

Roland C. Kufeld, Colorado Division of Wildlife
317 W. Prospect, Fort Collins, Colorado 80526

David C. Bowden, Department of Statistics
Colorado State University, Fort Collins, Colorado 80523

and

John M. Siperek, Jr., California Department of Fish and Game
601 Locust, Redding, California 96001

Evaluation of a Telemetry System for Measuring Habitat Usage in Mountainous Terrain

Abstract

Telemetry, the use of radio-transmitters to follow wildlife, has enjoyed popularity and widespread use because it can generate much animal location and activity data in a limited time. When animal locations are estimated by triangulation based on angle of signals received, rather than on visual contact, it becomes important to understand equipment limitations that may influence the accuracy of signal origin estimation. Problems of estimating signal origin are magnified in mountainous terrain by signal reflection. We tested directional accuracy of a precision-null antenna system in mountainous terrain of northcentral Colorado. Statistical tolerance limits applied to a two-wavelength system with two, three-element antennas, separated by two wavelengths, gave measurement error of no more than $\pm 3.4^\circ$ (at least 90 percent of the time) at the 90 percent confidence level based on a mean of four readings per transmitting site, taken in rapid succession. A precision-null antenna system was found superior to a one-wavelength antenna type. Signal quality and accuracy in determination of signal directionality decreased with increased height of terrain obstacles between transmitter and receiver. Transmitter-receiver distance up to 4.6 km (the maximum tested) accounted for only eight percent of the variation in directional accuracy. Signal quality categories are described which can assist an operator in judging relative directional accuracy of received telemetry signals. A new approach to determining habitat usage by instrumented animals is described which utilizes percent composition of each vegetation type occurring in error polygons to reflect probability that the transmitter is located within a given vegetation type.

Introduction

Radio-telemetry is commonly used to locate animals when estimating home range size, daily movements, and habitat use (Tester and Siniff 1965, Craighead and Craighead 1973, Lindzey and Meslow 1977, and Irwin and Peek 1983). Few telemetry studies, however, have addressed limitations of the tracking systems being employed. The value of reported results would be enhanced if an analysis of the systems' limitations was included.

Heezen and Tester (1967) discussed influences on accuracy incurred in radio-telemetry triangulation and described an error polygon that delineates the bounds of a particular location within which an instrumented animal will be found. Error polygon boundaries determined by the intersection of error confidence limits or error arcs are discussed by Springer (1979). If each error arc has a confidence level of $1 - \alpha$ of containing the true bearing of the transmitter, then the transmitter will be within the resulting error polygon formed from the two independent error

arcs with confidence $(1 - \alpha)^2$. In lieu of an error polygon, Hornbeck (1979) used a circle to represent the area of animal location. Circle size was based on a linear regression of location error and triangulation distance developed during preliminary experiments with a "test" transmitter. Rongstad and Tester (1969) used a grid system of 2.6 ha squares covering their study area and assumed the square from which a signal was received to be the location of their instrumented deer.

Accuracy of location decreases as error polygon size increases (Heezen and Tester 1967) so it is essential to use telemetry equipment that can detect signal directionality with a high degree of accuracy when triangulating. To be meaningful, error polygon size must be as small as possible. Heet (1977) reported an average error of 0.14 ha using triangulation for deer in Ohio. Springer (1979) also examined sources of bias in radio-telemetry and found no significant biases for observers, days, receivers, transmitters, and distance between transmitters and receivers when his "loudest signal method" was used.

Problems with accuracy are encountered in mountainous terrain as obstructions may block the most direct route of a signal from transmitter to receiver and cause the signal to be received from the direction of its path of least resistance through the terrain. Such distorted or "bounce" signals can result in directional accuracy error of many degrees (Hupp and Ratti 1983, Lee *et al.* 1985).

