SHORT COMMUNICATIONS

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AERIAL TELEMETRY ACCURACY IN A FORESTED LANDSCAPE

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Radiotelemetry is one of the more widely used tools for investigations of animal movements, home range size, habitat use, and survival. Radiotelemetric estimations of animal locations, however, are not without error. Bearing errors associated with ground-based triangulated estimates of radio-tagged animals can be in excess of 20 degrees (Hupp and Ratti 1983, Garrott et al. 1986), and depending on the aim of the study, excessive error may preclude meaningful analyses of data (White and Garrott 1990). Some researchers have chosen to ignore the issue of error in telemetry data (see Hupp and Ratti 1983, Saltz 1994, Withey et al. 2001), but ultimately the value of telemetry data is severely diminished when the magnitude of error is not investigated.

Aerial tracking may be more desirable than ground-based methods in studies involving telemetry of wide-ranging birds and other highly-mobile animals, or in dense forests where signal "bounce" may limit the effectiveness of ground-based telemetry (Gilmer et al. 1981, Marzluff et al. 1994). Aerial tracking allows researchers to avoid much of the potential error associated with ground-based tracking because fewer obstructions lie between the receiver and transmitter. However, aerial telemetry does not always provide "line of sight" radio fixes, especially in heavily forested landscapes. Although many studies have elucidated environmental factors contributing to bearing error from ground-based telemetry, no studies have documented how environmental factors influence conventional aerial telemetry accuracy.

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In this study, we evaluated the accuracy, precision, and sources of error for an aerial telemetry protocol designed for investigations of home range size and movement patterns of raptors and other wide-ranging birds at a heavily forested site in South Carolina, U.S.A. At this site, ground-based telemetry for wide-ranging animals is impractical due to substantial forest cover and extensive roadless areas.

METHODS

Study Area. This study was conducted at the 78 000 ha Savannah River Site (SRS), near Aiken, South Carolina. The SRS is a nuclear facility owned and operated by the United States Department of Energy, and is designated as a National Environmental Research Park. Approximately 64% of the SRS has been planted in loblolly pine (*Pinus taeda*), longleaf pine (*P. palustris*), and slash pine (*P. elliottii,* Workman and McLeod 1990), which are managed for timber production by the United States Forest Service. An additional 15% of the land cover is classified as bottomland hardwood (Workman and McLeod 1990). Although most of the SRS is forested, there are several industrial areas located throughout the site. Overhead powerlines of various sizes are present near industrial areas and along major roads. Elevation at the SRS ranges from 30 masl or less on the southwestern portion of the site near the Savannah River to 115 m on the northern portion of the site (White and Gaines 2000).

Field Procedures. Transmitters (Holohil Systems Ltd., Model AI-2B, 164–165 MHz) were attached to small trees or wooden stakes 1 m from ground level at 25 locations throughout the SRS. We placed transmitters (hereafter, beacons) arbitrarily in locations that varied with respect to habitat type and distance from overhead powerlines. We considered four habitat types, which were determined by visual inspection and by referencing a digital habitat map of the SRS (Wiggins-Brown et al. 2000): treeless habitat (N = 3 beacons), open-canopy pines (12), closed-canopy pines (4), and deciduous hardwoods (6). The number of beacons placed in each habitat type roughly corresponded to the relative proportion of each habitat type on the SRS. Distances between beacons and the nearest overhead powerline ranged from 26–5477 m ($\bar{x}$ = 1438; SD = 1620). Beacon locations were recorded in Universal Transverse Mercator (UTM) coordinates with a Trimble Pro XR Global Positioning System (GPS) unit (sub-meter accuracy).

We used a Cessna 172 airplane equipped with two-element Yagi antennas attached to each wing strut to estimate beacon locations (Gilmer et al. 1981). Beacon locations were estimated during three, 2-hr flights during the spring of 2001 after peak leaf emergence (10, 20, and 24 April). The same pilot, observer, and aircraft performed all flights. We generally flew 60–180 m from ground level at an air speed of 140–175 km/hr. We estimated beacon locations with a Garmin 12 CX handheld GPS unit (10–30 m accuracy; see Marzluff et al. 1994 for further description of aerial telemetry methods). We estimated beacon locations in random order. The pilot and observer were blind to beacon locations; they were given only a list of radio frequencies and had no prior knowledge of their placement. We generally followed steps outlined in Samuel and Fuller (1996) for aerial telemetry: once a signal was detected, the observer indicated the general direction of that signal to the pilot. An attempt then was made to keep the signal on one side of the airplane while circling the signal source. A visual estimate of the beacon location was made after circling the signal source several times and monitoring signal strength. We then flew directly over the estimated location and recorded the UTM coordinates with the GPS unit.

