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Research Article

Accuracy of conventional radio telemetry estimates: a practical procedure of measurement

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Abstract

Telemetry triangulation is commonly used for obtaining location estimates of animals in the field. Although this technique provides only an estimate of the animal true position, most authors do not report the error associated with the radio-telemetry location.

We show the results of estimating error in a radio-telemetry study of roe deer in a hilly environment in central Italy. Ten VHF radio-collars were hidden in the study area by an external field operator and five field workers involved in the collection of the data were asked to locate the transmitters. The position of the radio-collars was changed three times, thus generating thirty different locations. Radio-locations were obtained using standard triangulation from settled receiving stations. We estimated linear and angular errors associated with the radio-telemetry technique, we tested the experience effect of the filed workers and the topography effect of the study area on linear and angular errors. Furthermore, we quantified the proportion of estimated locations not correctly associated with the habitat types. The mean linear and angular errors were respectively 42.9 m and 12.6°. For both linear and angular errors, no differences were detected among field operators and between the expert and not expert field operators. The linear error was strongly related to the angular error and to the mean distance between the transmitter and the receiving stations. The angular error was negatively related to the slope of transmitters. The assignation of an erroneous habitat occurred on 22.7% of the times. This study is aimed to emphasize the importance of reporting radio-telemetry error in studies were triangulation technique is used.

Introduction

Radio-telemetry has enhanced the ability of wildlife ecologists to locate animals, increasing the opportunities to examine detailed ecological and management questions e.g. related to movement (e.g. Lamberti et al. 2004; Ramanzin et al. 2007) animal behaviour (e.g. Lodé 2011; Lovari et al. 2008), habitat use (e.g. Magrini et al. 2009; Pereboom et al. 2008) and activity (e.g. Martin et al. 2010; Zalewski 2001).

A commonly employed method for obtaining location of animals in the field is triangulation, where observers record azimuths to the transmitter from several known points and assume that their intersection indicates the animal's location. However, this technique provides only an estimate of the animal's true position, because locations obtained by radio triangulation are affected by bias and sampling errors (Amelon et al., 2009; Fuller et al., 2005; Millspaugh and Marzluff, 2001). Although several authors pointed out that radio-tracking results should include estimates of location error (e.g. Lee et al. 1985; Saltz 1994; Withey et al. 2001), few

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investigators have reported on the bias and the sampling error involved in radio-triangulation method (see Harris et al. 1990; Withey et al. 2001). Moreover, even in these studies, the information on the method used to calculate this error is missing.

Animal location estimates can be affected by the variability of radio-waves propagation due to the canopy cover (Chu et al., 1989; Dussault et al., 1999; Rempel et al., 1995), the animal movements during the triangulation (Moen et al., 2001; Shmutz and White, 1990), the equipment used (White and Garrot, 1990), the topographic characteristic of the study area, such as the slope of the terrain (Gantz et al., 2006; Heezen and Tester, 1967), and the distance between the transmitter and the receiver (Amelon et al., 2009; White and Garrot, 1986; Zimmerman and Powell, 1995). Furthermore, in most field studies several operators are involved in the data-collection, so it is very important to test the skill effect of the operators working in the field.

We show a field experiment carried out within a larger study on habitat use and reproductive behaviour of roe deer (*Capreolus capreolus*) in a hilly environment of central Italy. The aims of this study were 1) quantify the accuracy of radio-telemetry location estimates, 2) test the experience effect of the operators and the topography effect of the study area on linear and angular errors, 3) quantify the effect of radio-telemetry error in habitat-selection studies.

Materials and methods

The study was carried out from July to August 2006, at "Le Malandrine" estate (43° 09' N, 11° 30' E), 22 km south of Siena, central Italy. The study area covers 639 ha, at an altitude of 150–250 m a.s.l., and it includes open fields (68%), small oak woods (25%), and riparian woodland (6%). The eastern side of the estate is bordered by the Ombrone river and a few small artificial lakes and ponds are included in the area. The climate is Mediterranean, with warm, dry summers and rainfall concentrated mainly in autumn.

