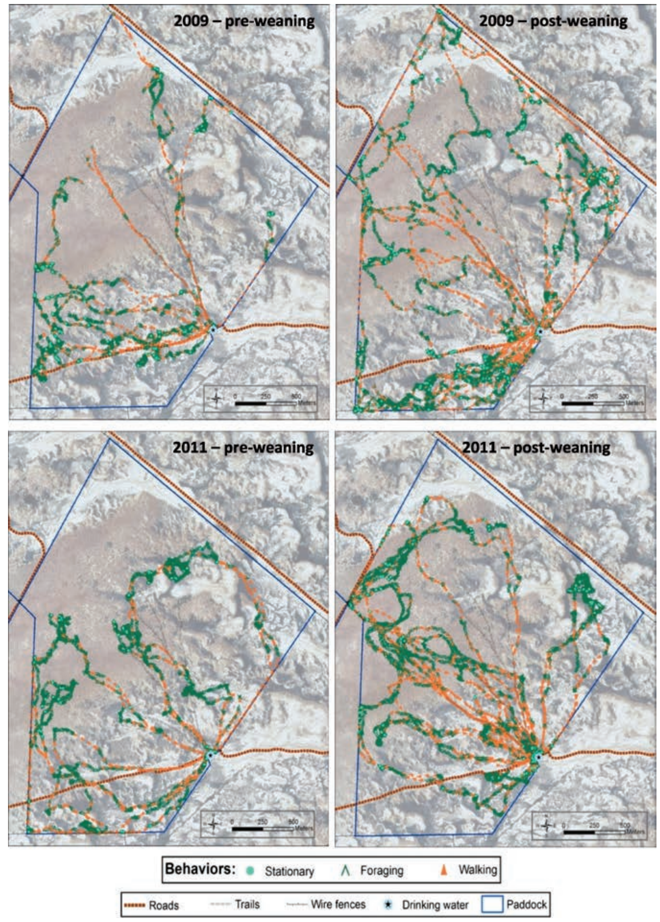

Figure 1. Activity of two cows between 30 March and 7 April 2009 and two cows between 14 and 25 March 2011 in a 433-ha paddock before and after weaning. Behaviors are classified as: stationary $<$0.060 m/second in 2009 and $<$0.050 m/second in 2011; foraging, 0.060 m/second to 0.55 m/second in 2009 and 0.050 m/second to 0.50 m/second in 2011; and walking, $>$0.55 m/second in 2009 and $>$0.50 m/second in 2011. The herd consisted of 30 and 12 cows in 2009 and 2011, respectively. Except for three cows, animals differed between years with 30 cows in 2009 and 12 cows in 2011 (Adapted from Anderson et al. 2012).[11]

Table 1. Stocking rate and stocking density* in a 433-ha mesquite-dominated paddock (106°41′W, 32°34′N) stocked over 11 consecutive days in 2009 (26 March to 6 April) and 11 consecutive days in 2011 (10 to 21 March) with mature Hereford × Brangus cows. Three behaviors (foraging, walking, and stationary) were characterized among four different cows (two per year) based on their rate of travel (m/second) obtained from 1-second global navigation satellite system (GNSS) fixes. During each of these two 11-day periods, the cows gave birth to calves on 30 and 14 March in 2009 and 2011, respectively (Adapted from Anderson et al. 2012[11]).

	2009		2011	
	Preweaning	**Postweaning**	**Preweaning**	**Postweaning**
Total area (m^2) within a 4,333,880 m^2 paddock impacted by two GNSS-instrumented cows per year over 11 days during three behaviors				
Stationary (∑ GNSS fixes * 3.1 m/fix)	19,815.20	34,084.50	20,952.90	33,362.20
Foraging (∑ of distances (m^2) between consecutive GNSS fixes)	21,845.85	42,930.19	29,473.84	54,953.53
Walking (∑ of distances (m^2) between consecutive GNSS fixes)	17,048.98	42,937.64	15,607.98	51,854.83
Used	58,710.03	119,952.33	66,034.72	140,170.56
Not used	4,275,169.97	4,213,927.67	4,267,845.28	4,193,709.44
The mean (ha/head) impacted = [(Mean ha impacted by GNSS-instrumented cows * No. cows) / No. cows)]				
Stationary	0.99	1.70	1.05	1.67
Foraging	1.09	2.15	1.47	2.75
Walking	0.85	2.15	0.78	2.59
TOTAL	2.94	6.00	3.30	7.01
Total area (ha) impacted by the cow herd				
Stationary	29.72	51.13	12.57	20.02
Foraging	32.77	64.40	17.68	32.97
Walking	25.57	64.41	9.36	31.11
Total of all GNSS based behaviors	88.07	179.93	39.62	84.10
Stocking rates in a 433-ha paddock expressed as ha/head				
Number cows in paddock	30	30	12	12
Conventional SR (ha/head)	14.43	14.43	36.08	36.08
Area NOT USED based on GNSS data	80%	58%	91%	81%
Area USED based on GNSS data	20%	42%	9%	19%