Springer (1979) has recommended that "future studies in which radiotelemetry is employed should devote some pilot effort to identify the factors that might affect bias and sampling error. The researchers should test these factors and determine the magnitude of the bias and sampling error, and then design an experiment with these results in mind." The purpose of this study was to determine directional accuracy of a precision-null antenna system in mountainous terrain and to facilitate a new approach to use of error polygons in a subsequent mule deer habitat usage study. Several modifications of an antenna system described by Hallberg *et al.* (1974), combined with certain antenna design characteristics used by Cochran *et al.* (1965) were tested in mountainous terrain near Red Bluff, California, by John Siperek. Two of the most accurate modifications were selected and subsequently compared in mountainous terrain near Fort Collins, Colorado, where the more promising modification was tested extensively.

Study Area

The study area is approximately five km west of Fort Collins, Larimer County, Colorado, and encompasses about 23 km², including the east side of Horsetooth Mountain. It is bounded on the east by Horsetooth Reservoir, the west by the crest of Horsetooth Mountain, the south by County Road 38E, and the north by Empire Gulch. Elevation ranges from 1646 m at the reservoir shoreline to 2211 m at the highest point on Horsetooth Mountain. The area is characterized by rugged mountainous terrain with numerous rock outcrops, ridges and canyons. Vegetation types include ponderosa pine (*Pinus ponderosa*) with various canopy densities and interspersed with Douglas fir (*Pseudotsuga menziesii*); mountain shrubs consisting primarily of mountain mahogany (*Cercocarpus montanus*); wet meadow; grassland; and a riparian type with cottonwood (*Populus sargentii*),

chokecherry (*Prunus virginiana*), wild plum (*Prunus americana*), skunkbush (*Rhus trilobata*), and hawthorn (*Crataegus erythropoda*).

Methods

Antenna System

The precision-null system consisted of two, vertically oriented, three-element, yagi antennas mounted parallel to each other (Figure 1). Antennas were wired 180° out of phase and connected at the mast by a union box or peak combiner. The system was designed for 149 MHz. The mast section inside the pickup camper, on which the system was mounted, was equipped with a compass rose and pointer for determining antenna direction. The system incorporated a telescoping mast and antennas that folded inward, making it easily portable by vehicle. A detailed description of the antenna system is available from the authors upon request. Adherence to construction details is critical to performance.

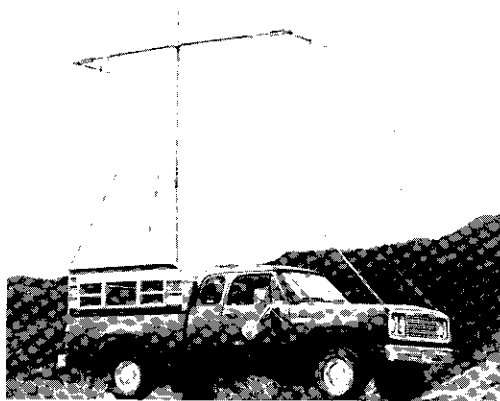


Figure 1. Precision null antenna system mounted on a pickup camper.

Antenna attitude was positioned, initially, each time it was used by orienting on a fixed beacon transmitter on Horsetooth Mountain with a known bearing from the receiver point and setting the compass rose pointer accordingly. When rotated 180°, this antenna received a signal in a pattern of four peaks and three nulls, which is apparent by listening to the signal while viewing the compass rose (Figure 2). The antenna was oriented toward the transmitter when receiving the center null. This null is from less than a degree to five or six degrees wide, depending on signal quality. A peak, another narrow null, and

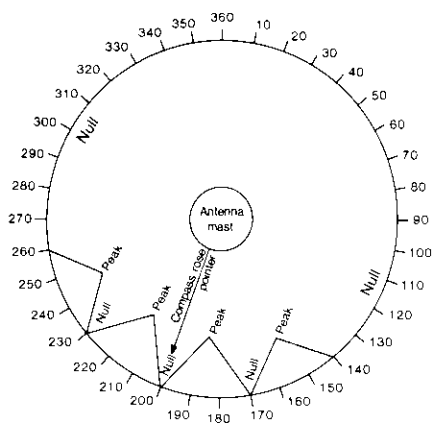


Figure 2. Signal pattern of peaks and nulls one would expect from a good quality signal using a two-wavelength antenna system. The compass rose pointer is oriented toward the center null, indicating direction to the transmitter is 200°.

another peak occur spaced about 15° intervals on each side of the center null. Nulls of about 90° in width occur beyond this outer peak. A similar pattern occurs on the rear side of the antenna, but peaks and nulls are poorly defined.