In order to estimate radio-telemetry accuracy, ten VHF radio-collars (TXE-2, Televilt) were hidden in the study area by a field operator not involved in the collection of the data. The position of the radio-collars was changed three times, thus generating thirty different locations. Locations were randomly selected on a digital map of the habitats drawn from an orthophoto (1:10000) and from field data collected during surveys in 2006. Four habitat types were recognised: (1) open field - mainly cultivated with cereals (mostly wheat), sunflower and corn; (2) oak woodland - *Quercus cerris* and *Q. pubescens* - with abundant scrub; (3) riparian woodland - mainly *Populus* sp.; (4) scrub - mainly *Rubus* sp., agaric *Prunus spinosa*, hawthorn *Crataegus monogyna*, that constitute hedges between fields and along streets. The number of collars hidden in each habitat type was chosen according to the habitat extent and following a stratified procedure (Cochran, 1977). Five field workers involved in the data collection for the roe deer research project (cf. Lovari et al. 2008) and without knowing the position of the transmitters, were asked to locate the radio-collars using portable receivers (RX98 Televilt and Biotrack Sika) and a hand-held 3-element Yagi antenna. Radio-locations (fixes) (N = 150) were obtained using standard triangulation from settled receiving stations (Kenward, 1987; Mech, 1983). Operator could choose three stations among those used in the roe deer research project (N = 102). A fix was considered as the centre of the error polygon estimated by the triangulation method (Kenward, 1987; White and Garrot, 1990).

In order to provide estimates of the linear and angular errors associated with the radio-telemetry technique, we calculated the distance between the true position of the radio-transmitter and its estimated location (linear error = E), and the differences in angular direction between the true position of the radio-transmitter and its estimated location (angular error = E_{ang}), recorded from the receiving stations. According the "location error method" (Zimmerman and Powell, 1995) the accuracy of an estimate can be calculated as the area which radius is the linear error (error area = AE).

To test the effect of operators and of their experience on radio-telemetry technique, the E and the E_{ang} errors were compared among operators, and between expert (N = 2, i.e. operators with previous experience, at least 1 year) and not expert (N = 3, i.e. operators with little experience, about 1 month) operators.

Physical factors due to the topography of the area were taken into account: the mean distance between the transmitter and the receiving stations (from where the measurements were taken), the slope of the real location of the transmitter and the slope of the receiving station. In order to measure the slope, a three-dimensional DTM (Digital Terrain Model) was created using the TIN technique (Triangulated Irregular Network). Furthermore, the proportion of estimated locations not correctly associated with the habitat of the true location was also quantified.

Radio-tracking and habitat data were analysed using the GIS software ESRI® ArcView 3.2 along with its extensions: Animal Movement, Distance/Azimuth Tools 1.6, Spatial Analyst 1.1 and 3D Analyst 1.0.

Before performing statistical analysis, data were tested for normality (Kolomogorov-Smirnov D test, Zar 1996) and log transformed if necessary. Differences among operators in linear and angular errors were analysed using one-way ANOVA (Zar, 1996), whereas differences between groups of operators using t test (Fowler and Cohen, 1983). Spearman correlation coefficients (Zar, 1996) were used to relate linear and angular errors to topographic variables. Linear regression (Zar, 1996) was used to model the relationship between errors and correlates variables. All tests were two tailed with the level of significance at 5%. Data were processed using the software SPSS 13.0 (SPSS, Inc. 2003).

Results

Linear error

The mean linear error was 42.88 m (CI 95%, 36.15 and 50.28) and the error area was 0.57 ha (CI 95%, 0.41 and 0.80 ha). The linear error did not differ significantly among the five operators ($F_{4,145}$ = 1.35, p > 0.05) and between the group of expert and non-expert operators (t_{148} = -0.22, p > 0.05) (Fig. 1).

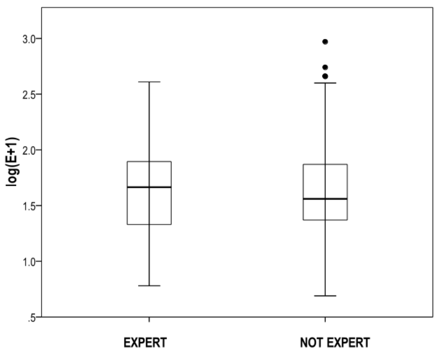

Figure 1 – Linear error $log(E + 1)$ (median ± interquartile distance) of the two groups of operators. *Expert*: operators with good experience (N = 2); *not expert*: operators with little experience (N = 3).

Angular error

The mean angular error was 12.64° (CI 95%, 8.33 and 10.48). As well as the linear error, no differences were detected among operators ($F_{4,145}$ = 0.15, p > 0.05) and between the expert and non-expert operators (t_{148} = 0.20, p > 0.05) (Fig. 2) indicating that the data of all operators could be cumulated.

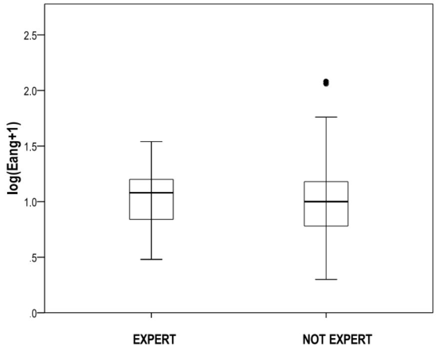

Figure 2 – Angular error $log(E_{ang} + 1)$ (median ± interquartile distance) of the two groups of operators. *Expert*: operators with good experience (N = 2); *not expert*: operators with little experience (N = 3).