Data Analyses. UTM coordinates of actual and estimated beacon locations were imported into a Geographic Information System (GIS; ArcView 3.2; Environmental Systems Research Institute, Inc., Redlands, CA) as point themes (Fig. 1). The GIS was used to determine the distances from actual beacon locations to estimated locations, and the distances from actual beacon locations to the nearest overhead powerline. It was not necessary to correct linear distances with respect to topography due to the relative uniformity of the terrain at the scale of the measured distances.

We examined the effects of habitat at the beacon location and proximity of the nearest overhead powerline on linear accuracy of location estimates. Linear accuracy was defined as the distance between the actual beacon locations and the locations estimated with the handheld GPS from the airplane. We used one-way analysis of variance to test whether the habitat within which the beacon was located influenced the linear error of estimates. The LSD procedure (SPSS 1999) was used for pair-wise *post hoc* comparisons between variables. We used simple linear regression to examine the influence of the proximity of the nearest overhead powerline to beacon locations on linear error. Confidence areas (95%) were computed by centering a circle with a radius of (1.96) × (SD of the linear estimate of error) at beacon location estimates (White and Garrott 1990). All analyses were performed using SPSS 10.0 (SPSS 1999).

RESULTS

We located 24 of the 25 beacons (96%) from the air. Location of one beacon was confounded by interference on its frequency from other sources on the SRS; this beacon was excluded from the analyses. Mean linear distance error for the 24 location estimates was 191 m (range = 22–1011 m, SD = 197 m; Table 1). The 95% confidence circles were 47 ha in size (Fig. 1). Twenty-two of 24 (92%) of the actual beacon locations fell within the confidence circles. One-way analysis of variance showed that linear error differed among habitat types (P = 0.02). *Post hoc* comparisons indicated linear error differences between beacons placed in deciduous hardwoods ($\bar{x}$ error = 401 m) and each of the other three habitat types (open pine, 117 m; dense pine, 130 m; treeless habitat, 124 m). The proximity of overhead powerlines to beacons had no discernable influence on linear error (R^2 = 0.05, P = 0.32).

DISCUSSION

According to Samuel and Fuller (1996), ". . . few data are available from tests of the precision and accuracy of aerial radio-tracking, but ±100–200 m is probably the best commonly achieved accuracy." Marzluff et al. (1994) reported a mean linear error of 409 m, with an associated 95% confidence circle of 112 ha around each point estimate. Carrel et al. (1997) used several location-recording methods to achieve linear errors of 73–386 m at unknown beacon locations. Hoskinson (1976) reported a linear error of 7–70 m with two different pilots, but he flew exceedingly slowly (95–115 km/hr), dangerously low to the ground (15–30 m from ground level), and circled each beacon for at least 5 min. Hoskinson's (1976) results probably reflect the minimum error possible for aerial telemetry with conventional equipment, but his methods were unrealistic for most research situations.

In all radio-tracking studies, the required level of accuracy depends on the study objectives. Our mean linear error of 191 m and the associated 95% confidence circles of 47 ha are probably sufficient for investigations of home range and local movement patterns of wide-ranging species, although this level of accuracy would be inadequate for many fine-scale analyses. For example, Coleman and Fraser (1989) reported annual home range sizes of 14 881 ha for Black Vultures (*Coragyps atratus*) and 37 072 ha for Turkey Vultures (*Cathartes aura*) in Pennsylvania and Maryland. Home range estimates for Ferruginous Hawks (*Buteo regalis*) have exceeded 9000 ha in south-central Washington (Leary et al. 1998). Our error rates would be relatively inconsequential when examining home range size and broad-scale movements of such birds. However, depending on habitat heterogeneity, an accurate description of microhabitat use at specific time intervals probably would not be possible.