Signal direction is best established by determining two direction bearings with identical signal strength, each one a few degrees to the right and left of the null, and then by computing their mean to pinpoint the null centerpoint. This is recorded to the nearest 0.5°. Signals were classified as follows:

Signal Class 1. Loud and clear with little or no background noise. Patterns obvious and easy to read. Good symmetrical patterns with four peaks and three nulls. Peaks about 30° apart and nulls about 30° apart. Difference between peaks and nulls is readily discernable. Narrow center null (approximately 1° to 3°).

Signal Class 2. Loud but with background noise. Same as Signal Class 1 except center null may be larger and it may be necessary to bracket it by listening to the increasing signal levels 3° or 4° either side of it. However, it is still relatively easy to determine the null centerpoint.

Signal Class 3. Weak signal with much background noise. Pattern difficult to discern and

difficult to read. Requires much time to establish the pattern. Relative difference between peaks and nulls is small. Peaks may not be symmetrical in intensity and peaks and nulls may be more or less than 30° apart. Nulls are wide and it is difficult to determine the null centerpoint.

Signal Class 4. No signal or signal too weak to establish any pattern.

Signal Class 5. Signals with two, four or more nulls regardless of signal strength.

Sampling Procedures

Several potential receiver points were selected near the study area perimeter to test signal directional accuracy. Efforts were made to select receiver points that offered maximum, unobstructed visibility of the area, and were free as possible of nearby terrain features that could cause incoming signal distortion. Some were found unsuitable during subsequent testing. Seven receiver points were retained. These were located on a ridge on the east and south sides of Horsetooth Reservoir.

Transmitting sites were located using a 1-ha grid system that encompassed the entire study area. A total of 111, 1-ha cells were randomly selected, and the center of each chosen cell became a transmitting site. The signal from each site was received from each of two different receiver points.

One observer located transmitting sites in the field through use of high quality 1:15840 scale, color aerial photos on which transmitting sites were plotted, and which were cut into photo quadrats small enough to be easily carried while the other operated the receiver. Both observers had previous telemetry experience and extensive experience using aerial photos to locate exact spots on the ground. Observers communicated by hand-held, two-way radios. Transmitters used for testing were 149 MHz radio-collars made for mule deer (*Odocoileus hemionus*). Transmitters and receivers were manufactured by Telonics, Inc.¹ (Mesa, Arizona). A transmitter was hung from a bush or limb 0.3 m to 1.0 m above ground at each of four locations within a 1.5-m radius of each transmitting site. The transmitter was

¹Reference to this company does not imply endorsement by the State of Colorado.

moved among locations and a reading was taken at each location. The recorded bearing was a mean of the four readings from the site. The receiver operator did not know the direction to the transmitter plaser. The compass bearing for each transmitting site was compared with the true transmitting site-receiver angle as measured on a large sized 1:14049 scale, high resolution, color infrared aerial photo taken by NASA from a U-2 plane at an altitude of 21,336 m. Distances and angles on this photo were compared with surveyed distances and angles on the ground. There was no apparent photo distortion.

