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Determination of Locational Error Associated with Global Positioning System (GPS) Radio Collars in Relation to Vegetation and Topography in North-Central New Mexico

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ABSTRACT

In 1996, we initiated a study to assess seasonal habitat use and movement patterns of Rocky Mountain elk (*Cervus elaphus nelsoni*) using global positioning system (GPS) radio collars. As part of this study, we attempted to assess the accuracies of GPS (non-differentially corrected) positions under various vegetation canopies and terrain conditions with the use of a GPS "test" collar. The test collar was activated every twenty minutes to obtain a position location and continuously uplinked to Argos satellites to transfer position data files. We used a Telonics, Inc. uplink receiver to intercept the transmission and view the results of the collar in real time. We placed the collar on a stand equivalent to the neck height of an adult elk and then placed the stand within three different treatment categories: (1) topographical influence (canyon and mesa tops), (2) canopy influence (open and closed canopy), and (3) vegetation type influence (ponderosa pine and piñon pine-juniper). The collar was kept at each location for one hour (usually obtaining three fixes). In addition, we used a hand-held GPS to obtain a position of the test collar at the same time and location. The hand-held unit was differentially corrected. Previous tests of the hand-held unit indicated that the accuracy was within two meters of an actual position. To determine locational error of the test collar within the different treatments, we made comparisons between the test collar and the hand-held GPS following correction. The overall mean locational error was 106 ± 16 m (354 ± 53 ft). There were no statistical differences ($\propto$ = 0.05) in locational errors between ponderosa pine and piñon pine-juniper vegetation types (p = 0.8199), open and closed canopies (p = 0.8672), or canyons and mesa tops (p = 0.9874). Observation rate was also calculated for each treatment category (e.g., the number of positions obtained in a defined period of time divided by the maximum number of positions possible). There were no statistical differences ($\propto$ = 0.05) between observation rates of the three treatments (topographical influences: p = 0.1120; canopy influences: p = 0.3897; and vegetation type influences: p = 0.6282).

1.0 INTRODUCTION

Radiotelemetry has provided increased opportunities to examine activity patterns, habitat use, and behavior of wildlife species (Samuel and Fuller 1994). At present, there are three forms of telemetry available for tracking large mammals, two of which are essentially new to the field and all of which use collars attached to the animal. The most commonly used method is a very high frequency (VHF) radio telemetry system which consists of hand-held receivers that pick up transmission from a radio collar containing a transmitter that is placed around the animals neck (Samuel and Fuller 1994). These receivers can be used on the ground (through walking or semipermanent stations) or from aircraft and, in many cases, both. A second method of radio telemetry also involves the use of receivers but which are attached to "permanent tracking stations" that are strategically located within the study area (Hansen et al. 1992; Loft and Kie 1988; Deat et al. 1980). The third method of tracking an animal is by satellite telemetry. This system also uses radio collars implanted with transmitters, but the signal is picked up via satellites orbiting the earth and the data is relayed to a servicing center. Until recently, satellite telemetry studies involved the use of platform transmitter terminals placed on animals (Heide-Jorgensen et al. 1992; Hansen et al. 1992; Keating et al. 1991) with, at times, highly variable accuracies. However, a newer and much more innovative form of tracking has been developed; this involves the use of GPS (geographical positioning system) units attached to radio collars. This system utilizes on board microelectronics that not only receive and store locational data but also allow for the uplinking of this information into a storage satellite for ultimate data dissemination by a data management center (i.e., Argos, Inc.). Because this is such a newly evolving technique, there have been very few studies that have investigated its usefulness and effectiveness in animal studies (Rempel et al. 1995).

