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SUITABILITY OF A GPS COLLAR FOR GRAZING STUDIES

C. T. Agouridis, T. S. Stombaugh, S. R. Workman, B. K. Koostra, D. R. Edwards, E. S. Vanzant

ABSTRACT. *The traditional means of tracking animal location in a field is by visual observation. Not only is this method labor intensive, it is also prone to error as the observer can alter cattle movement, observation periods are often too short to obtain confidence in general daily behavior patterns, and observer fatigue becomes an issue. In the 1990s, the University of Kentucky began using GPS collars on cattle to track their position with the goal of incorporating this information into cattle management practices. One of the key unanswered questions regarding the GPS collars is the accuracy of the position data recorded by the collar. The objective of this work was to assess the capabilities and limitations of using GPS collars to track animal movement in grazed watersheds. Static tests were conducted in an open field, under trees, and near fence lines to ascertain the impacts of various field features on collar performance. Dynamic tests were carried out to examine the errors associated with the collars while operated under real-world conditions. Results from these tests indicate that the collars generally provide data with horizontal accuracies of 4 to 5 m. This information will assist researchers in the development of experiments based on collar capabilities and limitations.*

Keywords. *Accuracy, Global positioning system, Grazing, Livestock behavior, Management practices.*

Many researchers confirm that cattle grazing negatively impacts stream systems (Belsky et al., 1999; Clark, 1998; Nguyen et al., 1998; Owens et al., 1996). Previous research into the water quality impacts of cattle grazing mainly used visual observations to track changes in cattle behavior associated with a particular BMP (best management practice), often an alternate water source (Sheffield et al., 1997; Gary et al., 1983; Miner et al., 1982). The periods in which cattle movement was visually tracked typically consisted of a few days (generally daylight hours) at various times during the year. The primary difficulties of tracking animal location via visual observation are that the method is labor intensive, it is prone to error since the observer can alter cattle behavior, observation periods are generally too short to obtain confidence in daily behavior patterns, and observer fatigue can be problematic.

While the use of GPS collars for tracking animal movement is quite common in wildlife studies, incorporation of the technology into cattle management studies is quite recent (Moen et al., 1996; Harbin, 1995). Utilization of GPS

collars allows researchers to collect a larger and, arguably more accurate, data set. Turner et al. (2000) provided the groundwork for assessing animal behavior patterns through the use of GPS collar receivers in the eastern U.S. Their work has provided the platform for using GPS technology at the University of Kentucky for the purpose of monitoring cattle behavioral responses to BMPs and the resultant water quality effects. The use of GPS collars allowed Bailey et al. (2001) to determine alterations in cattle grazing patterns as a result of introducing dehydrated molasses supplement on a foothills rangeland.

Questions remain regarding the accuracy of the position data recorded by the GPS collars relative to the true position. A number of factors including limitations in hardware and/or software and signal transmission errors affect GPS receiver accuracy (Stombaugh et al., 2002). For GPS systems, horizontal position accuracy is generally reported in four different manners: root mean square (rms or 1 sigma), twice distance rms (2drms or 2 sigma), circular error probable (CEP), and horizontal 95% accuracy (R95) (van Diggelen, 1998). Guided by the assumptions of Gaussian distribution, position precision ratios, and circular horizontal error distribution, van Diggelen (1998) provided conversion information to allow the user to compare GPS receiver accuracy from manufacturers who have used different reporting strategies. Previous examination revealed that the static accuracy of 8 m 95% of the time for these lightweight GPS collars, which was based on a 24 h data set from one collar at a single location (differential correction employed) (Udal, 1998; Turner et al. 2000). Dynamic accuracy, an important factor when interpreting results from the collars, was never determined. The University of Kentucky has since obtained additional collars to conduct an intensive study of cattle movement in grazed watersheds subjected to various amounts of stream access (i.e., from complete access to access only at designated crossings).

The goal of this project was to determine the accuracy of the horizontal position data collected by the GPS collars

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under both static and dynamic conditions. Both static and dynamic tests were performed to better assess the accuracies, capabilities, and limitations of using GPS collars to track animal movement in a grazed watershed. Results from these tests will provide researchers with a better understanding of the actual performance of the GPS collars while presenting them with vital information needed in the design and management of projects incorporating this new technology.

