Telemetry Accuracy and a Model for Predicting Telemetry Error

Bret D. Wallingford,[1] *The Fisheries and Wildlife Program, North Carolina State University, Department of Forestry, Box 8002, Raleigh, NC 27695-8002*

Richard A. Lancia, *The Fisheries and Wildlife Program, North Carolina State University, Department of Forestry, Box 8002, Raleigh, NC 27695-8002*

Abstract: We investigated telemetry error using a dual yagi null-peak antenna system mounted on a pick-up truck. One-hundred transmitters were placed in known locations in forest and field habitats on the Remington Farms study area. Most (755 of 830) pairs of azimuths gave useable estimates of the transmitter location. The median error distance (distance from the estimated to known transmitter location) was 133 m (N = 746, range = 2 − 1559 m). Error distance (ED) was closely related to 2 independent variables: the deviation of the intersection angle from 90° (DEV) and the mean distance from the receivers to the estimated location (RECDIST); these are variables that can be calculated in the field with a computer while radio locations are being taken. The model of $\mathrm{ED} = -9.19\,\mathrm{DEV} + 0.72\,\mathrm{DEV}^2 + 0.21\,\mathrm{RECDIST}$ was highly significant ($R^2 = 0.82$). Predicted error could be used as an objective criterion to reject telemetry locations with unacceptable error.

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Radio telemetry is an important and increasingly popular technique in wildlife research. Triangulation, a common technique used to locate animals (White and Garrott 1986), involves locating the same signal from a minimum of 2 different points with the estimated location being the intersection of the 2 bearings or the center of the polygon formed by >2 bearings. If ≥ 1 bearings are inaccurate, the estimated point is inaccurate.

Telemetry accuracy can affect the results of home range (Springer 1979), movement, habitat selection (White and Garrott 1986), and observability studies. Assessment of telemetry accuracy has increased in recent years, but historically, little effort was given to reporting telemetry error (Springer 1979, Hupp and Ratti

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[1] Present address: Pennsylvania Game Comm., Bur. of Wildl. Mgt., 2001 Elmerton Ave., Harrisburg, PA 17110-9797.

1983). However, accuracy assessment was given recognition in some of the earliest reported telemetry studies by Cochran and Lord (1963) and Verts (1963).

Procedures to evaluate error and estimate locations in telemetry studies have been reported (Lenth 1981, Pace and Weeks 1990, Saltz and White 1990). Saltz and Alkon (1985) suggested reporting the standard deviation on the bearing, and Saltz and White (1990) suggested reporting the mean and estimated standard deviation of the 95% maximum error on telemetry home range and movement studies. A description of accuracy and data censorship should be included in reports in which telemetry locations are used (Garrott et al. 1986).

Most studies of telemetry error focus on bearing precision and bias, and not on accuracy (error), to evaluate telemetry data (Heezen and Tester 1967, Lee et al. 1985, Garrott et al. 1986). Few papers report on empirically-determined linear error (i.e., the distance between the transmitter's estimated location and the true location [Schmutz and White 1990, Zimmerman 1990]) of telemetry systems in actual field tests. Although the specific cause of error may be difficult to determine, locational error should be estimated for all telemetry triangulation studies, and it should be incorporated in the calculation of results.

We tested a mobile radio-tracking system to locate transmitters in known positions to determine the accuracy we could expect when tracking radio-tagged white-tailed deer (*Odocoileus virginianus*). The evaluation of telemetry accuracy while locational data are being taken in the field has practical application to habitat use and observability studies by increasing the reliability of telemetry locations. The results of this telemetry error evaluation were applied to an observability study of white-tailed deer on Remington Farms, Chestertown, Maryland (Wallingford 1990).

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Methods

Research was conducted on Remington Farms, a 1,330-ha sharecropping farm and wildlife demonstration area located along the northeast shore of Chesapeake Bay, 12 km southwest of Chestertown, Kent County, Maryland. The area is composed of approximately 50% forest, 33% cropland, and 17% wildlife cover areas, wetlands, and farmsteads (Conner 1986). The study area has been previously described by Conner (1986), and Wallingford (1990).