Locational errors associated with VHF telemetry can vary greatly due to vegetation and topographical influences and can be greater than 1 km depending on the species and area of study. Triangulation of transmitter signals is the primary method of obtaining estimates of an animal's location. Two types of error can occur with triangulation—areal and linear (Saltz and White 1990). Areal is the area around the estimated location and linear is associated with the Euclidean distance between the estimated locations and the actual radioed locations. The size of the error polygons increase as the intersecting bearings depart from right angles and additional errors can occur from inaccuracies associated with misreading bearings on the compass, equipment inadequacies, and movement of the animal between successive readings (Macdonald and Amlaner 1980, Lee et al. 1985). Due to the varied terrain and vegetation types of north-central New Mexico inhabited by elk, error polygons can be relatively large. White (1981) estimated elk locations as far as 400 m from the actual locations while using VHF telemetry techniques in north-central New Mexico. Additional studies reporting error polygons of telemetry studies on elk were around 5.5 ha (13.75 ac)(Edge and Marcum 1989). Due to resource limitations, it is usually not feasible to obtain more than two or three locational fixes per week unless using an extensive system of fixed stationary receivers throughout the area of study. Additional costs associated with locating animals either by ground or air can increase due to accessibility problems related to terrain, weather, etc., and restricted access areas (e.g., military property, Department of Energy lands, National Park Service property, etc.).

The advantages of satellite telemetry are dependent on identifying locational accuracy and frequency of sampling and study designs need to account for these variables (Keating et al. 1991), the use of GPS technology in studying large animals can enhance the study of habitat use (Rempel et al. 1995). However, as with VHF telemetry, the effect of vegetation canopy and topographical influence needs to be assessed. Rempel et al. (1995) studied the influence of vegetation characteristics (tree height, basal diameter, spacing, and canopy closure) of multiple forest types on positional accuracy and satellite visibility. They found the locational error to be highly variable ranging from 3 to 650 m (10 to 2145 ft) with a median ranging from 51 to 74 m (168 to 245 ft). They did not find any direct effect of tree canopy on the GPS locational error. They also reported a 76% observation rate (number of actual locational fixes/expected number of total fixes) on collared moose.

In 1996, we initiated a study to evaluate the accuracy of using GPS radio collars in the vicinity of Los Alamos National Laboratory (LANL). The objectives of the study were 1) to determine the locational error (Euclidean distance) of a GPS radio collar to a differentially corrected rover GPS unit and 2) to identify locational error and observation rates (number of positions obtained/maximum number of positions possible) within three different treatments: topographical influence (canyons and mesas), canopy influence (open, less than 50% canopy closure and closed, greater than 50% canopy closure), and vegetation type (ponderosa pine and piñon pine-juniper plant community).

2.0 ENVIRONMENTAL SETTING

LANL is located in north-central New Mexico on the Pajarito Plateau, approximately 120 km (80 mi) north of Albuquerque and 40 km (25 mi) west of Santa Fe (Fig. 1). The Plateau is an apron of volcanic rock stretching 33 to 40 km (20 to 25 mi) in a north-south direction and 8 to 16 km (5 to 10 mi) from east to west. The average elevation of the Plateau is 2286 m (7500 ft). It slopes gradually eastward from the edge of the Jemez Mountains, a complex pile of volcanic rock situated along the northwest margin of the Rio Grande rift. From an elevation of approximately 1890 meters (6200 ft) at White Rock, N.M., the Plateau scarp drops to 1646 meters (5400 ft) at the Rio Grande. Intermittent streams flowing southeastward have dissected the Plateau into a number of finger-like, narrow mesas separated by deep, narrow canyons.

There is a large diversity of ecosystems because of the elevational gradient from the Rio Grande to the Jemez Mountains. Studies in 1972 characterized the plant communities into six vegetative types found on LANL and surrounding areas (Foxx and Tierney 1980). Within LANL, the predominant vegetative types are ponderosa pine and piñon pine-juniper (Foxx and Tierney 1980).

3.0 METHODOLOGY

GPS Test Collar

The GPS receiver we used in the test collar was a Telonics model ST14GPS. The 1996 version of the collar stored longitude, latitude, Greenwich Mean Time, Julian day, hour of the day, minute of the hour, and an error detection code. Data required for differential correction (the process of correcting GPS data collected at an unknown location with data collected simultaneously at a known location) of test collar data were not collected in the current version of the Telonics collar. Therefore, we could not differentially correct test collar data. Telonics programmed the rate of position acquisition and uplink to Argos satellites for downloading collar data. We supplied the acquisition and uplinking requirements to Telonics for programming the test collar. Telonics programmed the collar to acquire a GPS location every 20 minutes and to uplink to Argos satellites continuously.