MATERIALS AND METHODS

GPS COLLARS

Tests were conducted on up to 17 GPS_2200 Small Animal GPS Location Systems (Lotek Engineering, Inc., Newmarket, Ont.) as these collars were selected for use in an intensive grazing study at the University of Kentucky. These lightweight collars are typically used to track wildlife such as deer, large cats, bear, and wolves for habitat studies. The collar manufacturer reports accuracies between 5 and 10 m with differential correction employed, but offers no statistical basis for that specification (Lotek, 1998). Three collars were purchased in 1998 and retrofitted in 2001 to match the remaining 14 that were obtained in 2001. The collars are equipped with an eight-channel GPS receiver allowing for the simultaneous acquisition and lock of signals from eight satellites. Data were stored in non-volatile random access memory (RAM) with a capacity to store 5,208 position fixes. Stored information included collar identification, date, time, position (latitude and longitude), height, dilution of precision value, and fix status (2D or 3D) (Turner et al., 2000). Position data were recorded in decimal degrees (WGS-1984 geographic coordinates) to eight decimal points. All tests were conducted using the smallest allowable fix interval of 5 min. This is the same fix interval used in intensive grazing studies conducted at the University of Kentucky.

POST-PROCESSING

The data collected from the GPS collars were not differentially corrected in real-time and required post-processing to achieve differentially corrected accuracies. Post-processed differential correction uses position information collected at a base station sited at a precisely known location during the same time period in which the rover files were collected to correct rover position data. The data collected at the base station were used to calculate the error in the satellite signals by determining the difference between the positions calculated from the satellite signals and the known reference position. The resulting differential corrections were later applied to the rover files for the same time intervals.

Manufacturer software was used to input the uncorrected data files and the base station files and output differentially corrected data files (Lotek, 1998). The base station used for the differential correction is a National Geodetic Survey (NGS) continuously operating reference station (COORS) located near Taylorsville, Kentucky. This base station collects and records correction data at 30 s intervals. The COORS is located approximately 50 km from the grazing research project site in Woodford County, Kentucky, where two static tests were conducted, and approximately 70 km from the testing area in Fayette County, Kentucky, for the third static test. A web-based interface maintained by the NGS was used to query the COORS data by selecting the

appropriate time interval and downloading the appropriate base station files. The base station files were used to apply corrections to the GPS collar data files. The resulting data files contained both uncorrected and corrected position information.

STATIC TESTING

Static testing of the GPS collars was conducted during the spring and summer of 2003 at both the University of Kentucky's Spindletop farm located in Fayette County, Kentucky, and at the Animal Research Center (ARC) located in Woodford County, Kentucky. Three different static tests were performed to determine the accuracy of the GPS collars under various field conditions commonly encountered by grazing cattle. These conditions included an open field with no obstructions (i.e., trees), underneath trees with full foliage, and near high-tension electric fence lines. The open field test was conducted at the Spindletop farm because of its spacious, flat, crop fields, while the remaining two static tests were conducted at the ARC, the site of an ongoing intensive grazing research project. A Trimble real-time kinematic global positioning system (RTK-GPS) (5800 RTK rover, MS750 base station) with an advertised horizontal accuracy of 2 cm was used to determine the location of each collar during the open field and fence line static tests. Conventional surveying techniques were used to determine collar locations during the tree cover static test. The foliage from the tree interfered with the RTK-GPS system, producing an unacceptable level of accuracy.

The base station GPS receiver was placed at a surveyed position, and differential correction information was transmitted to the rover receiver in real-time. For the open field static test site, the RTK base station position consisted of a National Geodetic Survey benchmark maintained by the Lexington-Fayette Urban County Government. For the tree cover and fence line static tests, the RTK base station location consisted of a surveyed benchmark established on the ARC. Consecutively, a tripod was used to place the RTK rover antennae over each GPS collar position, and data were collected at 1 s intervals for a period of 1 min. The data were filtered in a spreadsheet to select only the points with the highest GPS quality (i.e., RTK fix). These data were then averaged to determine the precise locations of the GPS collars. These precise locations of the GPS collars were used to evaluate the accuracy of the data collected from the GPS collars during the static tests.

Open Field Static Test

Each GPS collar was individually placed on a testing stand that consisted of a 150 × 100 × 50 mm (length × width × depth) base that was nailed onto a 0.9 × 0.6 × 0.6 m (length × width × depth) wooden stake (fig. 1). The testing stations were arranged in a square grid pattern with 1 m spacing (fig. 2). One meter spacing was an acceptable separation to prevent any interference from one collar to the next while maintaining a close enough proximity such that the test site topography or satellite visibility did not bias the data. Data were collected at 5 min intervals from March 11 to March 14, 2003. A 24 h period (12:00 p.m., March 13, to 12:00 p.m., March 14) was selected to analyze the results from each GPS collar. This specific 24 h period was selected because it provided the greatest amount of position data with a 3D fix status for all of the tested collars. Since only data

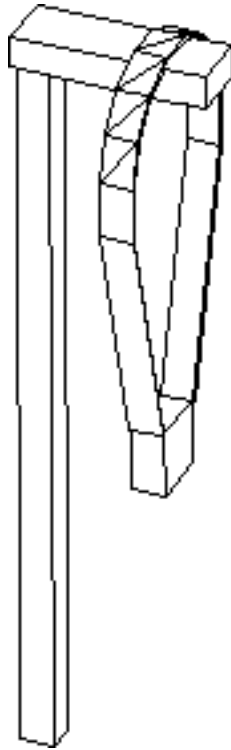


Figure 1. GPS collar on testing stand.

with 3D fix status (i.e., data with minimal error) will be examined in the intensive grazing studies underway at the University of Kentucky, it is preferable to examine the capabilities and limitations of the collars using this parameter as a guideline.