Transmitter Placement

One hundred known radio-collar locations were established on the study area. Ten radio transmitters operating in the 150–152 MHz range were placed on wooden stakes at 18.3-m intervals in a straight transect perpendicular to an edge between woods and agricultural fields. The midpoint of the line was bisected by a forest-field edge. Stakes were placed inside the forest at distances of 9.1, 27.4, 45.7, 64.0, and 82.3 m from the forest edge. The same procedure was repeated in the field. Ten transects were distributed in random locations on the study area. On 1 transect we collected data from 2 pairs of receiver stations located on different sections of the study area. This was treated as 2 different transects for the study, making a total of 11 transects.

Data Collection

Although we acknowledge and agree with the suggestion of Springer (1979) that each observer involved in a telemetry study be tested, we used only 1 observer to collect test data. A null-peak antenna system consisting of twin 4-element yagi antennas mounted on a rotating mast was used to gather data. A pick-up truck with a wooden frame mounted in the bed near the cab was used to support and transport the antenna system. Telonics (Mesa, Ariz.) and Advanced Telemetry Systems (Isanti, Minn.) receivers were used.

We used the procedure described by Cochran et al. (1965) and Banks et al. (1975) to locate the transmitters. Azimuths were measured with a Silva Ranger Type 15T compass by sighting along a line that bisected the antenna system. The distance from the vehicle to the observer was >4 m to minimize any influence of the truck on the compass reading.

Receiver locations were chosen such that the receiver-transmitter-receiver angle approximated 90°. To minimize observer expectancy bias, 1 azimuth was taken sequentially on each of 10 transmitters from the first receiver location, then the process was repeated for a total of 20 azimuths. Then, the tracking unit was moved to the second receiver location, and 20 more azimuths were recorded. This completed 2 estimated transmitter locations for each of the 10 transmitter locations. Thus, each transmitter location was replicated once before the transmitters were collected and redistributed at random on the transect. Complete data (on each of the 10 transmitters) of the transects were replicated from 2 to 11 times. Few data (approximately 20 locations) were collected during rainfall that could increase reflections and scattering of signals (Cederlund et al. 1979).

Data Analysis

Estimated transmitter locations were calculated on an IBM-XT or Tandy TRS-80 Model 100 personal computer using XYLOG4 (Dodge and Steiner 1986). Data were uploaded to Triangle Universities Computing Center (TUCC) for analysis using the Statistical Analysis System (SAS Inst., Inc. 1985).

We used analysis of variance of PROC GLM (SAS Inst., Inc. 1985) to determine whether the location of the transmitters on the transect line or habitat type significantly affected telemetry error. The LSMEANS option with a K-ratio *t*-test was used to determine which transects had similar mean telemetry errors. The location of the transmitter line on the study area and habitat type (field or forest) also were tested. Additionally, 4 variables were investigated with PROC GLM to determine their influence on telemetry error: intersection angle, deviation of the intersection angle from 90°, and the arithmetic and geometric means of the distances from the receiver to the estimated transmitter location. The quadratic of each variable also was included in the analyses. We chose these variables a priori because they are measurements that could be determined from field data without knowing the true location of the transmitter and because they have been shown to affect telemetry accuracy (Slade et al. 1965, Heezen and Tester 1967, Springer 1979). An equation was developed to predict error distance (distance from the estimated transmitter location to the known location) as a function of the independent variables and their quadratics. Quadratic functions were included because we hypothesized that error distance increased exponentially as the intersection angle deviated from 90° and as distance to the estimated location increased. Thus, a curvilinear regression line might have a better fit than a linear regression line. We forced the regression line through the origin because zero error would be expected when the transmitter was very near the receivers.