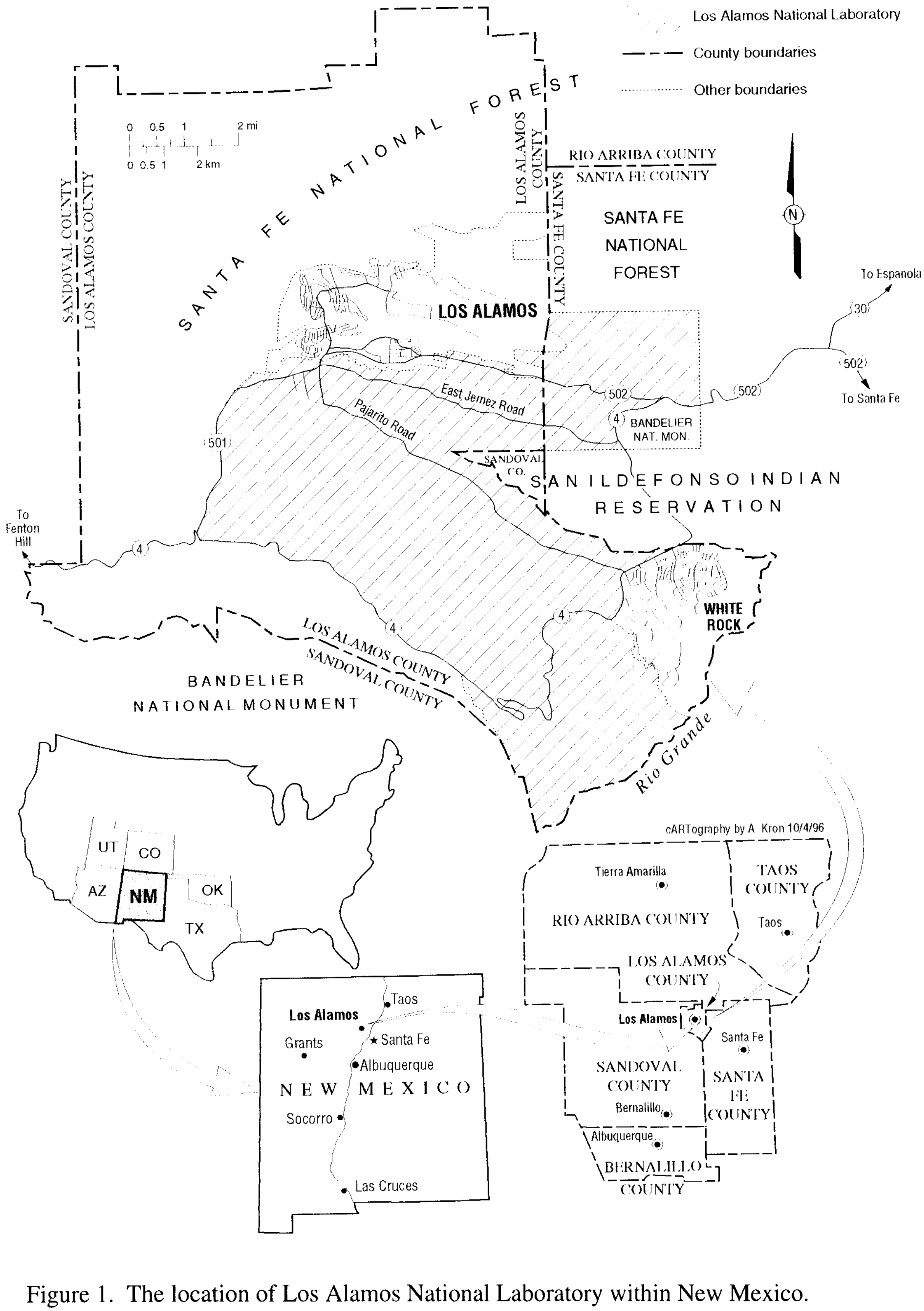

Figure 1. The location of Los Alamos National Laboratory within New Mexico.

We collected GPS test collar locational data from March 4, 1996, to April 12, 1996. The GPS test collar was placed on a stand equivalent to the average neck height of an adult Rocky Mountain elk. The stand was placed in 36 different locations within or near LANL boundaries and 93 total positions were obtained with the test collar (Fig. 2). Locations were selected based on three treatment requirements—topographical, canopy, and vegetation influence. We placed the test collar in canyon bottoms (canyon depth range of 25 to 100 m [82 to 330 ft]) and on mesa tops for evaluating topographical influences. For canopy influences, we placed the test collar in open canopy areas (less than 50% canopy closure) or in closed canopy areas (greater than 50% canopy closure). In addition, the test collar was placed either in a ponderosa pine plant community or a piñon pine-juniper plant community to evaluate vegetation type influence. Table 1 lists the number of locations and positions obtained for each treatment. At each location, the test collar was left running for 60 minutes, usually obtaining 3 positions (once every 20 minutes).