In practice an estimate of an animal's location is made at a specific point in time. Consequently, a multitude of locations will be considered over the duration of a study involving many points in time and different animals. Hence, accuracy of individual location estimates is of concern, as contrasted to accuracy of the mean of many estimates involving different times and locations. Tolerance limits (confidence level $1 - \alpha$ and proportion of population contained within the interval P) permit the statement that one can be 90 percent ($1 - \alpha = 0.9$) confident, using the same equipment and procedures, and under existing terrain conditions, that at least 90 percent ($P = 0.9$) of the individual estimated locations will be within the calculated number of degrees of the actual transmitting site. Thus, in addition to calculation of sample mean bias and a corresponding confidence interval for true mean bias, tolerance intervals for the error of individual estimated locations were constructed as $\bar{x} \pm ks$ with $1 - \alpha = .9$, $P = .9$ and $P = .75$. Dixon and Massey (1969, Table A-16) give k for selected values of n , $1 - \alpha$ and P (Their α is our $1 - \alpha$). Degrees of error in location estimates were assumed to be normally distributed.

Preliminary directional accuracy comparisons of antenna systems constructed with one and two wavelength separation (2.00 m and 4.01 m, respectively) between antennas were made on the study area using 11 transmitting sites. Transmitter-receiver distance was about 0.8 km. Procedures were as previously described except that only one receiver point was used. The two-wavelength antenna was found superior and was subsequently tested extensively using all 111 transmitting sites.

Since observers alternated between operating the receiver and placing the transmitter at ran-

domly selected sites throughout the study area, a test involving three people was conducted to determine degree of directional bias between observers. One individual placed the transmitter at four locations at each of 20 sites (situated at 30.5-m intervals) in a basin area where it had been determined that each signal class would be represented. Some sites were line-of-sight to the receiver (located 0.8 km from the basin area) while others were behind a 7.6-m cliff. Procedures for this test were exactly the same as used for sampling directional bias on the study area, except that signals were received by both observers who conducted the directional bias tests.

The 111 randomly selected transmitting sites and receiver points used to sample them were plotted on a 1:24000 scale U.S.G.S. topographic map with 40-ft (12.2-m) contours. Transmitter-receiver distance and signal clearance or lack of clearance of the highest terrain feature that occurred between the receiver and transmitter were measured on the contour map. To determine signal clearance for line-of-sight signals, perpendicular distance between the sightline and top of the highest terrain feature (elevationally) that occurred between receiver and transmitter was recorded and assigned a plus (+). If the signal path was not line-of-sight, indicating the signal was obstructed by terrain, distance between top of the highest terrain feature and a straight line between receiver and transmitter, through the terrain obstacle, was recorded and assigned a minus (-). Directional bias within each signal class was then compared with transmitter-receiver distance and with signal obstruction or clearance. These data were analyzed by a one-way analysis of variance followed by Tukey pairwise comparisons of means adjusted for unequal sample size.

Results

The one- and two-wavelength antenna systems received signals of Class 1 or 2 from four and eight transmitting sites, respectively, of the 11 sites tested. Class 3 signals were received from seven and three sites, respectively. Mean directional bias of Class 1 and 2 signals received from 11 sites with the one-wavelength system differed significantly from zero ($\bar{x} = +5.1^\circ$; $se = 0.35^\circ$; 90 percent confidence interval = $+4.27^\circ$ to $+5.92^\circ$). Mean directional bias of Class 1 and

2 signals received from the same 11 sites with the two-wavelength system, however, did not differ significantly from zero ($\bar{x} = +0.4^\circ$; $se = 0.24^\circ$; 90 percent confidence interval = -0.50° to $+0.85^\circ$) and variation in directional accuracy was lower. The two-wavelength system also gave a more discernible pattern of peaks and nulls.

Differences between observers in determining telemetry signal direction for individual and combined signal classes with the two-wavelength system were not significant ($P > 0.1$). There was 95 percent agreement by observers on classification of signals among the 20 locations. This suggests signal classes are well defined, and signals of each class can be readily recognized.

Mean directional bias with the two-wavelength system, based on 111 transmitting sites and readings from two receiver points per site, differed significantly from zero (Table 1) for Class 1 and 3, but not for Class 2 signals. Even though significantly different from zero, the highest possible bias at 90 percent confidence for Class 1 signals was only $+0.75$ degrees while it was -4.89 degrees for Class 3 signals. Tolerance limits on degrees of bias were much narrower for Class 1 and 2 signals than for those of Class 3 (Table 1).