Results

Sample Size and Censoring of Data

We recorded 830 pairs of azimuths on 100 known transmitter locations. Seventy-five pairs were rejected as errors for readily identifiable reasons (Table 1). The remaining 755 pairs gave usable locations. The median and mean error distances of these were 134 and 213 ± 16 m ($\bar{x} \pm$ SE), respectively. The range of error distance varied from 2 to 6,749 m. Because location estimates tend to be most reliable when the intersection angle is closest to 90°, we eliminated most estimated locations derived from intersection angles $\leq 22°$ that we felt would be readily identified as errors and would be routinely censored from telemetry studies. This removed an additional 9 estimated transmitter locations with error distances >1,610 m from the original data set, leaving a median error distance of 133 m, a mean of 172 ± 6 m, and a range of 2 to 1,559 m. A median error distance is a more useful measure of central tendency because the distribution of estimated errors is skewed toward larger distances (Fig. 1).

Table 1. Rejected azimuths from test data collected on transmitters placed in known locations on Remington Farms, Maryland, 1987.

Reason for rejection	*N* rejected
Nonintersecting azimuths	57
Location of collar between receiver sites	10
Parallel azimuths	6
Signal too poor	2
Total	75

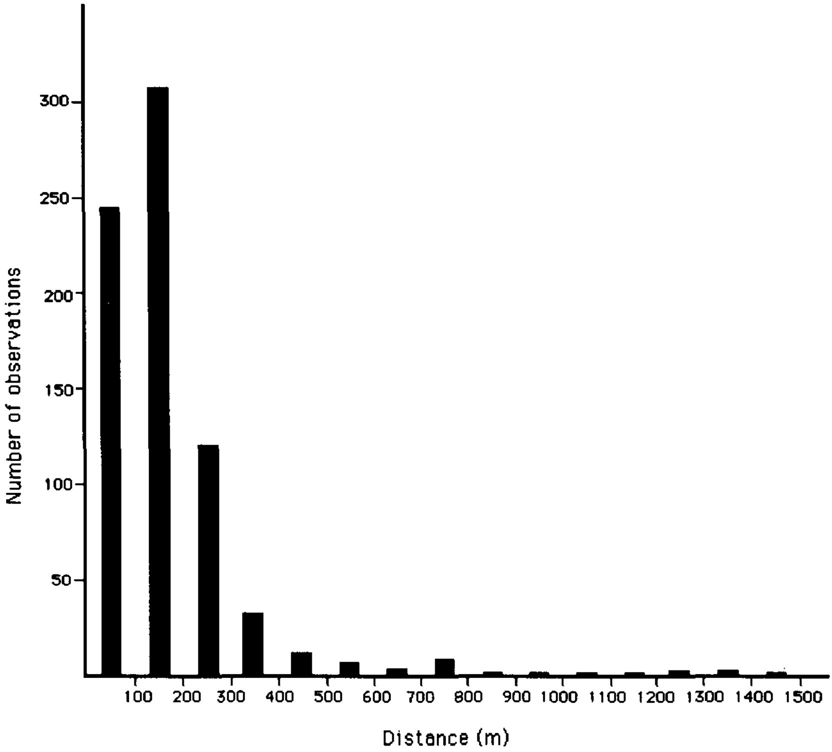

Figure 1. Distribution of telemetry error.

The Predictive Model

The location of the transmitter line on the study areas was significant ($F = 12.07$, $P = 0.0001$) indicating that telemetry error was not homogeneous across the study area (Fig. 2); however, habitat (field/woods) was not significant ($F = 1.58$, $P = 0.21$). Error distance (ED), or locational error, was closely related to 2

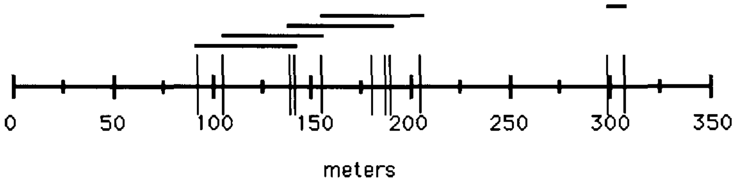

Figure 2. Mean telemetry error on transmitters placed on transects that bisected field/forest edges. Each transect consisted of 10 transmitters. Vertical lines represent mean error distance for a transect. Horizontal bars cover means that are not statistically different.

independent variables: the deviation of the intersection angle from 90° (DEV) and the mean distance from the receivers to the estimated point (RECDIST). The predictive regression model

$$ED = -9.19\ DEV + 0.72\ DEV^2 + 0.21\ RECDIST$$

was highly significant ($R^2 = 0.82$, $P = 0.0001$) and explained about 82% of the variance.