Table 1. Number of locations and positions obtained for each treatment.

Treatment	**Number of Locations**	**Number of Positions**
Topographical Influences	36	93
Canyon Bottom	19	44
Mesa Top	17	49
Canopy Influence	36	93
Open Canopy	18	49
Closed Canopy	18	44
Vegetation Influence	36	93
Ponderosa Pine	17	45
Piñon Pine-Juniper	19	48

We used a Telonics Model TSUR-B satellite uplink receiver/analyzer system to retrieve the positions stored within the test collar. We used the uplink receiver to retrieve the data instead of utilizing Argos satellites to immediately determine if the test collar was working properly. Data retrieved from the collar was stored on a laptop computer, and post-processing of the data, required to format the data into a useable form, was conducted.

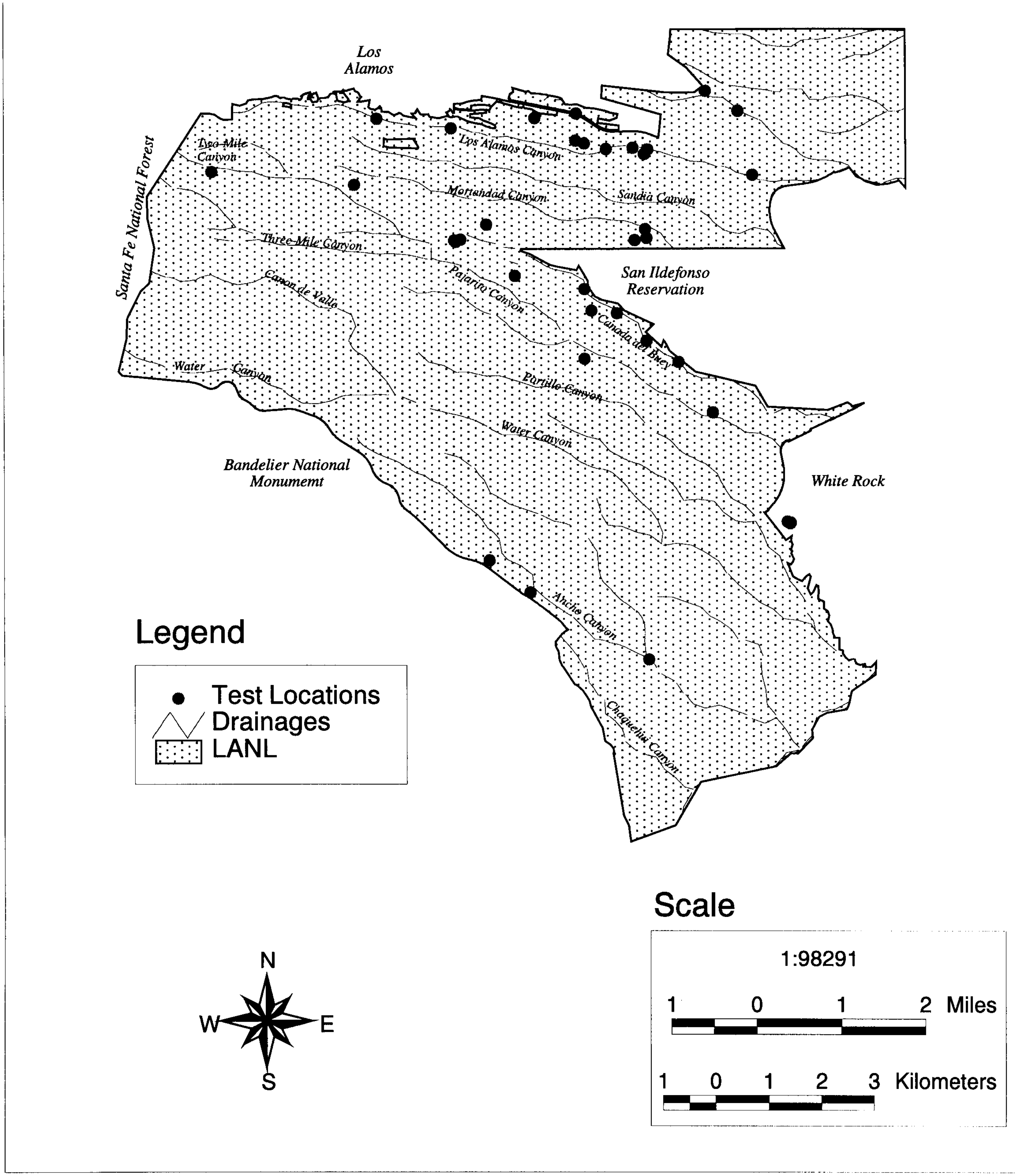

Figure 2. Map showing locations of test points of the GPS radio collar.

At each location a Trimble Pathfinder Professional GPS was used to obtain a locational position. Data from the Pathfinder was differentially corrected. Earlier studies had shown that differentially corrected Pathfinder positions had a location error of two meters (Bennett unpublished data). For this study, it was assumed that locational data collected with the Pathinder GPS could represent the true location of the test collar. The antenna for the Pathfinder GPS was placed on the test collar stand next to the test collar. The Pathfinder collected data at a frequency of once per second for a total of 60 minutes. At each location, we collected vegetation data within a 10-m- (30-ft-) radius circular plot. Percent canopy closure and vegetative species composition data were obtained. We used this data to determine which treatment category the location belonged to.

