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Radio location error and the estimates of home-range size, movements, and habitat use: a simple field test

Kaarina Kauhala[1] & Thea Tiilikainen[2]

[1)] *Finnish Game and Fisheries Research Institute, Evo Game Research Station, Kaitalammintie 75, FIN-16970 Evo, Finland (e-mail: kaarina.kauhala@rktl.fi)*
[2)] *Pesäpuunkuja 3 E 9, FIN-01450 Vantaa, Finland*

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The effect of location error on the estimates of home range size, movements and habitat use of an animal in a radio-tracking study was tested in the field. One person, outfitted with a transmitter (made for hares) and a GPS-instrument, imitated hare movements in the woods, while researchers located her every 15 min. using techniques used to locate true hares. The mean location error was 281 m and varied between seasons and persons. The route the 'hare' moved, calculated from radio locations, was 1.5 × the true route, but radio-tracking gave a correct picture of the home range size, especially that of the core area. When habitat patches were small (mean size 2.9 ha), only 22% of the radio locations were in a correct forest patch, whereas radio-tracking gave a better picture of habitat use when habitat patches were larger (mean size 7.1 ha). In radio-tracking studies, the effect of the location error on the reliability of the results should thus always be tested and taken into account. The acceptable error depends on the aims of the study.

Introduction

Radio-telemetry has become a routine method in wildlife ecology. It is used in determining home range sizes, habitat use, movements, and activity of mammals and birds, as well as in studies of the social behaviour of animals. When interpreting the results of radio-tracking studies it is essential to know the exact method used, the number and time interval (i.e. independence) of locations taken, and the mean location error. Location error may vary between persons and may depend on terrain, weather conditions, movements of the animal, and the distance between the transmitter and receiver (Laundré & Keller 1981, White & Garrott 1986, Schmutz & White 1990). Saltz and White (1990) and Zimmerman and Powell (1995) compared several methods of radio-telemetry in determining the location error. Most studies lack, however, any estimate of the effect of these factors on the results. Harris *et al.* (1990) reviewed 93 scientific papers, published between 1984 and 1988, on home range analyses using radio-tracking data and found that in the majority of papers, insufficient attention was given to accurate and sufficient data collection; in less than one third of the studies the location error had been tested. Tiilikainen (2002) did not find a single study where the effect of location error on the home range size or movements of an animal was tested in the field with a moving transmitter.

The present study is part of a larger mountain hare (*Lepus timidus*) project that includes studies of population dynamics, home range size, habitat use, and movements of hares in Finland. The aim of this paper was to conduct a simple field experiment using transmitters made for animals the size of the hare to test the accuracy of radio-tracking. We determined the mean location error of separate location points, and its effect on the estimates of (1) the length of the route the animal has moved, (2) home range size, and (3) habitat use.

Material and methods

Study area and radio-tracking

The study area was a woodland area near the Evo Game Research Station in southern Finland (25°10´E, 61°14´N). The area is mainly coniferous industrial forest with some pine swamps, clear-cuts and several small lakes and streams. Many small timber roads dissect the area, which facilitates radio tracking. The environment is rather barren with a fairly sparse mountain hare population; mountain hare density, according to snow-track counts, is < 2 ind. km^{-2} (K. Kauhala *et al.* unpubl.).

Radio-transmitters were ordinary transmitters from Televilt (Lindesberg, Sweden; 230 MHz, transmitter energy output = max 13 μwatt) and weighed 52 g. Their operation time was ca. 1 yr, and they sent different pulses when the animal was active or resting. Radio tracking was done from a vehicle with a Yagi-type antenna (with 5 elements) which could be lifted up to 4 m from the ground. Bearings were taken from at least 2 points so that the angle between them was as near 90° as possible, and the time interval as short as possible (usually about 5 min.). We compared the locations obtained using radio tracking to those obtained using a GPS-instrument (Trimble, Geo Explorer II). Since the location error of the GPS-instrument is only 2–5 m (Leick 1995, cited in Rouvinen *et al.* 1999), we considered GPS-locations as true positions.