Evaluation of the Model

Observed error was less than predicted error for 427 of 746 locations (57%) (Fig. 3). The model tended to slightly underestimate telemetry error when actual error was <305 m and to overestimate telemetry error when actual error was >305 m (Fig. 3). If only data with predicted error less than the median error distance of 133 m were used, then 181 of 378 (48%) observations had observed error less than predicted error. If data with observed error <305 m were used, then 358 of 677 (53%) locations had observed error less than predicted error.

Discussion

Because the location of the transmitter line was significant, we believe a representative portion of the study area was used for the test. Habitat (field or woods) had no effect on telemetry error, so we ignored habitat type in the analyses. This concurs with Cottam et al. (1989) who found no difference in open and wooded habitats during their accuracy test.

We designed our data collection procedure to locate transmitters with only 2 bearings, and hence, 1 intersection point. We agree with the recommendations of Slade et al. (1965), Cederlund et al. (1979), Springer (1979), and Garrott et al. (1986) that ≥3 bearings should be used. However, we designed our test to mimic field data collection where 2 simultaneous azimuths per location were recorded. We felt this was a reasonable compromise between the benefits of additional azimuths and the liability of additional movement by the radio-marked animal between the time additional bearings would be taken (see Schmutz and White 1990).

Mills and Knowlton (1989) suggested that accuracy tests where the observer knows he/she is being evaluated might not reflect error in normal radio-telemetry work. Although our test could have been improved by collecting error data covertly when deer location data were collected, we followed the same protocol for both this error study and the field locations of deer. Thus, the results should be a reflection of the accuracy we could expect from our antenna system regardless of the study being conducted.

Potential Sources of Telemetry Error

Many factors can combine to cause inaccurate telemetry readings. Zimmerman (1990) listed the 5 main sources of telemetry error: system error, reading error, movement error, map error, and topographic error. System error involves the inaccu-

