Considerations for use of Collar Mounted GNSS Receivers to Analyze Animal Behavior

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ABSTRACT

The use of GNSS (Global Navigation Satellite System) technology to analyze animal movements and behavior has become common practice. As with any technology proper experimental design is important to limit uncertainty. However the use of new technologies brings an additional consideration as a well-accepted experimental design may not exist. This paper addresses common problems associated with GNSS technology to analyze animal behavior using a case study by Webber et al. (2012). Issues addressed in this paper are 1) how GNSS receiver precision can be calculated, 2) receiver failures, 3) pseudo replication, and 4) spatial auto-correlation and sampling frequency. Using GIS, a precision assessment was calculated for two types of GNSS receivers. Horizontal precision was ± 4.45 m at 95% confidence interval (CI) and ± 3.56 m at 95% CI for receiver types one and two respectively. An overall failure rate of 79% was observed. By using a true repeated measures experiment, simple and sacrificial pseudo replication was eliminated. Lastly, the use of an appropriate statistical test (e.g., PROC MIXED) excludes implicit pseudo replication concerns. In this way, the experimental design and analysis techniques precluded the problematic issues of both pseudo replication and spatial auto-correlation.

INTRODUCTION

Methods to monitor animal location vary from observational position plotting, to radio telemetry, to collar mounted GNSS (Global Navigation Satellite System) receivers. The use of GNSS technology (Morehouse 2010, Woodside 2010) and radio telemetry (Shivik et al. 1996) to map and analyze animal activities has become common practice. Three types of GNSS receivers may be used; recreational-, mapping-, or survey-grade. Collar mounted GNSS receivers are typically considered either recreational- or mapping-grade receivers. Recreational-grade GNSS receivers cannot be differentially corrected and cannot achieve greater than ± 3 m precision, while mapping-grade receivers are differentiated by the ability to be differentially corrected (Ganskopp and Johnson 2007) and thereby achieve sub-meter precision. The precision of each receiver also depends on the chip set it contains as well as environmental factors encountered during the recording period.

The use of any methodology to plot animal locations requires an evaluation of positional uncertainty. Inferring action from a series of locations additionally requires an evaluation of sample frequency. Results from Johnson and Ganskopp (2008) demonstrated a positive relationship between the frequency of positional data collection and the precision of perceived animal activity measurements. In the Johnson and Ganskopp study sampling frequencies from five minutes to 160 minute intervals were used to measure distance traveled by each animal. Results illustrate a direct relationship between sampling frequency and the measurement of distance traveled. When sample frequency was raised from five minutes to ten minutes there was an approximate 12% decrease in overall distance traveled. As the frequency was raised to 160 minutes the estimated distance traveled was reduced by approximately 50% of the original five minute interval estimate. Measurement of distance traveled decreased as data frequency decreased but it is important to note as data collection frequency increases so does spatial autocorrelation, and the independence of a sample point. This study did not measure data collection at closer intervals than five minutes; in this way it could not determine when the points became so autocorrelated that there was no new data by the more frequent collection of points (e.g. - one second intervals or sub-second intervals).

In addition to positional uncertainty and sample frequency there is also concern of pseudo replication and spatial auto-correlation. Hurlbert (1984 and 2004) described pseudo replication by first identifying four types of pseudo replication; simple, sacrificial, Chi-square, and implicit pseudo replication. Simple pseudo replication is a non-replicated experiment. Sacrificial pseudo replication is where the experiment involves true replication but the data for the replicates is joined before statistical analysis or where more than one sample is taken from an experimental unit and treated as individual replicates, not subsamples. Chi-square pseudo replication is the misuse of the Chi-square test resulting in simple or sacrificial pseudo replication. Lastly, implicit pseudo replication involves using standard errors or confidence interval along with the mean to discuss effects of a variable in a non-replicated experiment without applying any direct tests of significance. Avoiding pseudo replication is important and needs to be considered at the experimental design stage of any study. It is important to note that some debate these guidelines and argue it is acceptable to use inferential statistics without replication (Oksanen 2001, Oksanen 2004, Cottenle and Meester 2003).