Signal quality and accuracy in determination of signal directionality decreased with increased height of terrain obstacles between transmitter and receiver. Figure 3 shows that error in measuring transmitter-receiver directionality of all individual Class 1 signals (depicted by circles) is least among the three classes because they are clustered closest to $X = 0$ degrees, and that most Class 1 signals originated from a point above the top of the highest terrain object between the transmitter and receiver. A 95 percent confidence interval of mean clearance of the highest terrain feature between transmitter and receiver was $22 \text{ m} \pm 9 \text{ m}$. Thus, most Class 1 signals were unobstructed. Error in measuring transmitter-receiver directionality of individual Class 2 signals (depicted by squares in Figure 3) was greater than for Class 1 signals but less than for those of Class 3. Most Class 2 signals ($\bar{x} \pm t.025 \text{ se}$) originated from a point below ($5 \text{ m} \pm 10 \text{ m}$ below) the top of the highest terrain object between the transmitter and receiver. Error was greatest in measuring individual Class 3 signals (depicted as diamonds in Figure 3) and the mean origin of Class 3 signals was $41 \text{ m} \pm 20 \text{ m}$ below the top of the highest terrain object between transmitter and receiver. Figure 3 also shows that variation in measuring transmitter-receiver

TABLE 1. Directional accuracy ($\bar{x} \pm t 0.05 \text{ se}$) of signals received from randomly selected transmitting sites using a two-wavelength precision-null antenna system.

Signal class	No. of transmitting sites ^{1,2}	Degrees of bias			Tolerance limits on degrees of bias at 90% confidence level ⁴	
		\bar{x}	sd	90% conf. ³	75% tol.	90% tol.
1	77	+0.5	1.89	+0.25 to +0.75*	± 1.7	± 2.4
2	71	+0.1	2.36	-0.37 to +0.57	± 3.1	± 4.4
1 and 2	148	+0.3	1.89	+0.04 to +0.56*	± 2.4	± 3.4
3	65	-2.9	9.59	-4.89 to -0.91*	± 12.6	± 18.0

¹For each transmitting site the recorded bearing is a mean of four readings derived by placing the transmitter at four locations within a 1.5-m radius of the site.

²Each of 111 random transmitting sites was sampled from two receiver points. Thus, excluding Class 4 and 5 signals, signal directional accuracy is based on 213 mean readings.

³90 percent confidence interval for mean bias ($\bar{x} \pm t \cdot se$).

⁴One can be 90 percent confident (using the same equipment and procedures, and under existing terrain conditions) that 75 or 90 percent of all signals of a particular class will be within a certain number of degrees of the actual transmitting site (Dixon and Massey, 1969:142).

*Denotes a significant difference from zero in directional bias at $\alpha = 10$ percent.