We determined location error (LE) for each GPS fix. The LE was the Euclidean distance of the observed location (GPS test collar position) from the true location (Pathfinder differentially corrected position) (Rempel et al. 1995),

$$LE = (sx^2 + sy^2)^{1/2},$$

where sx and sy were distance in feet from the differentially corrected GPS New Mexico Central State Plane position for the easting and northing. We also estimated the observation rate as the number of test collar positions obtained at a location divided by the maximum number of possible positions that could be obtained during that time period.

We compared LE between the three treatments. We conducted a normality test of the LE to determine if parametric statistics would be valid (PROC UNIVARIATE Normal; SAS Institute, Inc. 1988). Data were normally distributed, therefore we used parametric analysis. A t-test was used to test if there were differences in the mean LE between open and closed canopies, canyons and mesa tops, and ponderosa pine and piñon pine/juniper plant communities.

4.0 RESULTS

The differences between the test collar coordinates and the differentially corrected GPS coordinates were calculated and plotted on a scatter plot (Fig. 3). The 0,0 coordinate represents the actual location. Seventy-nine percent of the data are clustered within 120 m (400 ft) of the origin.

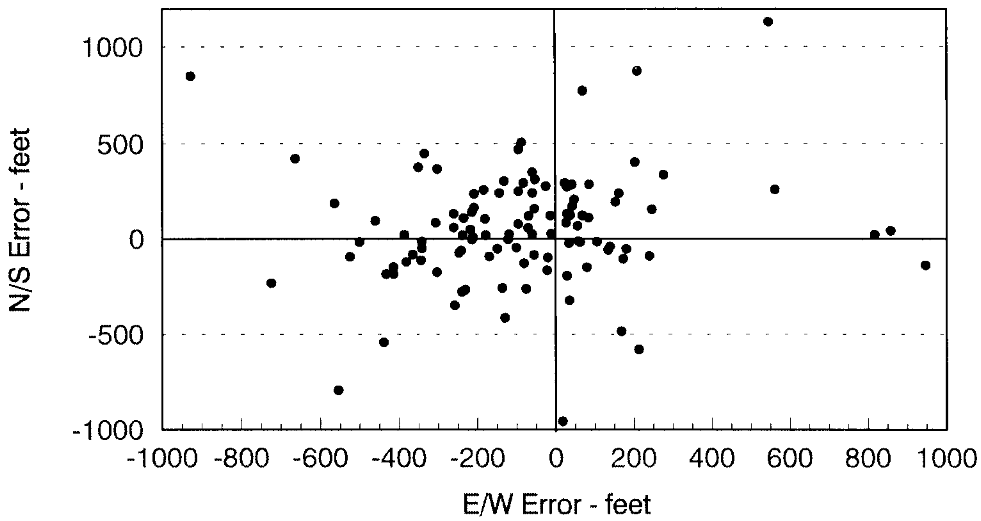

Figure 3. Scatter plot of north-south and east-west error (ft).