Tree Cover Static Test

To evaluate the effects of tree cover on GPS collar accuracy, the stands were aligned in two rows radiating from the trunk of a large tree (fig. 2). One row consisted of seven collars, while the other consisted of eight collars. Only 15 collars were tested in this manner because two collars were not functioning properly at the time the test was conducted. A minimum spacing of 1 m was maintained between each collar. Data were collected from the collars from May 30 to June 2, 2003, a period when the tree used for testing displayed full foliage. A 24 h period (12:00 p.m., May 31, to 12:00 p.m., June 1) was selected to analyze the collected data from each collar, as previously described.

Fence Line Static Test

Testing stands for the fence line test were erected adjacent to a five-strand high-tension electric fence (~5500 V). An effort was made to place collars next to a variety of fence features such as wooden posts, steel posts, gates, and wire while maintaining at least a 1 m spacing between collars (fig. 2). A total of 15 collars were tested in this fashion, as two were malfunctioning at the time the test was conducted. Data were collected from June 6 to June 9, 2003, and a 24 h period (12:00 p.m., June 7, to 12:00 p.m., June 8) was selected, as previously described, for analysis.

STATIC TESTING DATA ANALYSIS

The accuracies of the GPS collars during all three static tests were examined using guidelines established by the Institute of Navigation as outlined in *ION STD 101: Recommended Test Procedures for GPS Receivers* (ION, 1997). This manual is based in large part on original Department of Defense GPS specification documents and is the recommended protocol for performing static GPS accuracy tests (Stombaugh et al., 2002). Because the tracking of grazing activity focuses on animal location, specifically latitude and longitude, only the horizontal accuracy and not the vertical accuracy of the collars were examined. ArcGIS was used to convert the stand data and collar data from WGS-1984 geographic coordinates to UTM Cartesian coordinates (NAD 83, Zone 16N). While it is recognized that some researchers have demonstrated that latitudinal and longitudinal errors have differing distributions, the choice was made to use the procedure recommended by ION (1997) to compute composite horizontal accuracy (ΔH) as shown in equation 1:

$$\Delta H = (\Delta e^2 + \Delta n^2)^{\frac{1}{2}} \quad (1)$$

where Δe is the change in longitude or easting, and Δn is the change in latitude or northing. The change in easting or longitude (Δe) is relative to the specified testing stand location (eq. 2). Similarly, the change in northing or latitude (Δn) is relative to the specified testing stand location (eq. 3):

$$\Delta e = \lambda_{\text{collar}} - \lambda_{\text{stand}} \quad (2)$$

$$\Delta n = \phi_{\text{collar}} - \phi_{\text{stand}} \quad (3)$$

where λ is longitude and ϕ is latitude.

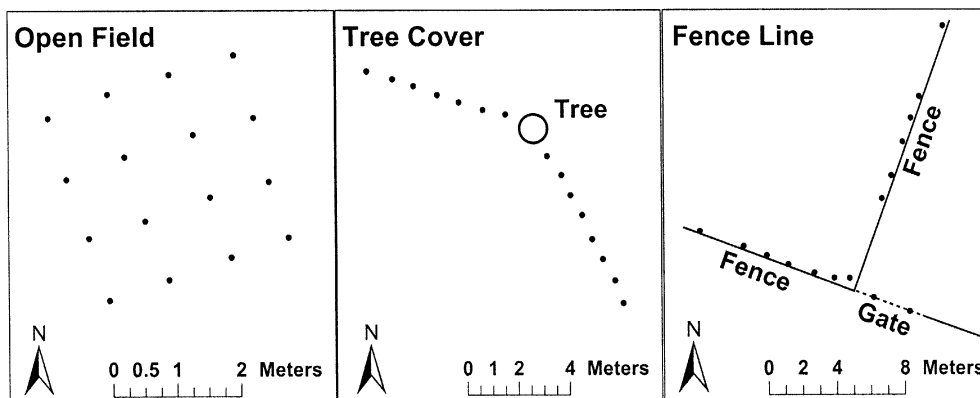


Figure 2. Configuration of GPS collars during static testing.