Data collecting

One person, imitating hare movements, walked in the woods with a radio-transmitter (fitted on the bootleg) and a GPS-instrument. The mean rate of movement was 0.81 km h^{-1}. She was located every 15 minutes in a similar way to that done during intensive location periods of true hares.

The mean distance between the 'hare' and the observer was 520 m (range = 110–1000 m), and the location error correlated positively with the distance ($r = 0.63$, $p < 0.001$, $n = 57$). The tests ($n = 10$) were done between January 2000 and January 2001, and a total of 207 radio locations were collected (161 from winter and 46 from early summer). Four persons did the radio tracking in varying terrain and weather conditions.

The mean location error was calculated as the distance (arithmetic mean) between the simultaneous locations obtained using radio tracking (intersections of bearings) and GPS-positioning, as Zimmerman and Powell (1995) suggested. We also calculated the 90% and 95% confidence distances and areas, i.e. we estimated the 90% and 95% confidence distances for radio locations and used that as a radius for the confidence area (Zimmerman & Powell 1995).

The position and shape of the routes ($n = 10$) obtained from GPS-positioning and from radio tracking were compared by drawing them on a map. The lengths of the routes were calculated and compared: route 1 (GPS_{tot}) was obtained from GPS-positioning using locations several times a minute and was considered to be the true route, route 2 (GPS_{15}) from GPS-positioning using only locations every 15 min., and route 3 (radio) from radio-locations every 15 min. The difference between routes 1 and 2 gives the error (shortening of the route) that results from the fact that the 'hare' was located only every 15 min. The difference between routes 2 and 3 gives the actual location error, and the difference between routes 1 and 3 is the net error between the true route and that obtained from radio locations. The mean number of locations/routes 2 and 3 was 20.7 (range 10–37), while that for route one was 318.1 (111–641).

Home range calculations

From these data we also calculated home range sizes for six 'hares' (we combined the data for some routes to get enough locations for calculating home ranges): home range 1 (GPS_{tot}) was obtained using GPS-positioning and locations several times a minute and was considered to be the true home range, home range 2 (GPS_{15}) using GPS-positioning and locations every 15 min., and home range 3 (radio) using radio-locations every 15 min. The difference between home ranges 1 and 2 gives the error in home range size that results from a rather small number of locations when GPS_{15} home ranges were calculated, and the difference between home ranges 2 and 3 gives the error that results from the actual location error. The difference between home ranges 1 and 3 gives the net error.

We calculated home ranges using the harmonic mean method (Dixon & Chapman 1980); we calculated the 100% and 95% home ranges and the 80% core area (i.e. the areas where the animal spends 100%, 95% and 80% of the time). The 100% home range includes all locations, 95% home range excludes the most distant 'outliers' and will here be considered the total home range. We also calculated outer convex polygons (OCP) by connecting the outermost locations so that each external angle > 180°. The mean number of locations/home ranges 2 and 3 was 34.5 (range 25–40), while that for home range 1 was 562.5 (436–726). We also calculated the overlap between GPS_{15} and radio home ranges.

We examined whether the separate fixes (obtained using radio tracking) were in the same forest/habitat patches as the simultaneous GPS-locations by projecting both on a forest patch/habitat map. We also compared the frequency distributions of simultaneous locations obtained from radio tracking vs. GPS-positioning in different habitats. We then compared both frequency distributions to 532 random fixes from the study area (*see* Kauhala 1996). To see how the size of the habitat patch affects the reliability of the results, the size of the 90% and 95% confidence areas for radio locations was also compared with the size of the habitat patches. Finally we also compared the habitat composition of core areas of GPS_{tot} and radio home ranges, because in real home range studies, we use the habitat composition of the core areas, and sample size is the number of individuals or core areas rather than the number of locations.