Topographic variables

The mean distance between transmitters and receiving stations (REC.DIST.) was 170.52 m (range: 52-361 m), the mean slope of the real locations of the transmitters (TRA.SLOPE) was 11.10° (range: 0-29.9°) and the mean slope of the receiving stations (STA.SLOPE) was 6.19° (range: 0-14°). The linear error was strongly correlated to the receiving distance (r_{150} = 0.31, p < 0.01) (Tab. 1) and to the angular error (r_{150} = 0.62, p < 0.01) (Tab. 1). The angular error was negatively correlated to the slope of transmitters r_{150} = -0.18 p = 0.03 (Tab. 1). A positive correlation resulted between the REC.DIST and TRA.SLOPE (r_{150} = 0.19, p = 0.02) (Tab. 1) and between the TRA.SLOPE and STA.SLOPE (r_{150} = 0.35 p < 0.01) (Tab. 1).

The linear regression between the linear error and the recording distance (the only one strongly significant correlation between error and topographic variable) was significant (r^2 = 0.11, p < 0.0001) and was expressed by the equation: $log(E + 1) = 1.33 + 0.002 \times REC.DIST.$

Table 1 – Spearman correlation coefficients. Linear error = $log(E+1)$; angular error = $log(E_{ang}+1)$; distance between transmitters and receiving stations = REC.DIST.; slope of the real locations of the transmitters = TRA.SLOPE; slope of the receiving stations = STA.SLOPE. Significant correlations are indicated by * for p < 0.05 level and ** for p < 0.01.

	$\mathbf{log(E+1)}$	$\mathbf{log(E_{ang}+1)}$	**REC.DIST**	**TRA.SLOPE**	**STA.SLOPE**
$\mathbf{log(E+1)}$	1.00	0.62**	0.31**	0.10	0.02
$\mathbf{log(E_{ang}+1)}$		1.00	-0.03	-0.18*	0.03
REC.DIST			1.00	0.19*	-0.06
TRA.SLOPE				1.00	0.35**
STA.SLOPE					1.00

(Fig. 3).

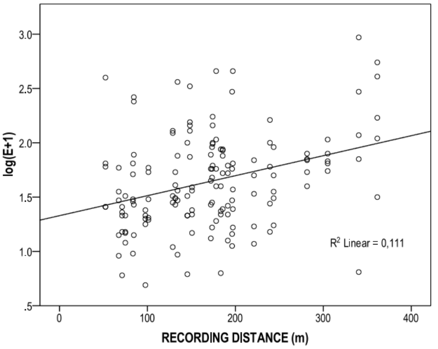

Figure 3 – Relationship between the linear error $log(E+1)$ and the distance between transmitters and receiving stations (recording distance).

Habitat selection

The percentage of error when the transmitter positions were associated with the four habitat types (open field, oak woodland, riparian woodland and shrub) was estimated at 22.7%.

Discussion

The results of the radio-telemetry should always include estimates of the location error that could be used to interpret the results themselves (Pyke and O'Connor, 1990; Saltz, 1994; Samuel and Fuller, 1996). In a review of radio-telemetry studies Withey et al. (2001) recommends to estimate and show the error associated with the radio-tracking technique in the specific study area, expressed through the precision (e.g. standard deviation of angular error) and the accuracy (e.g. mean linear error). Unfortunately, also in deer researches the location error is often not taken into account (e.g. Lamberti et al. 2001; Saïd et al. 2005; Tolon et al. 2009; Tufto et al. 1996.

We calculated location error of triangulation according to Zimmerman and Powell (1995) to determine whether radio-telemetry data were accurate enough to meet study objectives (see Lovari et al. 2008). The acceptable error depends on the aim of the study. Zimmerman and Powell (1995) found an error of 279 m (range 10-440 m) in their study of black bears (*Ursus americanus*) and Garrot et al. (1987) reported a location error of 74-1025 m in their research on the mule deer (*Odocoileus hemionus*). In a study of Iberian lynx (*Lynx pardinus*) habitat use, Palomares et al. (2000) found a 95% confidence distance of 207 m, whereas Kauhala et al. (1993) found a mean location error of 180 m in their research on raccoon dogs (*Nyctereutes procyonoides*). Theuerkauf and Jerdzejewski (2002) stated a mean error of 194 m (98% CI: 157-231 m) in wolf (*Canis lupus*) radio-tracking. In this study area the accuracy measure ranged between 0.41 and 0.79 ha and the linear error of locations was comparable to the value obtained in other studies carried out on roe deer movements in the same study area (Cimino and Lovari, 2003; Melis et al., 2005) and in similar environmental conditions (Börger er al., 2006a,b). In the same study area of this research Cimino and Lovari (2003) reported a mean distance radio-locational error of 26.1 m $\pm$ 4.6, whereas Melis et al. (2005) stated a mean error of 25 m, although the authors do not specify how the error was calculated. Börger er al. (2006b), in the Maremma Regional Park, described a location error of 112 m (SD = 65 m), estimated from 433 locations obtained at between 130-800 m distance, using 18 test beacons, eight observers, and three different radios.