As determined from the average of the RTK–GPS survey data points, the testing stand latitude and longitude were subtracted from each collar position point (latitude and longitude) collected from the respective GPS collar. Equations 1 through 3 were then used to calculate ΔH for each data point for each GPS collar within the specified 24 h period. The calculated ΔH values within the designated time period were then ranked to determine the most common methods of comparing GPS accuracy: minimum (0%), CEP (circular error probable) or 50%, rms (root mean square error) or 1 sigma (one standard deviation, 68%), R95 (horizontal 95% accuracy), 2drms (distance root mean square error) or 2 sigma (two standard deviations, 98%), and maximum (100%) (Stombaugh et al., 2002). These values indicate the horizontal distance from the stand that contains the specified percentage of GPS collar data points. The primary assumption made for this analysis is that the error distribution is Gaussian rather than Rayleigh (fig. 3). A Gaussian distribution is fairly representative of stand-alone GPS errors over a period of hours (van Diggelen, 1998; Moen et al., 1997; Moen et al., 1996). As such, both the static and dynamic GPS collar tests were each conducted over a 24 h period, which should closely follow a Gaussian distribution. One-way ANOVAs were used to: (1) determine if statistical differences existed between GPS collars for a given test, and (2) determine if the above listed horizontal accuracies of the collars statistically differed among the tests. To ensure that the differences in horizontal accuracies detected between the tests or treatments were not due to individual collars, those collars that differed from the others were not considered. Collars that were not used in all three static tests were also eliminated. Statistical software was used to conduct the ANOVA's checks for violations of normality and equal variance. If either assumption is violated, the software provides the option of performing non-parametric procedures.

DYNAMIC TESTING

While static tests provide an understanding of the capabilities and limitations of the GPS collars under specific conditions, such as the ones previously specified, they

provide limited information on the performance of these collars under real-world conditions (i.e., cattle movement). For research, a significant percentage of the data points will be collected under conditions in which the animal is moving. As such, testing of the GPS collars should reflect the dynamic state of these animals.

Dynamic testing occurred on a fixture-based test facility located on the roof of the Charles E. Barnhart building at the University of Kentucky. The device is optimally located in that it provides the GPS unit with a relatively unobstructed view of the sky. Consisting of a 7.5 m rotating arm, the dynamic testing device rotates the GPS unit (affixed to the end of the arm) in a circular motion with a constant velocity. This apparatus only permitted the testing of one GPS collar at a time. Stombaugh et al. (2002) provides detailed information regarding the testing apparatus as well as advantages and disadvantages associated with conducting dynamic tests in this fashion.

DYNAMIC TESTING DATA ANALYSIS

The distance measurement of each data point collected by the GPS collar to the GPS collar's actual path was determined using a custom script in ArcGIS. As noted by Stombaugh et al. (2002), this method tends to underestimate the error of the GPS collar.

Once the distance of each point from the known test path was computed, the values for the test period were ranked to determine the common GPS accuracy comparison values previously described. Due to the length of time required for each test (24 h period) plus the concurrent use of the collars in an active research project to intensively monitor beef cattle movement, dynamic testing of the collars occurred over a three-month period, and the allotted testing period was limited to a few days. As with the static testing, one-way ANOVAs were performed to determine: (1) if the collars used in the dynamic testing differed from one another regarding horizontal accuracy, and (2) if the horizontal accuracies exhibited during the static tests differed from those seen during the dynamic testing. The same criterion used in the static test analysis for removing collars from further consideration was used in the dynamic test analysis.

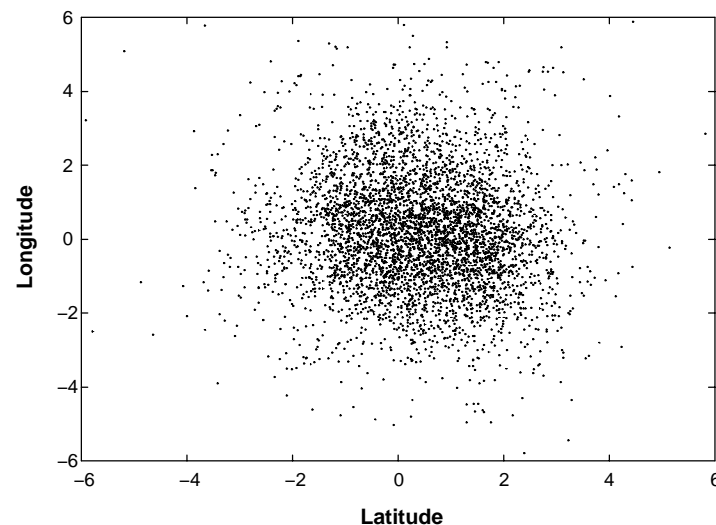


Figure 3. Sample of error distributions from the open field static test.

RESULTS

STATIC TESTING

Results from the open field, tree cover, and fence line static tests revealed horizontal position accuracies for the three examined 24 h periods at the 1 sigma or 68% of 2.22 ± 0.17 m, 5.22 ± 0.69 m, and 3.29 ± 0.54 m, respectively (tables 1 to 3).