*Cattle stocking density based on GNSS data can be calculated as follows: 1) determine the total linear distance (m) between consecutive GNSS fixes for all instrumented moving cows by behavioral category,[11] i.e., walking or foraging; 2) for stationary cows, sum the number of stationary fixes and multiply this number by 3.1 m^2, a realistic area occupied by a stationary cow;[12–14] 3) assume that a distance of 0.5 m on either side of a moving instrumented cow can be influenced by her presence; 4) multiply the total linear distance obtained in step 1) by 1 m and divide by the number of instrumented cows used to calculate a mean area of impact by forward-movement category, i.e., foraging or walking; and 5) multiply the mean area by behavioral category by the total number of cows in the paddock to get the total area impacted by that behavior. The square meters in each behavior category can easily be converted to hectares by multiplying by 0.0001.

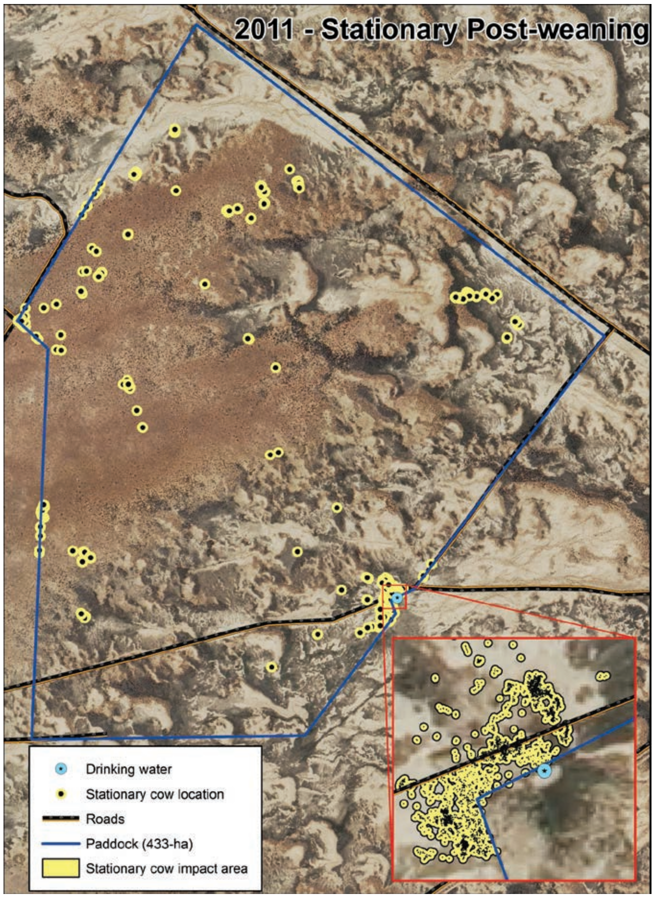

Figure 2. Location of two stationary cows in a 433-ha paddock between 14 and 21 March 2011 (post-weaning). Blowout (red square) highlights individual cows, with the yellow circle representing an area having a 1.5-m radius around each cow (black dot).

cows would need to be instrumented in order to accurately characterize the entire group. However, the longer GNSS-instrumented animals are tracked among seasons and years and the greater percentage of the herd that is instrumented, the more accurate the percentage use data will become for guiding resource managers in placing the correct number of animals on the landscape and subsequently managing them for optimum landscape utilization.

Implications

Traditional SR calculations assume most forage within a paddock will be used to some degree at some time during the stocking period. Current technologies indicate that this assumption might underestimate the actual animal impact on certain areas if one assumes 1) the use patterns of instrumented animals accurately reflect the spatio-temporal behavior of the entire herd, 2) foraging and walking behaviors can be determined based on rate (m/second) of forward movement, 3) stationary cows occupy an estimable area that reflects inactivity when multiplied by the total number of cows in the herd, 4) none of the behavioral categories assume exclusive use of any area on the landscape, and 5) the accuracy of these calculations will improve as data are collected from more instrumented animals over longer time intervals. Furthermore, distribution calculations can be honed to a particular animal species; for example, the area of impact on either side of the head and the standing or lying areas likely differ for small ruminants. Calculating areas of use based on where on the landscape animals spend time can optimize labor expenditures. In the future, when virtual fencing becomes a reality[8] it will be possible to improve distribution and bring all areas of a landscape under a more "proper use," which could be even or uneven depending on management goals. Such information will make it easier to assess soils or vegetation in specific areas where animal impact is concentrated and implement a prescription-based management on a site-specific basis. Conventional SR calculations for this paddock in 2009 and 2011 were 14.4 and 36.1 ha/head, respectively. During the 11-day interval in 2009 and 2011 on which these data focus, only 9% to 42% of the 433-ha paddock was used (Table 1), suggesting a much heavier stocking density actually existed than would have been assumed based on SR alone. This suggests a proper SR, based on an entire paddock in reality, might be impacting a "subset area" of the paddock with an extreme high stocking density, which could potentially degrade a landscape in years without optimum growing conditions. Therefore, managing stocking density (animal distribution) under a proper stocking rate will be the only way to facilitate adaptive management[17] to positively impact ecologically based landscape stewardship.