In radio-telemetry studies, where a high sampling effort is required, different workers are involved in the data collection. In this study no differences in linear and angular errors were detected among the five operators, indicating that the data from all field workers could be cumulated. There were no differences in linear and angular errors between expert and non-expert workers, pointing out that experience does not influence the ability to locate the radio-transmitters. Nevertheless, radiotelemetry seems to be a relatively easy technique to learn, but it is very important that it is carried out in a correct way. In fact, the three field operators with less experience have made biggest errors, which are statistically defined as outliers. Tester (1971) stated that signal reflection was not a serious problem in his study because an experienced field operator could detect and modify his bearing accordingly. Lindsey and Arendt (1991) found that changes in recording signal direction caused by reflection could be eliminated by experienced field operator. In our view, inexperience in radiotelemetry practice can be a source of random rather than systematic errors and in our study, probably because of the large sample size, they were irrelevant.

The correlation analysis showed that the angular error increases with decreasing slope of the terrain where the transmitter was hidden. The possible explanation of this finding could lay in the absence of trees in the flat areas. Actually in the agricultural estate "Le Malandrine" the only flat zones are used for cereal, sunflower or corn plantations, whereas the steep zones, which cannot be cultivated, are covered by woodland. Thus in the lowlands transmitters were hidden on the ground, while in the woodland at the same height of the withers of the roe deer (approximately 60-70 cm from the ground). Transmitter height influences error of ground-based radio-telemetry (Cochran, 1980; Townsend et al., 2007). Townsend et al. (2007) found that error rates were approximately four times greater at transmitter heights of 15 and 46 cm, than at heights of 92 cm, indicating that micro-topography may influence bearing error when signals are transmitted from heights of $\leq$ 46 cm. Accordingly, the error estimated in this study could be overestimated with respect to the data collected in roe deer research, although in this last case radio-telemetry error can also be affected by animal movement (Shmutz and White, 1990).

In accordance with Heezen and Tester (1967), Springer (1979) and Zimmerman and Powell (1995), in our study the linear error was positively correlated to the recording distance, although these authors considered distance as the distance between the recording station and the estimated transmitter position (not real transmitter positions as in this study). The distance of the telemetry station to the radio-transmitter position can influence the risk of record a bounced or reflected signal (Withey et al., 2001). However the low value of the angular coefficient in the regression function indicates that the linear error is influenced by environmental factors, which are not taken into account in this study. In effect the recording distance explains just 11% of the linear error. We think that the choice of the receiving stations from which to measure the signal directions is a decisive factor in determining radio-telemetry errors, because, for example, it may receive a strong signal even when the animal is far from the station but the station is located at an elevated position with respect to the animal. In accordance with Springer (1979) and MacDonald and Amlaner (1980), we pointed out the need to intensify efforts by the field workers in choosing recording stations that are as close as possible to the animals (though without affecting the their normal behaviour) to obtain a more accurate estimate of their position. Furthermore, when signal reflection or bouncing is suspected, bearings could be taken at more than three stations (White and Garrot, 1990) then drawn on the field map to determine which of the bearings was suspect.

The radio-telemetry error has serious implications in the determination of habitat selection (Nams, 1989; White and Garrot, 1990). In fragmented landscapes, like "Le Malandrine" estate, there is a higher risk to assign a wrong habitat (White and Garrot, 1986). In this study the assignation of an erroneous habitat occurs 22.7% of the times. The ratio of location error to the size of habitat patches is essential when habitat use is studied using radio-tracking (Nams, 1989). Nams (1989) found, however, that even when location error is great in relation to the size of habitat patch, it is possible to test habitat selection by increasing sample size. It is also possible that false positive and false negative errors have balanced each other out, and produced unbiased estimates of habitat use (Samuel and Kenow, 1992). Kauhala and Tiilikainen (2002) recommended that it must be careful when using single fixes for habitat analysis, especially when habitat patches are small. However ad hoc solutions and statistical procedures (Cochran, 1968; Samuel and Kenow, 1992) may improve estimates of habitat use when misclassification is probable for radio-location by triangulation.

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