We calculated mean LE and mean observation rates for each treatment as well as for all the treatments combined. Figures 4, 5, and 6 show the mean LE and upper and lower 95% confidence intervals in feet for each treatment as well as all the data combined. The mean LE was not statistically different ($\alpha= 0.05$) between any of the treatments (topographical influences: $t = 0.0158$, $p = 0.9874$; canopy influences: $t = 0.1676$, $p = 0.8672$; and vegetation type influences: $t = -0.2283$, $p = 0.8199$). The mean LE and upper and lower confidence interval for all treatments combined were 354 $\pm$ 53 ft.

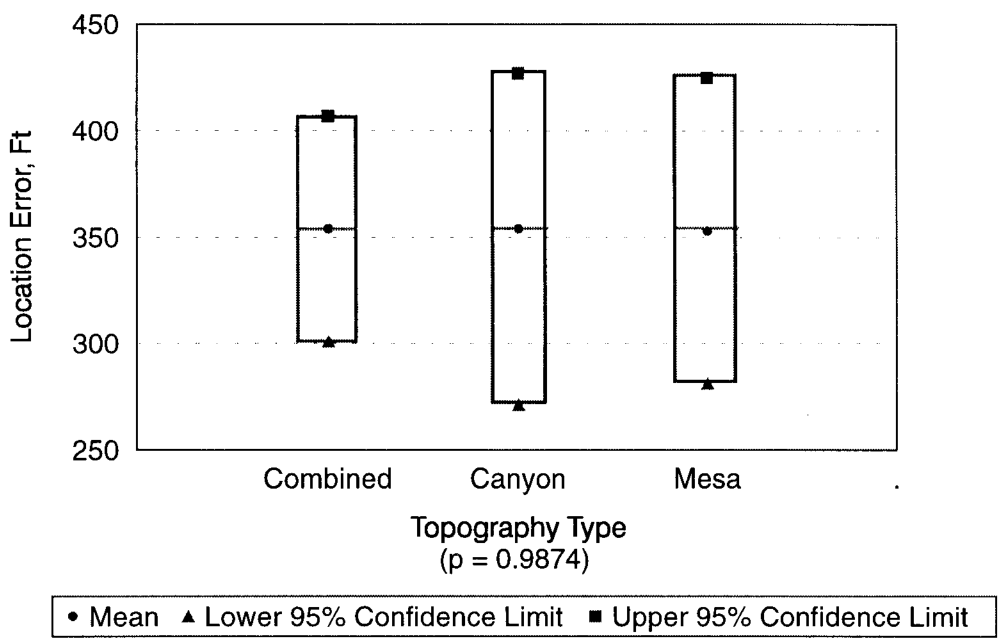

Figure 4. Mean LE and upper and lower 95% confidence interval for the treatment of topographical influence.