References

1. Allen, V. G., C. Batello, E. J. Berretta, J. Hodgson, M. Kothmann, X. Li, J. McLvor, J. Milne, C. Morris, A. Peeters, and M. Sanderson. 2011. An international terminology for grazing lands and grazing animals. *Grass and Forage Science* 66:2–28.
2. Holechek, J. L. 1988. An approach for setting the stocking rate. *Rangelands*. 10:10–14.
3. Holechek, J. L., and R. D. Pieper. 1992. Estimation of stocking rate on New Mexico rangelands. *Journal of Soil and Water Conservation* 47(1):116–119.
4. Norton, B. E., M. Barnes, and R. Teague. 2013. Grazing management can improve livestock distribution. *Rangelands* 35(5):45–51.
5. Anderson, D. M., C. S., Hale, R. Libeau, and B. Nolen. 2003. Managing stocking density in real time. *In*: H. Allsopp, A.R. Palmer, S J. Milton, K.P. Kirkman, G. I. H. Kerley, C.R. Hurt, and C. J. Brown [eds.]. Proceedings of the VIIth International Rangeland Congress. 26 July–1 August 2003, Durban, KwaZulu-Natal Province, Republic of South Africa. Grahamstown, Eastern Cape Province, Republic of South Africa: Grassland Society of Southern Africa. p. 840–843.
6. Hunt, L. P., S. Petty, R. Cowley, A. Fisher, A. J. Ash, and N. MacDonald. 2007. Factors affecting the management of cattle grazing distribution in northern Australia: preliminary observations on the effect of paddock size and water points. *The Rangeland Journal* 29:169–179.

7. Anderson, D. M. 2010. Geospatial methods and data analysis for assessing distribution of grazing livestock. *In*: B. W. Hess, T. DelCurto, J. G. P. Bowman, and R. C. Waterman [eds.]. Proceedings of the 4th Grazing Livestock Nutrition Conference. 9–10 July 2010. Estes Park, CO, USA: Champaign, IL, USA: Western Section American Society Animal Science. p. 57–91.
8. Anderson, D. M., R. E. Estell, J. L. Holechek, S. Ivey, and G. B. Smith. 2014. Flexible livestock management with virtual shepherding. *The Rangeland Journal* 36:205–221.
9. Anderson, D. M., R. E. Estell, and A. F. Cibils. 2013. Spatiotemporal cattle data—a plea for protocol standardization. *Positioning* 4:115–136.
10. Valentine, K. A. 1967. Seasonal suitability, a grazing system for ranges of diverse vegetation types and condition classes. *Journal of Range Management* 20:395–397.
11. Anderson, D. M., C. Winters, R. E. Estell, E. L. Fredrickson, M. Doniec, C. Detweiler, D. Rus, D. James, and B. Nolen. 2012. Characterizing the spatial and temporal activities of free-ranging cows from GPS data. *The Rangeland Journal* 34:149–161.
12. Milani, A.P., and F. A. De Souza. 2010. De granjas leiteiras no região de Ribeirão Preto-SP, Brazil. *Engenharia Agrícola* 30:742–752. http://www.scielo.br/scielo.php?pid=S0100-69162010000400018&script=sci_arttext&tlng=pt. Accessed (March 18, 2014).
13. Faull, W. B., J. W. Hugher, M. J. Clarkson, D. Y. Downham, F. J. Manson, J. B. Merritt, R. D. Murray, W. B. Russell, J. E. Sutherst, and W. R. Ward. 1996. Epidemiology of lameness in dairy cattle: the influence of cubicles and indoor and outdoor walking surfaces. *Veterinary Record* 139:130–136.
14. Ceballos, A., D. Sanderson, J. Rushen, and D. M. Weary. 2004. Improving stall design: use of 3-D kinematics to measure space use by dairy cows when lying down. *Journal of Dairy Science* 87:2042–2050.
15. Ralphs, M. H., D. Graham, and L. F. James. 1994. Social facilitation influences cattle to graze locoweed. *Journal of Range Management* 47:123–126.
16. Stoye, S., M. A. Porter, and M. S. Dawkins. 2012. Synchronized lying in cattle in relation to time of day. *Livestock Science* 149:70–73.
17. Williams, B. W., and E. D. Brown. 2014. Adaptive management: from more talk to real action. *Environmental Management* 53:465–479.

Authors are Research Animal Scientists, USDA–ARS Jornada Experimental Range, Las Cruces, NM 88003, USA (Anderson, deanders@nmsu.edu, and Estell); and Senior GIS Specialist, USDA–ARS Jornada Experimental Range, Las Cruces, NM 88003, USA (Schrader).