STATIC TESTING DATA ANALYSIS

Since the collar horizontal accuracy data used to detect differences between collars within a test group were determined to be from a non-normal distribution, the

Kruskal–Wallis one-way ANOVA on ranks was performed for the first part of the analysis procedure. For the open field test, the collar comparison indicated that collar 711 differed significantly from the others ($P = 0.003$) and was therefore removed from further consideration. Differences from the remaining collars were also noted for collar 711 ($P < 0.001$) and collar 004 ($P < 0.001$) for the tree cover test, thus eliminating them from further consideration. Interestingly, both collars were two of the farthest away from the base of the tree. Finally, analysis of the collars used in the fence line test indicated that two collars displayed significant differences from the others: collars 706 ($P < 0.001$) and 708 ($P <$

Table 1. Horizontal accuracy comparison of GPS collars for the open field static test.

Collar	Accuracy Description ^[a]					
	Minimum (0%) ^[b]	CEP (50%)	1 Sigma (68%)	R95 (95%)	2 Sigma (98%)	Maximum (100%)
001 ^[c]	0.2	1.7	2.1	3.6	4.3	5.0
004	0.0	1.6	2.1	3.7	4.6	8.5
011 ^[c]	0.2	1.6	2.2	3.6	4.6	5.3
703 ^[c]	0.3	1.6	2.1	3.8	4.7	11.5
704 ^[c]	0.1	1.7	2.3	3.6	4.2	8.2
705 ^[c]	0.1	1.7	2.1	3.8	4.5	7.8
706	0.1	1.6	2.2	3.7	4.4	5.4
707	0.1	1.7	2.3	3.7	4.2	7.8
708	0.1	1.7	2.3	4.0	4.6	15.2
710 ^[c]	0.0	1.7	2.2	3.9	4.9	7.4
711	0.2	2.1	2.8	7.1	9.0	25.9
712 ^[c]	0.1	1.7	2.2	4.0	5.2	7.6
713	0.1	1.7	2.2	3.8	4.2	5.3
714	0.1	1.7	2.1	3.6	4.3	6.4
715 ^[c]	0.0	1.6	2.1	3.6	4.4	6.3
716	0.1	1.7	2.2	3.4	4.2	7.6
Mean \pm SD (all collars)	0.11 \pm 0.08	1.69 \pm 0.11	2.22 \pm 0.17	3.93 \pm 0.86	4.77 \pm 1.16	8.83 \pm 5.23
Mean \pm SD (selected collars) ^[c]	0.13 \pm 0.10	1.66 \pm 0.05	2.16 \pm 0.07	3.74 \pm 0.16	4.60 \pm 0.33	7.39 \pm 2.04

^[a] All horizontal accuracies are expressed in meters.

^[b] Values in parentheses indicate associated probabilities.

^[c] Eight GPS collars met the criteria for the static test comparisons.

Table 2. Horizontal accuracy comparison of GPS collars for the tree cover static test.

Collar	Accuracy Description ^[a]					
	Minimum (0%)	CEP (50%) ^[b]	1 Sigma (68%)	R95 (95%)	2 Sigma (98%)	Maximum (100%)
001 ^[c]	0.3	3.8	5.1	10.4	13.6	17.3
004	0.2	4.3	5.7	13.3	16.2	28.4
011 ^[c]	0.3	3.5	4.7	11.1	13.5	17.9
703 ^[c]	0.2	4.1	5.5	14.8	20.4	68.7
704 ^[c]	0.3	3.7	5.0	13.6	18.4	47.0
705 ^[c]	0.0	3.9	5.4	15.0	17.1	42.2
706	0.3	3.6	4.7	9.2	12.8	19.9
707	0.3	3.8	5.3	11.9	13.7	19.4
708	0.1	3.9	5.3	11.4	19.2	30.9
709	0.3	3.2	4.4	9.9	13.5	47.5
710 ^[c]	0.1	3.6	5.1	12.6	14.8	36.5
711	0.1	4.9	7.3	16.8	23.9	62.3
712 ^[c]	0.1	3.5	4.8	12.1	16.2	33.5
714	0.1	3.4	4.5	9.8	13.3	31.9
715 ^[c]	0.3	3.9	5.5	12.7	15.9	35.0
Mean \pm SD (all collars)	0.21 \pm 0.10	3.81 \pm 0.41	5.22 \pm 0.69	12.31 \pm 2.15	16.17 \pm 3.18	35.89 \pm 15.52
Mean \pm SD (selected collars) ^[c]	0.14 \pm 0.05	2.33 \pm 0.10	3.04 \pm 0.13	5.49 \pm 0.41	6.23 \pm 0.48	9.29 \pm 1.78

^[a] All horizontal accuracies are expressed in meters.

^[b] Values in parentheses indicate associated probabilities.