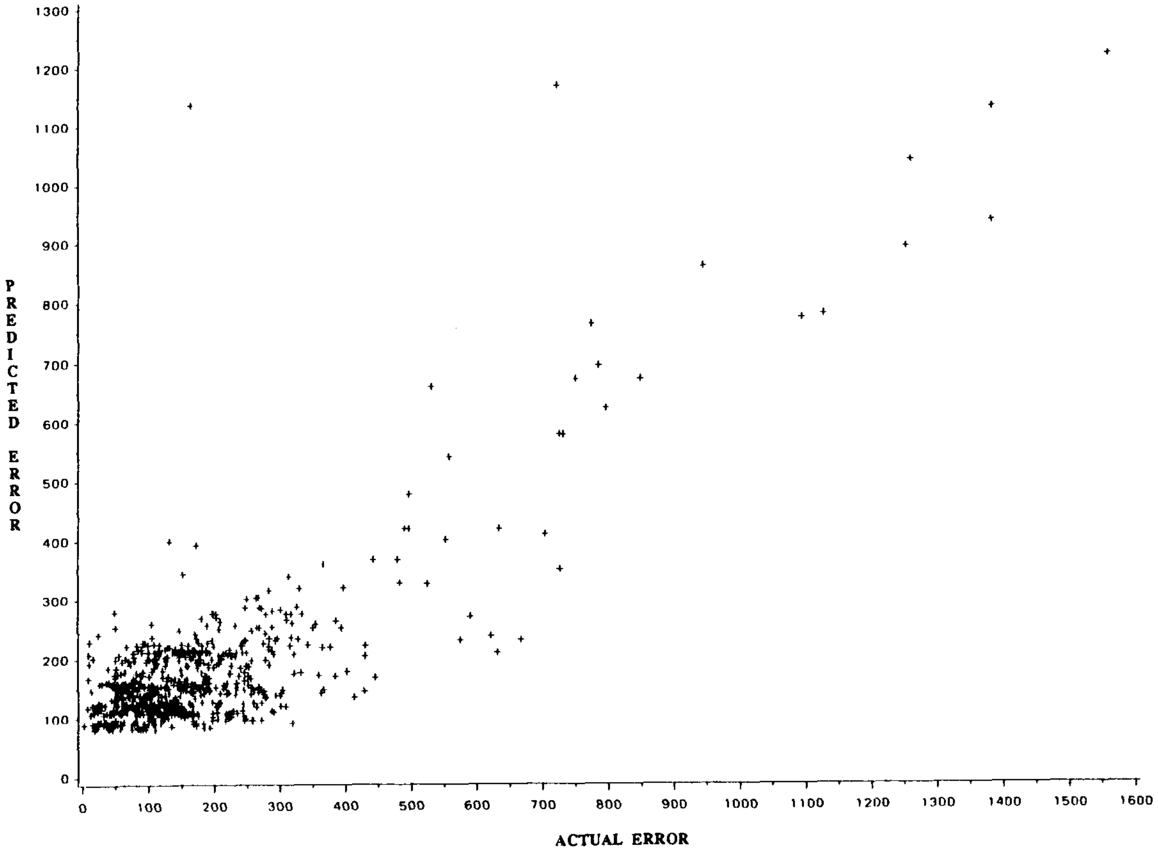

Figure 3. Predicted telemetry error (m) versus actual telemetry error (m). Predicted error was calculated from the regression model generated from telemetry error data. (See text for regression equation.)

racies inherent to a receiving system under standard field conditions. However, of the factors that may cause error in a telemetry system (see Macdonald and Amlaner 1980), we believe the most important contributor was the transporting vehicle. Receiver antennas should be extended a minimum of 1 wavelength above the ground or metal surface (Springer 1979, Amlaner 1980, Hupp and Ratti 1983, Anderka 1988). The vertical mast of our system was located ≈ 35 cm behind the cab. When the antennas were pointed over the cab of the truck, the elements cleared the truck cab by <8 cm. The distortion caused by the truck metal was demonstrated using a standing wave ratio bridge and spectrum analyzer with a tracking generator (A. Kealy, pers. commun.). The instrument measured the resident frequency of the antenna and showed how sensitivity was affected depending on whether both, 1, or neither antenna was across the truck cab. Hupp and Ratti (1983) reported an antenna held close to the ground would obstruct signal reception. Our low antenna height combined with the influence from the transporting vehicle probably contributed to the inaccuracy of the telemetry system.

The other major sources of error listed by Zimmerman (1990) could have had some effect on telemetry error. Some reading error could have occurred from misreading the compass, incorrectly recording a bearing, or incorrectly determining the strongest (peak) and lowest (null) signal (Heezen and Tester 1967). Observer expectancy bias (Mills and Knowlton 1989) was reduced as much as possible by randomly placing transmitters on transect lines and by ignoring the antenna direction during the test. Mapping error (Mech 1983) could have occurred due to photographic distortion from aerial photos used to construct the study area map and plotting of known transmitter locations.

Topographic errors are caused by radio signals being absorbed, deflected, or reflected from various factors of the surrounding landscape (Lee et al. 1985). Although our study area was composed of relatively flat terrain with nonhomogeneous habitats, most signals had to cross 1 or several edges before reaching the receiver. Some edges, like the border of a field and heavily wooded area, could have caused signal bounce. One receiving station, where signal quality and directionality were poor at a distance of about 635 m from the transmitter to the receiver, was near an edge formed between a reservoir and a heavily wooded hardwood stand. In this case, vegetation appeared to have a profound effect on accuracy.