Forest patch is a unit area for forestry purposes, the mean forest patch size in the study area being 2.9 ha. Habitat patches were larger because the habitats of adjacent forest patches were often similar. The mean size of habitat patches in the study area was 7.1 ha (range 1–17 ha, radius 150 m). Habitats were classified roughly into seven categories: clear-cuts/plantations (0–9 yr) of moist heath, young moist heath (10–30 yr), old moist heath (> 30 yr), clear-cuts/plantations (0–9 yr) of barren heath, young barren heath (10–30 yr), old barren heath (> 30 yr) and shores (within 50 m of water). The basis for this classification lies in the undergrowth of each habitat type (*see* Kauhala 1996).

Statistical tests

We used ANOVA to test the differences in mean location errors between seasons and persons. We made cube root transformation to the location error data to make it normally distributed. We used ANOVA also to test the differences between the mean lengths of routes and mean home range sizes calculated with different methods. Chi-square tests were used to test for differences in frequency distributions between radio locations, true (GPS) locations and random fixes in different habitats. Paired *t*-tests were used to compare the habitat composition of core areas. The level of significance was 0.05.

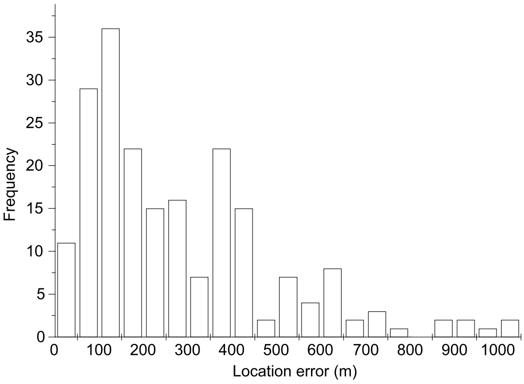

Fig. 1. Frequency distribution of location errors (n = 207).

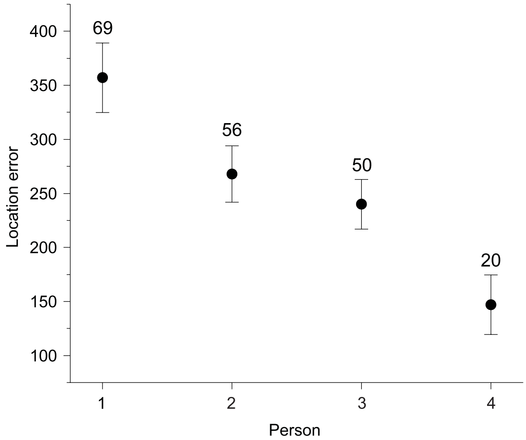

Fig. 2. Mean (± S.E.) location error between four persons involved in the study. Numbers above S.E. bars refer to sample size.

Results

Location error

The mean location error of separate fixes was 281 m (SD = 218.9, range 20–1123 m, $n = 207$). In 50% of the cases the location error was < 218 m (Fig. 1), and the 90% and 95% confidence distances were 581 m and 704 m, respectively. Location error was not normally distributed (Kolmogorov-Smirnov $D = 0.125$, $n = 207$, $p = 0.003$) but was biased towards small errors. Cube root transformation resulted in normal distribution ($D = 0.068$, $p = 0.290$). Location errors varied between persons, the mean error of the 'best' person being 147 m and that of the 'worst' person being 358 m (ANOVA with season as a covariate: $F_{3,1} = 9.25$, $p < 0.001$; Fig. 2). Location error was larger in early summer than in winter (mean error in winter: 241 m ± 203 m, $n = 161$, in summer: 422 m ± 216 m, $n = 46$; ANOVA with person as a covariate: $F_{1,1} = 44.30$, $p < 0.001$).