Spatial auto-correlation is also another relevant and important issue (Legendre 1993). Integrally tied to spatial auto-correlation is the independence of animal movements (Swihart and Slade 1997, Weber et al. 2001). Swihart and Slade (1997) described a method to determine independence of animal movements; they also state that independent observations contain more spatial information than auto-correlated observations. For instance, the measure of distance traveled may be directly affected because *where* an animal moves is effected by factors such as habitat (Dausrud et al 2006), the location of other animals (Animut et al 2005, Dausrud et al 2006, and Sibbald 2008), aspect, and slope. Once again experimental design is important to avoid issues of spatial auto-correlation as is the understanding that some types of auto-correlation may be unavoidable but are nonetheless important to be recognized.

To better understand these issues, a case study is introduced (Webber et al. 2003) where domestic sheep were fitted with collars carrying GNSS receivers to determine if the presence of livestock guardian dogs (LGD's) affect their behavior. This study was a manipulative study (Hurlbert 1984) consisting of four trials where each trial had a group of sheep with LGDs and another group where LGD's were absent. The experimental design used two replicated trials varying spatially or temporally. Within each of the four trials subsamples were taken of individual sheep and the movement and behavior of these sheep used to determine if a change in behavior was observed relative to LGD presence.

METHODS

Study Area

The case study was conducted at the U.S. Sheep Experiment Station (USSES) located in East Idaho and Southwestern Montana. The USSES consists of five separate ranches totaling approximately 19558 ha. These lands were used for spring, summer, and fall grazing with feed lots used year-round as necessary. The USSES maintains 3000 adult sheep (Rambouillet, Targhee, Columbia, Polypay, Suffolk, and crossbreeds) with additional attending young (Laufman 2009).The sheep may be exposed to predation by grizzly bears (species), black bears (*Ursus americanus*), mountain lions (*Puma concolor*), grey wolves (species), and coyotes (species) (Kozlowski 2009, Shivik 1996, Zimmermann 2003). Elevation at the USSES ranges from 1463 meters to over 3000 meters above sea level. USSES lands within the Snake River Plain of Idaho receive approximately 25 cm of precipitation annually.

The specific site selected for this study were four pastures (approximately 65 ha each in size) at the USSES Headquarters Property near Dubois, Idaho (Fig. 1). These pastures were fenced with predator-proof fencing. Annual plant production was relatively uniform and estimated to be 144 animal unit months (AUM) within each pasture. The primary plant community is three-tip sagebrush (*Artemisia tripartita*). Blue bunch wheatgrass (*Psuedoroegenaria spicata*) is the dominant grass species.