Whereas factors such as pilot skill and attitude (Hoskinson 1976), wind speed (Hoskinson 1976, T. DeVault pers. observ.), and airplane altitude and speed (Caughley 1974) are known to influence aerial telemetry accuracy,

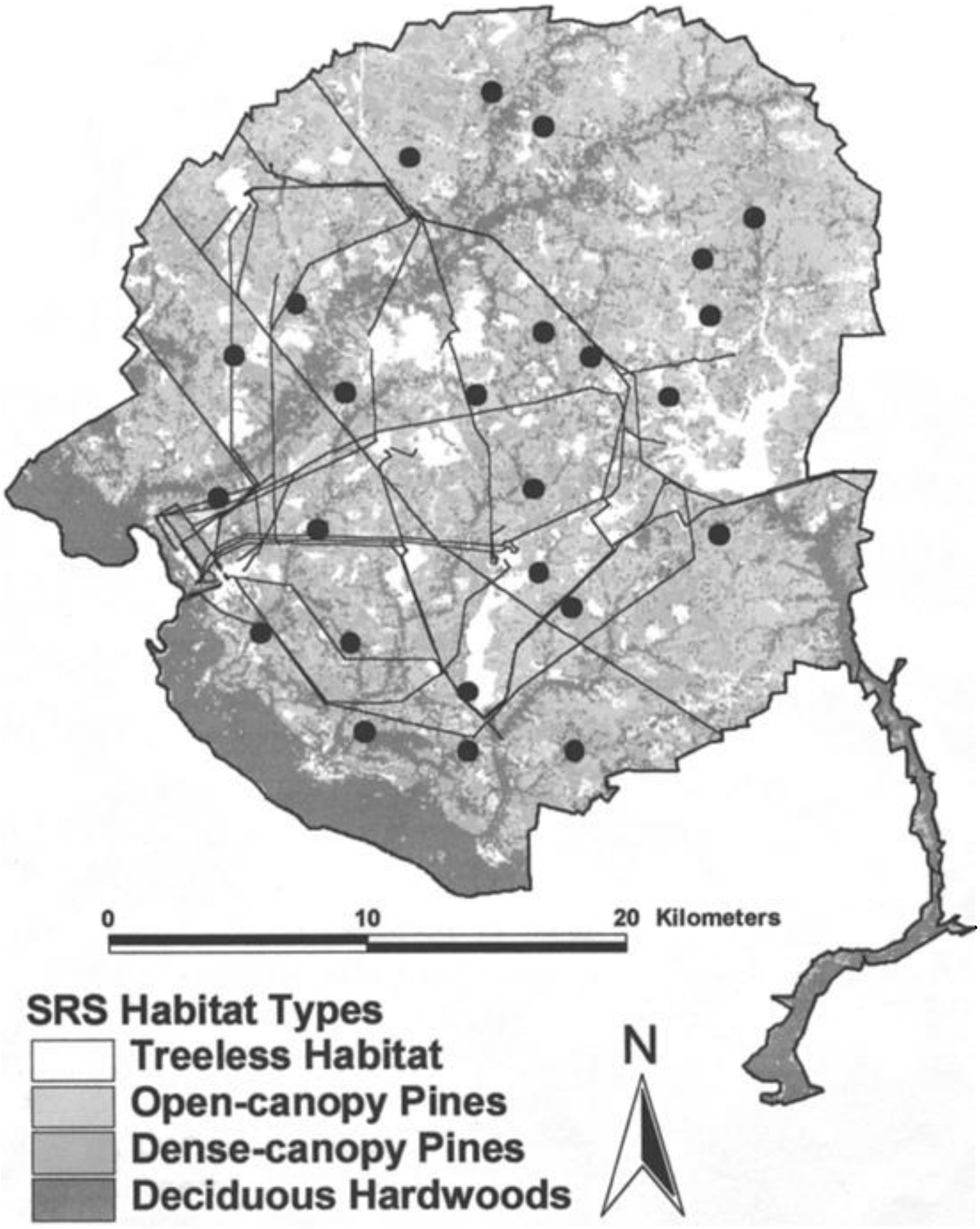

Figure 1. Map of the Savannah River Site, South Carolina, depicting major habitat types, location of overhead powerlines (thin lines) and beacon locations (solid circles). The circles representing beacon locations also represent the relative size of the confidence circles (47 ha). This figure was modified from a 1999 digital habitat map (30 m resolution) with 33 original habitat types (Wiggins-Brown et al. 2000).

Table 1. Mean linear distance error and coverage by major habitat type of beacon locations estimated with aerial telemetry.