Table 1. Route lengths (m) obtained using three different methods: route 1 (GPS_{tot}) was obtained from GPS-positioning using locations several times a minute, and was considered the 'true' route, route 2 (GPS_{15}) from GPS-positioning using only locations every 15 min. and route 3 from radio-locations every 15 min.

Route no.	Date	Route 1 GPS_{tot}	n	Route 2 GPS_{15}	n	Route 3 Radio	n
1	18 Jan. 2000	6959	436	4221	37	10363	37
2	2 Mar. 2000	4049	272	3049	23	8806	23
3	10 Mar. 2000	1926	202	885	17	4173	17
4	20 Mar. 2000	4942	641	1623	25	7998	25
5	22 Mar. 2000	3872	111	3478	17	4006	17
6	14 Jun. 2000	2189	236	1776	14	3561	14
7	15 Jun. 2000	3371	255	2615	22	6137	22
8	16 Jun. 2000	1608	109	1014	10	2616	10
9	2 Jan. 2001	6149	497	4107	20	6443	20
10	3 Jan. 2001	3643	422	2099	22	3721	22
Mean		3870.8	318.1	2497.7	20.7	5782.4	20.7
SD		1761.9		1223.7		2593.8	

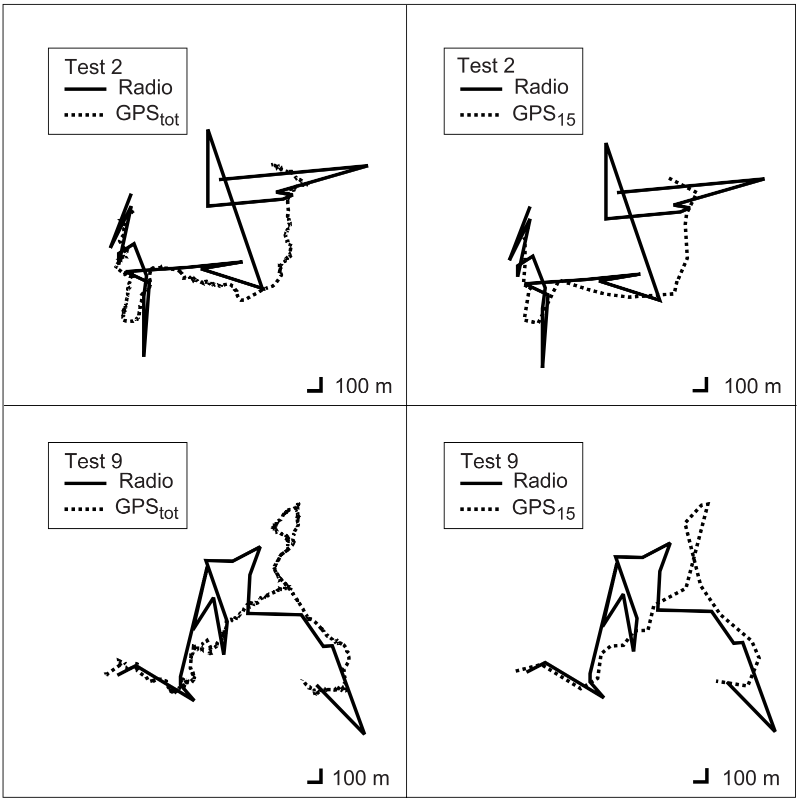

Fig. 3. Two examples of the routes obtained using radio-tracking vs. GPS data. Radio-locations were taken at 15-min. intervals, GPS-positioning several times per minute (GPS_{tot}, left) or at 15-min. intervals (GPS_{15}, right).

Routes

Radio route (route 3) was the mean of 1.5 × the true route (route 1) and 2.3 × route 2, indicating that radio locations gave too long routes because of location error (Table 1 and Fig. 3). Route 2 (GPS_{15}) was 0.65 × the true route, i.e. taking locations at 15-min. intervals shortened the routes, which counteracted the location error. The ultimate error is thus smaller than the actual location error. The differences in route lengths between the 3 groups (GPS_{tot}, GPS_{15} and radio) were significant (ANOVA: $F_{2,27} = 7.21$, $p = 0.003$).