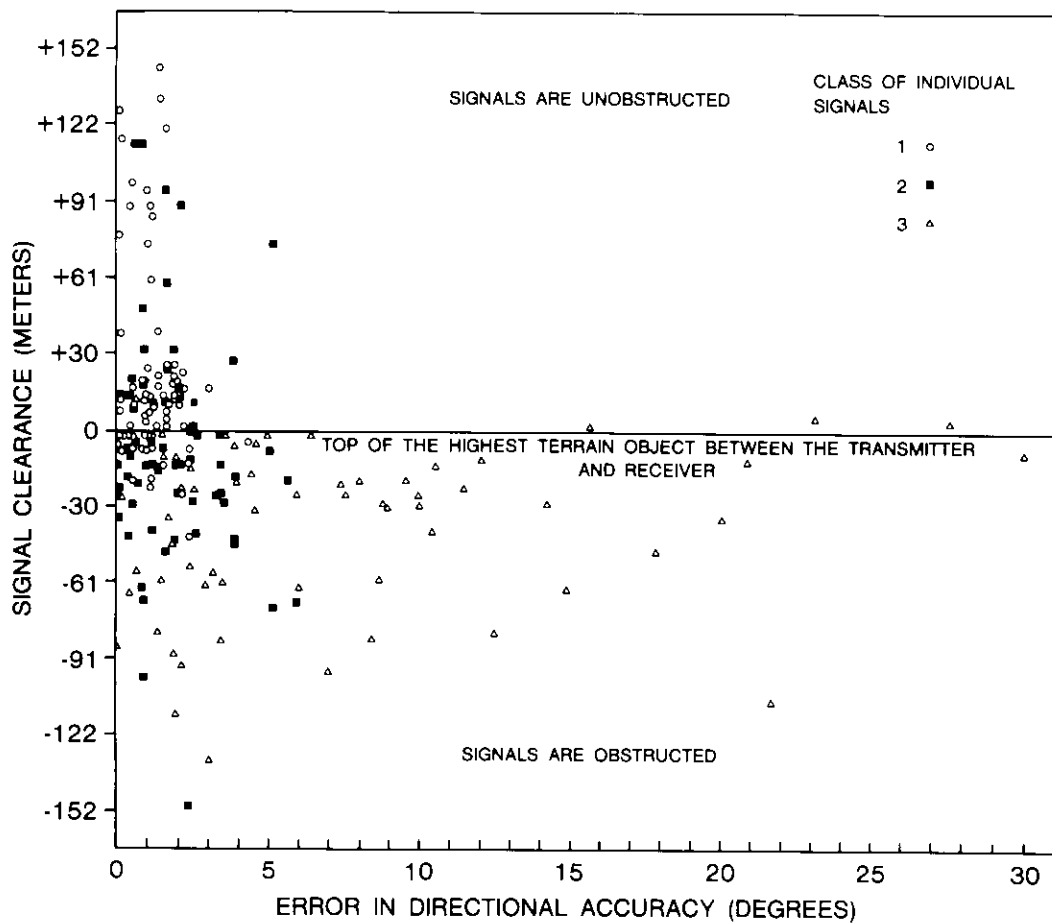


Figure 3. Distribution of Class 1, 2, and 3 signals showing degrees of error determination and origin of each individual signal with respect to the top of the highest intervening terrain object.

directionality of Class 1 signals was least, Class 2 signals second, and Class 3 signals greatest. Class 4 signals ($N=4$) were transmitted from a mean of $122\text{ m} \pm 53\text{ m}$ below the top of the highest terrain obstacle. The five class 5 signals received were emitted from a mean of $11\text{ m} \pm 11\text{ m}$ below the top of the highest terrain obstacle. All pairwise differences among Class 1, 2, 3 and 4 signals in mean clearance or lack of clearance of the highest terrain feature existing between transmitter and receiver were significant ($P < 0.1$).

Our analysis of terrain effect by measuring only one feature, clearance height, is crude; it is reasonable to assume signal quality and directionality may have been even more closely related

to terrain had it been possible to measure effects of all encountered terrain combinations on signal directionality.

Distance between transmitter and receiver up to 4.6 km, the maximum tested, did not appear to be an important factor influencing signal quality or directionality. There was poor correlation ($r=0.280$ —but more than zero correlation $P < 0.1$) between distance and directional accuracy of Class 1, 2, and 3 signals combined, and distance accounted for only eight percent of the variation in directional accuracy. Although mean distance between receiver and transmitter tended to be highest for Class 3 signals and lowest for Class 1 signals, there was a great deal of overlap in transmitter-receiver distances among the

three signal classes. Thus, accurate determination of signal directionality depended on whether the signal was obstructed by terrain and height of obstruction, regardless of distance.

Discussion

Lee *et al.* (1985) reported better precision ($P=0.02$, $N=10$) with nonmodulating signals from stationary transmitters than with modulating signals associated with transmitter movement. Our use of a mean of four location bearings within a 1.5-m radius of each transmitting site was an attempt to avoid trying to locate modulating signals, yet acquiring a mean directional bearing in the event a transmitter was attached to a slowly moving animal that stopped frequently as during feeding. In such an event, each of the four bearings would be taken only when the animal was momentarily still.