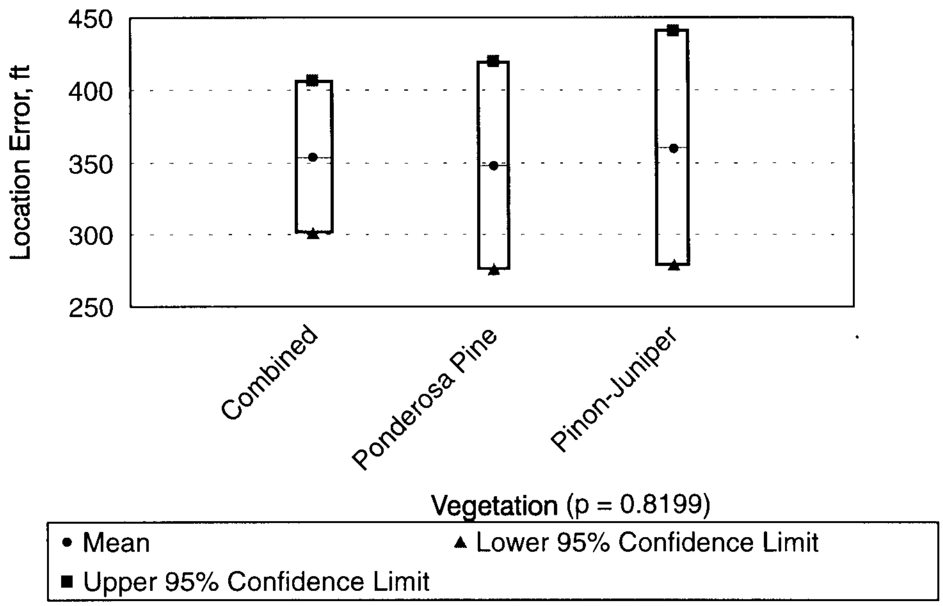

Figure 5. Mean LE and upper and lower 95% confidence interval for the treatment of vegetation type influence.

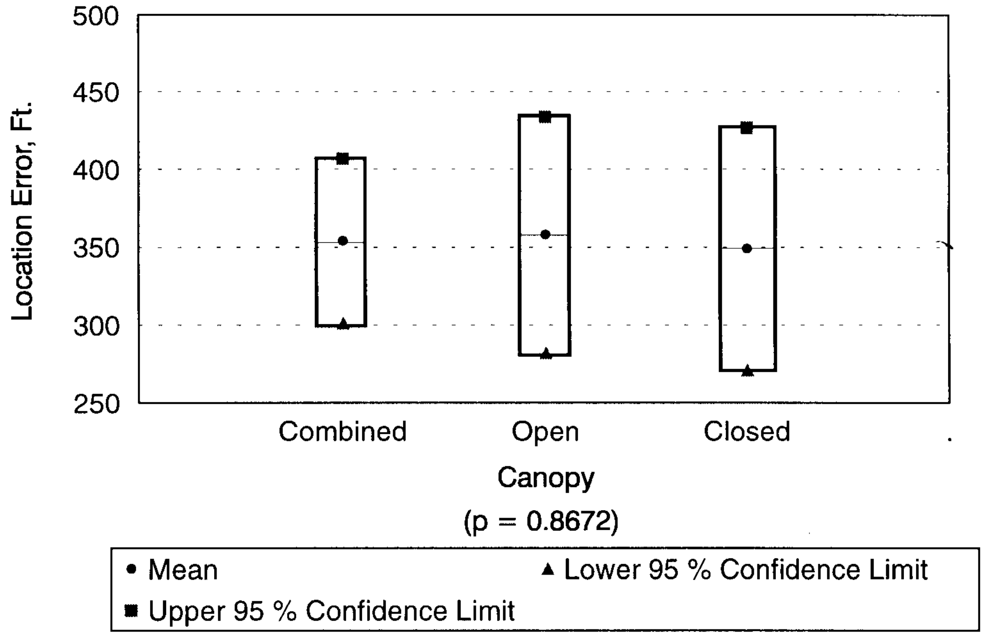

Figure 6. Mean LE and upper and lower 95% confidence interval for the treatment of canopy influence.

The mean observation rates of each treatment and all treatments combined are shown in Figure 7. The mean observation rate was not statistically different ($\alpha = 0.05$) between any of the treatments (topographical influences: $t = -1.6314$, $p = 0.1120$; canopy influences: $t = 0.8712$, $p = 0.3897$; and vegetation type influences: $t = 0.4887$, $p = 0.6282$). The mean and upper and lower 95% confidence interval for the observation rate for all treatments combined were 86% $\pm$ 8%.