^[c] Eight GPS collars met the criteria for the static test comparisons.

Table 3. Horizontal accuracy comparison of GPS collars for the fence line static test.

Collar	Accuracy Description ^[a]					
	Minimum (0%) ^[b]	CEP (50%)	1 Sigma (68%)	R95 (95%)	2 Sigma (98%)	Maximum (100%)
001 ^[c]	0.1	2.3	3.0	5.2	5.8	8.7
004	0.2	2.5	3.2	5.5	6.4	10.2
011 ^[c]	0.2	2.2	3.0	5.3	6.3	10.3
703 ^[c]	0.2	2.4	3.1	6.4	7.1	10.8
704 ^[c]	0.1	2.3	3.0	5.4	6.2	8.4
705 ^[c]	0.2	2.2	2.9	5.3	6.6	12.6
706	0.1	3.6	4.5	9.4	12.5	38.8
708	0.2	3.4	4.5	8.8	9.9	16.8
709	0.2	2.2	3.0	5.1	5.8	13.3
710 ^[c]	0.1	2.5	3.3	5.6	6.1	7.6
711	0.1	3.0	3.8	9.8	17.6	79.8
712 ^[c]	0.1	2.4	3.1	5.1	5.5	8.3
713	0.2	2.3	2.9	5.1	6.7	9.6
715 ^[c]	0.1	2.3	2.9	5.6	6.2	7.6
716	0.3	2.4	3.1	5.6	6.8	11.8
Mean ±SD (all collars)	0.16 ±0.06	2.53 ±0.44	3.29 ±0.54	6.21 ±1.66	7.70 ±3.30	16.97 ±19.01
Mean ±SD (selected collars) ^[c]	0.21 ±0.10	3.75 ±0.21	5.14 ±0.31	12.79 ±1.63	16.24 ±2.37	37.26 ±16.48

^[a] All horizontal accuracies are expressed in meters.

^[b] Values in parentheses indicate associated probabilities.

^[c] Eight GPS collars met the criteria for the static test comparisons.

0.001). The most notable difference regarding these two collars was that they were both placed on a metal gate, while the other collars were placed on test stands as shown in figure 1. These two collars were also removed from further analysis procedures. A total of four additional collars (707, 709, 713, and 714) were removed from statistical consideration because they were not tested in all three scenarios. Since differences were detected between collars within a test, the collars themselves are a source of variability. As such, it is questionable to perform a one-way ANOVA on the test conditions using the collars as repetitions (i.e., since the collars were shown not to be the same, they are not actually repetitions). The remaining collars considered for further analysis included 001, 011, 703, 704, 705, 710, 712, and 715.

Results from the one-way ANOVAs conducted to determine if the horizontal accuracies of the collars differed among the static tests indicated that the method of comparing GPS accuracy – i.e., minimum (0%), CEP (circular error probable) or 50%, rms or 1 sigma (one standard deviation, 68%), R95 (horizontal 95% accuracy), 2drms or 2 sigma (two standard deviations, 98%), or maximum (100%) – largely controlled whether differences were detected between the tests (table 4). For example, at the CEP level, differences in horizontal accuracy were only detected between the tree test and the open field test, with other combinations (tree vs. fence and fence vs. open) resulting in no significant

difference. However, a 1 sigma GPS accuracy rating detected differences in horizontal accuracies among all three treatment or test combinations. Without careful consideration of the mean values of the selected collars evaluated in the tests, the results of these ANOVAs can be misleading (tables 1 to 3). For the most part, the tree test differed significantly from both the open field and the fence line test in that it produced much larger horizontal or position errors for the majority of the comparison levels.

DYNAMIC TESTING

Due to the demands of an ongoing research project at the University of Kentucky, plus the 24 h period required to test each collar, dynamic testing of the GPS collars spanned a three-month period in 2003. Collars were tested for 12 separate periods of approximately 24 h: June 24 to 25 (collar 709), July 2 to 3 (collar 712), July 8 to 9 (collar 011), August 21 to 22 (collar 710), August 25 to 26 (collar 707), August 27 to 28 (collar 703), August 28 to 29 (collar 705), September 8 to 9 (collar 704), September 9 to 10 (collar 001), September 10 to 11 (collar 708), September 15 to 16 (collar 716), and September 16 to 17 (collar 004) (table 5). Five of the collars were damaged during use in a grazing study in August 2003, so they were not available for the dynamic test. Over the test period, the average GPS accuracy values for the 12 collars were as follows: minimum or 0% (0.00 ±0.00 m), CEP or

Table 4. Pairwise comparison results for the static tests.