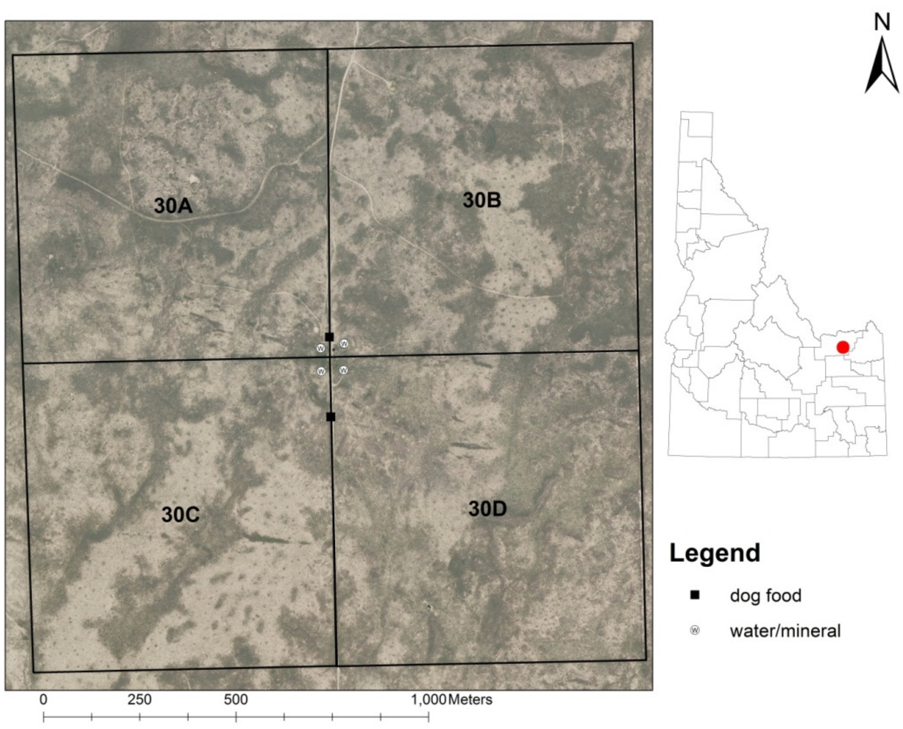

Figure 1 Map of four pastures (65 ha each), located at the U.S. Sheep Experiment Station near Dubois, Idaho. Pastures were enclosed with predator-proof fencing and used for sheep behavioral trials investigating the effects of livestock guardian dog (LGD) presence on the daily distance traveled by sheep grazing sagebrush steppe rangelands. Water/mineral supplement and dog food locations are marked.

Experimental Design

With proper experimental design and true replication the problem of pseudo replication can be eliminated. In this case study 560 mature ewes and their suckling lambs (Targhee, Columbia, Polypay, or crossbreeds) --or about 19% of the USSES adult sheep population-- were used. These ewes were experienced with LGDs and, prior to the study had been continuously managed with them throughout all parts of the year. Ewes, with their attending lambs, were randomly assigned to four groups (Groups 1, 2, 3, and 4) of 140 ewes each. These groups were studied in specific trial periods called Trials 1, 2, 3, and 4 (described in more detail below). Groups 1 and 2 were used during Trials 1 and 2 (test period one) and Groups 3 and 4 were used during Trials 3 and 4 (test period two). During each trial, groups were placed in diagonally adjacent pastures, one group with two LGDs (an Akbash and an Akbash/Great Pyrenees cross) and one group without LGDs. At the end of each trial the sheep were moved to opposing pastures and the LGDs were placed with the previously unaccompanied group of sheep. Following trial two, the sheep were removed from the pastures and the experiment was replicated with the two independent groups of sheep and the same LGDs (table 1). This represented a true replication, where animals were not resampled but additional samples came from new groups of sheep.

Table 1 Livestock guardian dog (LGD) treatment and pasture assignments for sheep behavioral trials conducted at the U.S. Sheep Experiment Station near Dubois in eastern Idaho during spring 2010.

Test Period	Trial	Start Date	End Date	Sheep Group	Pasture	LGDs
1	1	4/29/2010	4/30/2010	1	30D	Present
1	1	4/29/2010	4/30/2010	2	30A	Absent
1	2	5/2/2010	5/3/2010	1	30C	Absent
1	2	5/2/2010	5/3/2010	2	30B	Present
2	3	5/6/2010	5/7/2010	3	30A	Present
2	3	5/6/2010	5/7/2010	4	30D	Absent
2	4	5/9/2010	5/10/2010	3	30B	Absent
2	4	5/9/2010	5/10/2010	4	30C	Present

Data Collection

Two GNSS receiver types were used and later determined to be distinguishable by their level of precision. All GNSS receivers were programmed to collect and record the collared sheep's location and speed at one-second intervals. The date and time of each location record along with additional quality parameters such as the number of GNSS satellites used to calculate the location were also recorded.

Positional uncertainty and receiver failure rates

Neither of the two GNSS receiver types used was differentially correctable. To determine their positional uncertainty, two GNSS receivers (one of each type) were attached to fence posts within the study area, and remained stationary throughout the entire study. These receivers were used to determine the precision of each type of GNSS receiver and were assumed to be representative of each receiver type. However, since only one sample of each collar type was used, measures of central tendency are not available for this case study. Using the ArcGIS spatial statistics tool (Directional Distribution using Standard Deviational Ellipse) positional uncertainty was calculated using two standard deviations about the mean resulting in an ellipse with 95% of observations falling within the ellipse.

Many factors effect receiver functionality such as physical impact and battery failure. Overall failure rate was calculated as was failure rate by sheep group. Batteries were replaced at the end of each test period and not when animals were moved between pastures.