Hupp and Ratti (1983) reported good accuracy in relatively flat, open areas but found a large amount of error in directional accuracy associated with mountainous terrain. Lee *et al.* (1985) also reported a large amount of directional accuracy error in mountains. They used precision-null antenna systems with approximately one-wavelength separation. Hallberg *et al.* (1974) were able to use only one-half wavelength separation because their study area was flat. We found directional accuracy of the two-wavelength antenna system superior to the one-wavelength type in rugged terrain. Our sample of random transmitter locations covered a wide range of mountain terrain configurations and vegetation complexes.

Widths of tolerance intervals for Class 1 and 2 signals were considered sufficiently narrow to allow individual animal locations to be estimated with a reasonable level of accuracy (Table 1, Figure 3). The large standard deviation and, hence, wide tolerance limits for Class 3 signals (Table 1, Figure 3), however, were considered unacceptable. Thus, it is recommended that telemetry locations of radio-collared animals be based on Class 1 and 2 signals and that the receiver points be located to eliminate the occurrence of Class 3, 4, and 5 signals. The finding that a fairly large portion of signals (32 percent in this study) were classified as 3 and 5 and, thus, considered too inaccurate for use is unfortunate. However, it is better to be able to recognize an

inaccurate signal by quality characteristics and exclude it than to include both accurate and inaccurate signals in one's data.

Accepting only good quality signals could bias an estimate of habitat usage or home range size if poor signals were consistently received from one portion of a home range. During a subsequent habitat usage study on the same area involving 27 instrumented mule deer during three winters, using only Class 1 and 2 signals, we were able, through careful receiver point selection, to get at least one location on each deer during 98 percent of 168 scheduled, six-hour monitoring periods. Thus, we conclude that a two-wavelength precision-null system using the mean of four readings per transmitting site (taken in rapid succession when the signal is not modulating), which results almost entirely in Class 1 and 2 signals, will serve to reduce the magnitude of error in detecting directionality of a radio signal in mountainous terrain. This will produce smaller error polygons when triangulating. Receiver points should be situated on prominent sites where nothing in the vicinity can interfere with incoming signals.

As magnitude of location error increases in habitat usage studies, the proportion of correct determinations of habitat types containing the transmitter will decrease. White and Garrott (1986) provide information describing the decrease in power of tests of no preference in habitat usage with increasing error in location estimation. Large sample size increases are needed to compensate for relatively small increases in location error. Thus, we recommend that, before a habitat usage study is conducted, performance of the antenna system and receiver sites be evaluated to determine if study area terrain conditions are such that meaningful results can be obtained. Error data derived from the preliminary evaluation of the antenna system and receiver sites can then be used in the following alternative procedure for measuring habitat usage based on error polygons.

Suppose each estimated location point in a habitat study will be based on one pair of triangulation bearings. Then, an error arc given by tolerance limits with $1-\alpha$ and P derived from the error analysis will be attached to each member of all pairs of triangulation bearings according to its signal class. Thus, with $(1-\alpha)$ 100 percent confidence at least 100 P^2 percent of

all error polygons contain the corresponding actual transmitter location. Habitat usage, then, is based on percent composition of each vegetation type occurring in the error polygon. Power of tests of no preference in habitat usage based on error polygon vegetation composition data can be substantially higher than the power that results when only the habitat type containing the estimated location point is considered. We recommend use of error polygons developed from tolerance limits since, at the given confidence level ($1 - \alpha$), the probability of all actual locations being in their error polygons does not depend on the number of error polygons constructed in the habitat usage study.