Static Test	Detectable Differences					
	Minimum (0%) ^[a]	CEP ^[b] (50%)	1 Sigma (68%)	R95 ^[b] (95%)	2 Sigma ^[b] (98%)	Maximum ^[b] (100%)
Tree cover	A ^[c]	A (3.75) ^[d]	A (5.14)	A (12.65)	A (16.05)	A (37.75)
Fence line	A ^[c]	AB (2.30)	B (3.04)	AB (5.35)	AB (6.20)	B (8.55)
Open field	A ^[c]	B (1.70)	C (2.16)	B (3.70)	B (4.55)	B (7.50)

^[a] Column title values in parentheses indicate associated probabilities.

^[b] Indicates nonparametric procedures were used. Median value is reported instead of mean value.

^[c] Overall mean reported because ANOVA resulted in no significant differences (0.16 m).

^[d] Table content values in parentheses indicate mean or median values in meters.

Table 5. Horizontal accuracy comparison of GPS collars for the dynamic tests.

Collar	Mean Values ^[a]					
	Minimum (0%) ^[b]	CEP (50%)	1 Sigma (68%)	R95 (95%)	2 Sigma (98%)	Maximum (100%)
001 ^[c]	0.0	1.3	2.0	4.2	5.1	6.4
004	0.0	1.3	2.1	5.0	5.7	9.1
011 ^[c]	0.0	1.0	1.6	3.5	4.7	7.8
703	0.0	1.6	2.5	4.8	6.3	7.3
704 ^[c]	0.0	1.4	2.0	4.2	5.4	8.6
705 ^[c]	0.0	1.4	2.0	4.	5.7	8.4
707	0.0	1.6	2.9	6.4	7.8	15.9
708	0.0	1.2	1.7	3.9	4.8	7.0
709	0.0	1.1	1.7	3.6	5.2	12.3
710 ^[c]	0.0	1.1	1.6	3.8	5.3	9.1
712	0.0	1.8	2.8	5.3	6.3	9.7
716	0.0	1.4	2.2	4.3	5.2	6.7
Mean ±SD (all collars)	0.00 ±0.00	1.33 ±0.24	2.09 ±0.44	4.48 ±0.83	5.63 ±0.85	9.03 ±2.70
Mean ±SD (selected collars) ^[c]	0.00 ±0.00	1.24 ±0.18	1.84 ±0.22	4.10 ±0.49	5.24 ±0.37	8.06 ±1.04

^[a] All values are in meters.

^[b] Values in parentheses indicate associated probabilities.

^[c] Eight GPS collars met the criteria for the static test comparisons.

50% (1.33 ±0.24 m), 1 sigma or 68% (2.09 ±0.44 m), R95 or 95% (4.48 ±0.83 m), 2 sigma or 98% (5.63 ±0.85 m), and maximum or 100% (9.03 ±2.70 m).

DYNAMIC TESTING DATA ANALYSIS

The horizontal accuracy data used to detect differences between the collars used in the dynamic testing was determined to be from a non-normal distribution, so the Kruskal–Wallis one-way ANOVA on ranks was performed. A comparison of the collars indicated that collars 703, 707, and 712 differed from the others tested. All three of the differing collars had higher median errors than the other dynamically tested collars.

After excluding collars 703, 707, and 712 from the dynamic data set and removing any other collars that were not present in all three static tests and the dynamic test, only five collars were left for further comparison (001, 011, 704, 705, and 710). Results from the one-way ANOVAs conducted to determine if the horizontal accuracies of the collars differed between the static tests (open field, tree cover, and fence line) and the dynamic test were quite mixed. Detectable differences between the static and dynamic tests were largely associated with the method of comparing GPS accuracy (table 6). As the comparison criteria increased in percentage (i.e., 68% to 95%), differences between the static and dynamic tests were less significant. At the minimum (0%), CEP (50%), and 1 sigma (68%) levels, the dynamic tests produced horizontal errors significantly less than those seen in the static tests. However, at the R95 (95%), 2 sigma (98%),

and maximum (100%) levels, the horizontal accuracy errors from the dynamic tests were comparable to those from the static tests. As stated in Stombaugh et al. (2002), the errors from the dynamic testing of the GPS collars are most likely an underestimate.

CONCLUSIONS

This project provided much needed information regarding the accuracy of the horizontal position data collected by the GPS collars used in an intensive riparian grazing study being conducted at the University of Kentucky. Results from the static tests indicated that the key pasture feature most negatively impacting collar performance was tree cover. Based on 1 sigma (68%), a common method used in reporting GPS receiver accuracy, the GPS collars produced errors on the order of 2.5 times greater under tree cover than in an open field. Using the same accuracy level, the GPS collars produced errors an average of 1.5 times greater near fences than in an open field. It is important to note that the only accuracy level at which the GPS collars tested near the fence line produced horizontal position errors that were significantly greater than those produced under open field conditions was at the 1 sigma (68%) accuracy level. However, this equated to a difference of less than 1 m.