Comparisons with Other Studies

Garrott et al. (1987) and Zimmerman (1990) reported error distance test results of 74 to 1,025 m ($\bar{x}$ = 267, SD = 206) and 10 to 1,440 m (median = 270 m), respectively. Our error distance of 2 to 1,559 m (median = 133 m) compares favorably with these previously reported studies. However, the performance of our telemetry system does not concur with the reported accuracy of other dual yagi antenna systems. Hallberg et al. (1974) reported a precision of ±1° for a sample size of 2,000, and then erroneously reported a linear error (accuracy) of ±14.3 m. Amlaner (1980) claimed the null-peak system was very accurate using triangulation and could achieve a precision of ±0.5°. Hupp and Ratti (1983) reported that the null-peak antenna system in flat terrain was highly accurate, and they usually could determine the direction to the transmitter within 1.0°. Cottam et al. (1989) were able to classify 80% of test transmitters in a 50- × 50-m area and 90% within a 100- × 100-m area. The results of our study and those of Cottam et al. (1989) can be compared directly. The largest error in a 100- × 100-m cell would be 141 m, the equivalent of our error distance measurement. If we convert our median error distance of 133 m at our mean receiver-to-estimated location-distance of 703 m, our angular error is 10.7°. However, it should be noted that our test evaluated accuracy and not precision as did the other tests (except Cottam et al. 1989).

Intersection Angle and Distance

Because the true angle of intersection approximated 90°, it is intuitive that this angle influenced the regression equation. A 90° angle is usually the target for intersecting azimuths to minimize the size of the error polygon. However, this is only true if the bearings have a confidence arc of ±1°. Zimmerman (1990) demonstrated that as precision decreases, the optimum angle of intersection needed to minimize error polygon size increases. An angle of intersection between 90° and 100° is probably suitable for most telemetry studies.

The distance factor in our regression equation also has been investigated before and shown to influence error in telemetry readings. Slade et al. (1965) found that error increased as distance to the signal source increased. Heezen and Tester (1967) and Springer (1979) also showed that distance was an important factor in the size of an error polygon, which uses bearing precision. Precision of telemetry bearings was shown to decrease with increasing distance to the source (Springer 1979). White (1985) used distance as one of the components comprising precision of bearings, and Tester and Siniff (1965) also recognized that error varied depending on distance from receiving towers to the animal with respect to the baseline formed by the towers.

Application of Predicted Error

Our approach of developing an error regression based on empirical measurements could be used as an objective means for identifying telemetry locations with an unacceptable predicted error. Acceptable error would depend on study objectives, and separate equations would have to be produced for individual study areas. Telemetry locations with large predicted errors could be identified with a computer in the field and adjustments could be made to reduce the error by reducing the distance to the transmitter and/or by improving the angle of intersection. Another possibility is that locations with unacceptable error could be censored in the field or when data were analyzed.

Literature Cited

Amlaner, C.J., Jr. 1980. The design of antennas for use in radio telemetry. Pages 251–273 *in* C.J. Amlaner Jr. and D.W. Macdonald, eds. A Handbook on Biotelemetry and Radio Tracking. Pergamon Press, Oxford.

Anderka, F.W. 1988. Radiotelemetry techniques for furbearers. Pages 216–227 *in* M. Novak, J.A. Baker, M.E. Obbard, and B. Malloch, eds. Wild Furbearer Management and Conservation in North America. Ontario Trappers Assoc., Ontario, Can.

Banks, E.M., R.J. Brooks, and J. Schnell. 1975. A radiotracking study of home range and activity of the brown lemming (*Lemmus trimucronatus*). J. Mammal. 56:888–901.

Cederlund, G., T. Dreyfert, and P.A. Lemnell. 1979. Radiotracking techniques and the reliability of systems used for larger birds and mammals. Swedish Environmental Protection Board, Solna, Sweden. 102pp.

Cochran, W.W. and R.D. Lord, Jr. 1963. A radio-tracking system for wild animals. J. Wildl. Manage. 27:9–24.

———, D.N. Warner, J.R. Tester, and B.V. Kuechle. 1965. A radio-tracking system for monitoring animal movements. Bioscience 15:98–100.

Conner, M.C. 1986. Refinement of the change-in-ratio technique for estimating abundance of white-tailed deer. Ph.D. Thesis, N.C. State Univ., Raleigh. 80pp.

Cottam, D.F., G.L. Storm, and R.H. Yahner. 1989. Accuracy and efficiency associated with radio tracking deer. Pages 195–204 *in* C.J. Amlaner, ed., Proc. 10th Internatl. Symp. Biotelemetry. Univ. Ark. Press, Fayetteville.