HABITAT TYPE (N)	MEAN LINEAR DISTANCE ERROR	SE	COVERAGE[a]
Treeless habitat (3)	124	54.3	100
Open-canopy pines (11)	117	15.1	100
Closed-canopy pines (4)	130	26.2	100
Deciduous hardwoods (6)	401	127.9	67
Total (24)	191	40.3	92

[a] Percentage of actual beacon locations that fell within confidence circles.

our data indicate that the forest type within which a transmitter is located also can influence accuracy, and should be considered when assessing aerial telemetry accuracy. Rempel et al. (1995) and Rumble and Lindzey (1997) demonstrated that forest type and tree density affected GPS collar observation rate and accuracy, so it follows that signal bounce from vegetation could influence accuracy of conventional transmitters detected by aerial telemetry as well. Conversely, our results do not support evidence that the presence of overhead powerlines decreases telemetry accuracy (Withey et al. 2001). However, due to low sample sizes, we were unable to examine the influence of powerlines on mean linear error within each habitat type, even though we found differences in mean linear error across habitat types. Thus, this analysis may be somewhat unreliable.

Marzluff et al. (1994) expressed concern about the ability of aerial telemetry to accurately represent movements and home ranges of Prairie Falcons (*Falco mexicanus*) because the researchers often could not obtain radio fixes until the birds were perched, and often already back at their nests. Pilot studies at the SRS have shown that this problem does not exist to a large extent when tracking soaring birds, like buteo hawks and vultures (T. DeVault unpubl. data). Such birds move throughout their home ranges much more slowly than falcons, facilitating rapid and unbiased location estimates. However, we tested only stationary beacons, thus our results may not be applicable to moving instrumented birds. Furthermore, it should be noted that the inferential value of our data may be limited because we did not place beacons randomly throughout the study site.

Our study suggests that aerial telemetry is an effective method for some radio-tracking applications in areas where ground-based methods are not feasible due to extensive forest cover and the need for large distances between receiver and transmitter (i.e., when tracking wide-ranging birds). Although aerial telemetry does not provide completely unobstructed paths from the transmitter to the receiver, it appears that the obstructions do not influence the quality of the radio signal to a large extent, even in heavily forested landscapes.

RESUMEN.—Evaluamos la precisión y las fuentes de error de la telemetría aérea en la zona boscosa del Rio Savannah en Carolina del Sur, U.S.A. Los radiotransmisores fueron ubicados en 25 localidades en un sitio de 78.000 ha. Usamos un aeroplano/avión Cessna 172, equipado con antenas duales para localizar los transmisores. El error medio lineal para telemetría aérea fue de 191 m, y el círculo de confianza del 95%, fue de 47 ha. Veintidós de 24 (92%) de las localidades actuales de los transmisores estuvieron dentro del círculo de confianza. El tipo de hábitat influenció la precisión aérea: el error lineal entre las localidades de transmisores actual y estimada, fue mayor para los transmisores ubicados en bosques deciduos y en otros tipos de hábitats. La proximidad de líneas de energía no tuvo un efecto significativo en la precisión de la telemetría aérea. Especialmente en hábitats de bosques densos, la telemetría aérea provee una alternativa precisa y práctica a la telemetría en tierra.

[Traducción de César Márquez]

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PERCH-SITE SELECTION AND SPATIAL USE BY CACTUS FERRUGINOUS PYGMY-OWLS IN SOUTH-CENTRAL ARIZONA

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KEY WORDS: *Ferruginous Pygmy-Owl;* Glaucidium brasilianum; cactorum; *Altar Valley; Arizona; endangered species; habitat selection; perch site.*

Cactus Ferruginous Pygmy-Owls (*Glaucidium brasilianum cactorum*) are federally endangered in Arizona and therefore of significant conservation and management interest (U.S. Fish and Wildlife Service 1997). Concern for pygmy-owls has resulted in major efforts in conservation planning including a focal role in the Sonoran Desert Conservation Plan, proposed designation of critical habitat, and recent release of a Draft Recovery Plan by the U.S. Fish and Wildlife Service (USFWS 2002, 2003). Descriptions of areas occupied by pygmy-owls in Arizona are limited to anecdotal accounts from the late 1800s and early to mid 1900s (e.g., Fisher 1893, Breninger 1898, Gilman 1909, Phillips et al. 1964), a recent study by Richardson (2000), and unpublished reports. No published information exists on characteristics and size of areas used by pygmy-owls in semidesert grasslands in Arizona.

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