The best of $1 - \alpha$ and P is not clear. As P is increased for fixed α , the size of error polygons increases. Larger error polygons will, in general, contain more habitat types and not necessarily have improved power in tests of no preference. Note that use of the habitat type containing the estimated location point only is the same as using $P=0$ in tolerance limit construction. Errors associated with four readings taken in rapid succession may not be independent. Thus, in our er-

ror analysis the mean of four such readings is considered to produce one bearing and, hence, one error. The standard deviation of these errors for each signal class is used in the tolerance limits construction. Actual transmitter locations are required to find these errors. Thus, error analysis is required separately from actual animal monitoring when error polygons are to be part of a habitat usage study. Our results from a deer habitat selection study based on these concepts will be forthcoming.

Acknowledgments

The study was financed by Federal Aid in Fish and Wildlife Restoration, Colorado Project FW 26P. We thank T. Fowler and H. Geduldig for assistance with fieldwork, L. Lovett for assistance in manuscript preparation, R. Morris, C. Bergman, and B. Mayer of Colorado Division of Parks and Recreation for their cooperation in making the study area available. We also thank A. E. Anderson, D. L. Baker, G. D. Bear, L. H. Carpenter, and N. T. Hobbs for critically reviewing the manuscript.

Literature Cited

- Cochran, W. W., D. W. Warner, J. R. Tester, and V. B. Kueckle. 1965. Automatic radio-tracking system for monitoring animal movements. *BioScience* 15:98-100.
- Craighead, J. J., and F. C. Craighead, Jr. 1973. Home ranges and activity patterns of nonmigratory elk of the Madison Drainage herd as determined by biotelemetry. *Wildl. Mono.* No. 33.
- Dixon, W. J., and F. J. Massey, Jr. 1969. Introduction to statistical analysis. McGraw-Hill, New York.
- Hallberg, D. L., F. J. Janza, and G. R. Trapp. 1974. A Vehicle mounted directional antenna system for biotelemetry monitoring. *Calif. Fish Game* 60:172-177.
- Heet, G. C. 1977. Habitat utilization of white-tailed deer in southeastern Ohio as determined by radiotelemetry. Ohio State University, Columbus. M.S. Thesis.
- Heezen, K., and J. R. Tester. 1967. Evaluation of radio-tracking by triangulation with special reference to deer movements. *J. Wildl. Manage.* 31:124-141.
- Hornbeck, G. E. 1979. Winter distribution, seasonal movements and cover type relationships of elk in southwestern Manitoba. Colorado State University, Fort Collins. M.S. Thesis.
- Hupp, J. W., and J. T. Ratti. 1983. A test of radio telemetry triangulation accuracy in heterogenous environments. *In* D. G. Pincock (ed.) *Proc. Intnl. Wildl. Biotelem. Conf.* Halifax, Nova Scotia. Pp. 31-46.
- Irwin, L. L., and J. M. Peek. 1983. Elk habitat use relative to forest succession in Idaho. *J. Wildl. Manage.* 47:664-671.
- Lee, J. E., G. C. White, R. A. Garrott, R. M. Bartmann, and A. W. Alldredge. 1985. Assessing accuracy of a radiotelemetry system for estimating animal locations. *J. Wildl. Manage.* 49:658-663.
- Lindzey, F. G., and E. C. Meslow. 1977. Home range and habitat use by black bears in southwestern Washington. *J. Wildl. Manage.* 41:413-425.
- Rongstad, O. J., and J. R. Tester. 1969. Movements and habitat use of white-tailed deer in Minnesota. *J. Wildl. Manage.* 33:366-379.
- Springer, J. T. 1979. Some sources of bias and sampling error in radio triangulation. *J. Wildl. Manage.* 43:926-935.
- Tester, J. R., and D. B. Siniff. 1965. Aspects of animal movement and home range data obtained by telemetry. *Trans. North Amer. Wildl. Conf.* 30:379-392.
- White, G. C., and R. A. Garrott. 1986. Effects of biotelemetry triangulation error on detecting habitat selection. *J. Wildl. Manage.* 50:509-513.

Received 19 June 1986

Accepted for publication 1 June 1987