Dodge, W.E. and A.J. Steiner. 1986. XYLOG: A computer program for field processing locations of radio-tagged wildlife. U.S. Fish and Wildl. Serv. Tech. Rep. 4. 22pp.

Garrott, R.A., G.C. White, R.M. Bartmann, L.H. Carpenter, and A.W. Alldredge. 1987. Movements of female mule deer in northwest Colorado. J. Wildl. Manage. 51:634–643.

———, ———, ———, and D.L. Weybright. 1986. Reflected signal bias in biotelemetry triangulation systems. J. Wildl. Manage. 50:747–752.

Hallberg, D.L., F.J. Janza, and G.R. Trapp. 1974. A vehicle-mounted directional antenna system for biotelemetry monitoring. Calif. Fish and Game 60:172–177.

Heezen, K.L. and J.R. Tester. 1967. Evaluation of radio-tracking by triangulation with special reference to deer movements. J. Wildl. Manage. 31:124–141.

Hupp, J.W. and J.T. Ratti. 1983. A test of radio telemetry triangulation accuracy in heterogeneous environments. Proc. Internatl. Wildl. Biotelemetry Conf. 4:31–46.

Lee, J.E., G.C. White, R.A. Garrott, R.M. Bartmann, and A.W. Alldredge. 1985. Accessing accuracy of a radiotelemetry system for estimating animal locations. J. Wildl. Manage. 49:658–663.

Lenth, R.V. 1981. On finding the source of the signal. Technometrics 23:149–154.

Macdonald, D.W. and C.J. Amlaner, Jr. 1980. A practical guide to radio tracking. Pages 143–159 *in* C.J. Amlaner, Jr., and D.W. Macdonald, eds. A Handbook on Biotelemetry and Radio Tracking. Pergamon Press, Oxford.

Mech, L.D. 1983. Handbook of animal radio-tracking. Univ. Minn. Press, Minneapolis. 107pp.

Mills, L.S. and F.F. Knowlton. 1989. Observer performance in known and blind radio telemetry accuracy tests. J. Wildl. Manage. 53:340–342.

Pace, R.M., III and H.P. Weeks, Jr. 1990. A nonlinear weighted least-squares estimator for radiotracking via triangulation. J. Wildl. Manage. 54:304–310.

Saltz, D. and P.U. Alkon. 1985. A simple computer-aided method for estimating radio-location error. J. Wildl. Manage. 49:664–668.

——— and G.C. White. 1990. Comparison of different measures of the error in simulated radio-telemetry locations. J. Wildl. Manage. 54:169–174.

SAS Institute, Inc. 1985. SAS user's guide: statistics, version 5 ed., SAS Inst. Inc., Cary, N.C. 956pp.

Schmutz, J.A. and G.C. White. 1990. Error in telemetry studies: effects of animal movement on triangulation. J. Wildl. Manage. 54:506–510.

Slade, N.A., J.J. Cebula, and R.J. Robel. 1965. Accuracy and reliability of biotelemetric instruments used in animal movement studies in prairie grasslands of Kansas. Trans. Kan. Acad. Sci. 68:173–179.

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 Am. Wildl. Nat. Resour. Conf. 30:379–392.

Verts, B.J. 1963. Equipment and techniques for radio-tracking striped skunks. J. Wildl. Manage. 27:325–339.

Wallingford, B.D. 1990. Use of radio-telemetry to determine observability of female white-tailed deer on Remington Farms. M.S. Thesis, N.C. State Univ., Raleigh. 74pp.

White, G.C. 1985. Optimal locations of towers for triangulation studies using biotelemetry. J. Wildl. Manage. 49:190–196.

——— and R.A. Garrott. 1986. Effects of biotelemetry triangulation error on detecting habitat selection. J. Wildl. Manage. 50:509–513.

Zimmerman, J.W. 1990. A critical review of the error polygon method. Internatl. Conf. Bear Res. and Manage. 8:251–256.