Results from the dynamic tests indicated that the horizontal accuracy errors were significantly lower at the minimum (0%), CEP (50%), and 1 sigma (68%) levels but were

Table 6. Pairwise comparison results for the static tests versus the dynamic tests.

Test	Detectable Differences					
	Minimum (0%) ^[a]	CEP (50%)	1 Sigma (68%)	R95 (95%)	2 Sigma (98%)	Maximum (100%)
Tree cover	A (0.30) ^{[b],[c]}	A (3.70)	A (5.06)	A (12.60) ^[c]	A (14.80) ^[c]	A (35.50) ^[c]
Fence line	AB (0.10)	B (2.30)	B (3.04)	AB (5.30)	AB (6.20)	AB (8.70)
Open field	AB (0.10)	C (1.680)	C (2.18)	B (3.60)	B (4.50)	AB (7.40)
Dynamic	A (0.00)	D (1.24)	D (1.84)	B (4.20)	B (5.30)	B (8.40)

^[a] Column title values in parenthesis indicate associated probabilities.

^[b] Table content values in parenthesis indicated mean or median values in meters.

^[c] Indicates nonparametric procedures were used. Median value is reported instead of mean value.

comparable to the static tests at the R95 (95%), 2 sigma (98%), and maximum (100%) levels. At the 1 sigma (68%) level, the dynamic tests produced horizontal errors 1.2 times less than the open field static test, 1.7 times less than the fence line static test, and 2.75 times less than the tree cover static test. This equated to a difference of less than 1 m for the open field test, 1.2 m for the fence line test, and over 3.2 m for the tree cover test. These results indicate that the circular testing path of the dynamic testing apparatus underestimates the horizontal accuracy of the collars.

Knowledge of the capabilities and limitations of these collars must be weighed to determine the most appropriate method of experimental design, data collection, and data analysis. Several key points that must be considered are:

- Some GPS collars differed statistically from other collars used within a static test and within the dynamic tests. This condition is likely occurring during normal use, but it would be impossible to detect which collar differed from the others at the time of use. As seen in the static and dynamic tests, no single collar differed significantly from the others across all tests, thus preventing its elimination from future use. When using these collars in grazing studies, the underlying assumption is that all collars perform the same with regard to horizontal accuracy.
- With regard to pasture design and data analysis, the open field test was similar to the predominate physiographic conditions present at the ARC, especially along the stream banks. As such, the collars will likely produce horizontal accuracies similar to those seen in the open field tests (4 m 95% of the time). When analyzing collar data, a 4 to 5m buffer surrounding the boundaries of the creek would be sufficient to identify cattle presence in these highly sensitive areas.
- Fence lines, areas frequented by cattle, may produce some additional error over that seen in an open field.
- The greatest errors in horizontal accuracy occur under tree cover (i.e., full foliage). During the winter months, when deciduous trees lose their foliage, these errors would likely be reduced. Therefore, the method of analyzing position data with respect to tree cover would differ seasonally. Understanding the impact of tree cover on GPS collar performance is especially important if the researcher requires information on frequency and duration with regards to a shaded pasture feature.
- These GPS collars are most practical in open fields or in pastures with a low level of tree cover (i.e., little or no foliage) and are not ideal for wooded areas. The degree of accuracy required by the researcher would dictate whether or not to use visual observations rather than the GPS collars.
- Each GPS collar can generate 5,208 data points. A potential method to determine inaccurate data points would be to compare each point subsequent in time and make a judgment regarding the probability that the animal did or did not move in that manner. For example, if at time A and time C, the animal was within 5 m of a water tank but was 30 m away at time B, the data point for time B is probably inaccurate and could be filtered from the data set.
- Buffers representing the expected error in horizontal position accuracy could be created around key pasture features. Data points falling within a single buffer

could be assigned to that pasture feature. These buffers, used to approximate error, would likely overlap in certain areas. Those data points located in overlapping buffer areas would be more difficult to assign to one particular feature.

- To better test the capabilities and limitations of the GPS collars under dynamic conditions, RTK-GPS should be employed. Pairing a GPS collar with the rover from the RTK-GPS system, so that both instruments travel parallel paths, would achieve a higher level of accuracy.

While GPS collars provide vital information regarding animal movement without the labor intensity and observer interference associated with visual observations, their use in grazing studies must be carefully planned with consideration of collar accuracy limitations. This is especially true if pasture improvements such as fertilizer and/or herbicide application rates are tested in subplots within a pasture. The researcher must ensure that: (1) the minimum subplot size is greater than the range of expected errors, and (2) no other pasture features of interest (i.e., trees or water) are located nearby (i.e., within the range of expected errors). When features are located more closely than the expected range of errors, difficulty may be encountered in assigning the GPS collar data to a specific feature or treatment. Understanding the capabilities and limitations of the GPS collars is essential for a successful experimental design.

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