RESULTS AND DISCUSSION

The design strengths of this study are that its experimental design limited the treatment within the experiment to one, LGD presence, while still having replication within the experiment. A weakness of the study is that variation existed spatially (Hurlbert 1984). Since the experiment took place from 29 March 2010 to 10 April 2010 there is a period of temporal variability to be addressed. As a result, several related factors could play a role in altering animal behavior across this time period. One factor is varying weather conditions, another is the fact that the young lambs are aging and growing and may exhibit different nutritional demands between the beginning and end of the experiment period, thereby effecting the movement and behavior of the sheep, and yet another temporal factor is related to the phenology of forage in the pastures which can rapidly change in the active growth periods of the spring. The temporal issues of this study were minimized by completing the entire experiment in approximately one week.

Another weakness of this study's experimental design was that there is only one true replication within the study (test period two was a replicate of test period one).This was done to eliminate other errors such as having limited forage availability that would likely confound LGD effects.

By applying tests of significance (PROC MIXED) and having a true replicated study, both implicit and simple pseudo replication were eliminated (Hurlbert 1984, 2004). Chi-squared pseudo replication does not apply to this study or sacrificial pseudo replication because each trial was not treated as a repeated measure.

Calculated positional uncertainty was ± 4.45 m for receiver type one and ± 3.56 m for receiver type two (at 95% CI) (figure 2). The precision of GNSS receivers varied between types by almost one meter. Although this did not affect the outcome of the case study it had to be accounted for in the statistical model. This is important because an experiment tested with less rigor could make false inferences. It is recommended that only one receiver type be used in future studies to eliminate the receiver type effect.

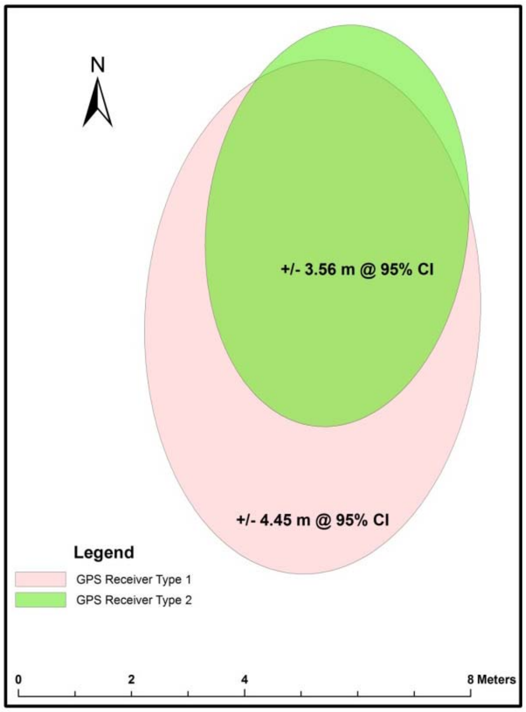

Figure 2. Standard deviational ellipses (two standard deviations) of type one and type two GNSS receivers representing 95% CI.

The high rate of GNSS receiver failures (79%) resulted in unequal sample sizes among trials (Table 2). For instance group one began with 11 functioning GNSS receivers on day one of trial one and ended with only four functioning receivers on day two of trial two. Failure rates by group were 60%, 67%, 100%, 88% (groups one through four, respectively).

Table 2 Number of functioning GNSS receivers at the end of each test period by receiver type.

	Test Period 1		Test Period 2	
	Start	End	Start	End
Type 1	16	8	15	1
Type 2	9	0	2	0

When conducting an experiment, planning and developing a robust experimental design is important. While not all problems can be foreseen (e.g., GNSS receiver failures) the experimental design needs to account for all known factors within the experiment. In addition, appropriate statistical analyses need to be selected which are complimentary of the study's goals and structure of collected data. A well-developed statistical test should account for any weaknesses and these weaknesses and assumption plainly disclosed to the scientific community

CONCLUSIONS

When planning a manipulative experiment, the design of that experiment needs to be planned so that pseudo replication is reduced or eliminated. Other factors also need to be taken into account such as what type of positional precision or precision is required (i.e., is non-differentially corrected data sufficient). In addition it became very clear in the case study discussed here that only one type of GNSS receiver should be used and in addition, a large number of receivers should be available to accommodate equipment failure without jeopardizing the entire study. Sampling frequency and battery life should be balanced with battery changes planned accordingly.

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