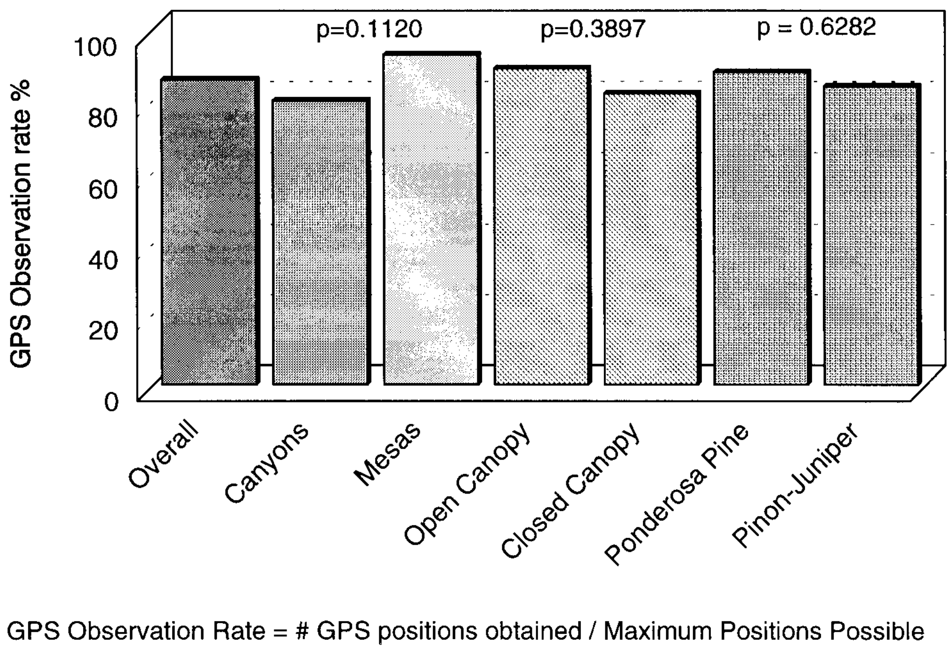

Figure 7. Mean observation rates for all treatments combined.

5.0 DISCUSSION

We did not find any direct effect of tree canopy on the GPS test collar LE and there was no statistical difference in the mean LE between the two vegetation types (ponderosa pine and piñon pine-juniper). These findings are similar to those found by Rempel et al. (1995). In addition, we did not find any differences in mean LE between mesa tops and canyons. Therefore, it may be possible to apply a standard LE to fixes occurring within any of the treatments, so that 95% of the time a position obtained from the GPS collar will be within 122 m (407 ft) of the actual location. An LE of 122 m (407 ft) was improved over VHF telemetry LE (390 m [1300 ft]) found by White (1981) in the Jemez Mountains area of New Mexico.

Although canyons had the lowest mean observation rate (80%) and mesa tops the highest (93%), the mean observation rates for the treatments were not statistically different. Studies conducted by Rempel et al. (1995) showed slightly lower observation rates which may have been due to the greater variability in plant communities tested and the greater density of tree species within some of their selected treatment sites.

We believed terrain would have a greater influence on the observation rate than what was found, and it is therefore encouraging information for wildlife researchers/managers seeking to deploy GPS collars on animals utilizing habitat in varied terrain. The technology for GPS tracking of wildlife is continuing to develop. The version of the Telonics collar used in our study could not be differentially corrected and 2-dimensional and 3-dimensional fixes could not be separated from one another. Most certainly, newer versions of GPS collars will be differentially correctable and 2-dimensional and 3-dimensional fixes can be identified. With these enhancements, LE will most likely decrease.

6.0 MANAGEMENT IMPLICATIONS

Use of automated GPS collars in north-central New Mexico appears to compete well with conventional VHF collars. Within LANL large ungulates inhabit expansive areas that have restricted access to personnel, making an evaluation of habitat use, activity patterns, etc. difficult to attain. Locational errors associated with our GPS test collar were well within acceptable limits when compared to use of traditional VHF systems. Error polygons calculated for radio-collared elk and deer inhabiting the Pajarito Plateau during previous studies were at times quite large, which made locating animals within certain habitat types difficult. This was particularly true for animals utilizing canyons and mesas during different times of the day or night.

Because locational errors did not differ significantly within various vegetation types and canopy closures, it may be possible to apply a "standard" error rate to each locational fix. Furthermore, as technology progresses, it will likely be possible to separate 2-dimensional and 3-dimensional fixes from one another (S. Tomkiewicz, personal communication), which will allow further differential correction to take place, and thus, a greater accuracy for each fix to be determined.

When designing studies, the use of GPS collars will need to be thoroughly considered due to increased costs of equipment. We found that the initial equipment investment cost of a GPS system was approximately 10 to 15 times greater than the cost of the use of traditional VHF systems. However, a cost savings using GPS collars would be seen within approximately 3 to 4 months of data collection (based on our current labor rates) when estimating the costs of tracking and triangulating animals more than 2 times per week using VHF systems. In addition, the cost associated with triangulating animals with VHF systems to a level less than or equal to locational error rates observed in our study must be considered.

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