Home ranges

The mean sizes of home ranges 1–3 did not differ, indicating that location error or number of locations did not affect home range size in this study (ANOVA: 100% harmonic mean home range: $F_{2,15} = 0.82$, $p = 0.459$, total (95%) home range: $F = 0.45$, $p = 0.646$, core area (80% home range): $F = 0.197$, $p = 0.823$, OCP: $F = 0.304$, $p = 0.742$; Fig. 4). GPS_{15} home ranges overlapped the mean of 56% of radio home ranges (56.3% for 100% home range, 58.5 % for total home range, 51.3% for core area and 59.2 % for OCP).

Habitat use

When we compared radio locations to the simultaneous GPS locations, we found that only 22.2% of the corresponding locations were in the same forest patches. Since habitat patches were larger than forest patches, 33% of the radio locations were in the correct habitat patch. The frequency distributions of radio locations vs. GPS_{15} locations in different habitats did not, however, differ

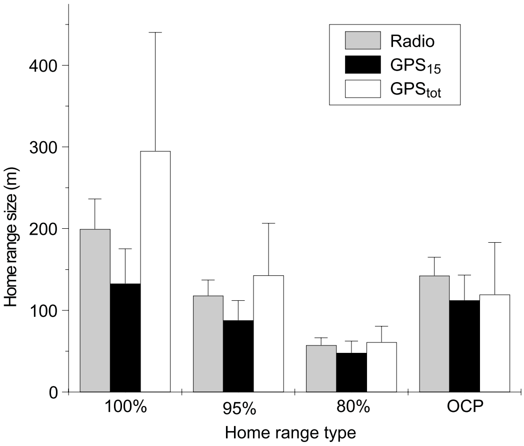

Fig. 4. Mean (± S.E.) home range (n = 6) calculated with different methods. Radio-locations were taken at 15-min. intervals, GPS-positioning several times per minute (GPS_{tot}) or at 15-min. intervals (GPS_{15}). 100%, 95% and 80% refer to 100%, 95% and 80% harmonic mean home ranges and OCP to outer convex polygons.

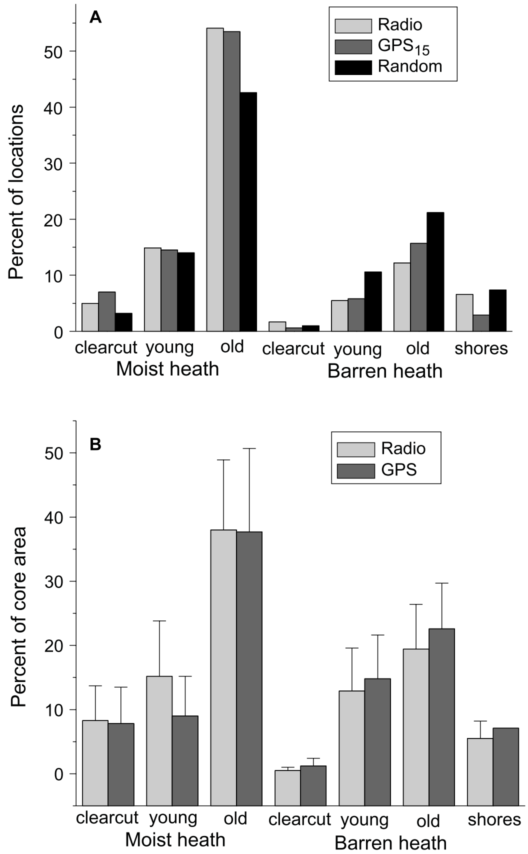

Fig. 5. — **A**: Distribution of GPS locations (n = 172), radio locations (n = 181) and random fixes (n = 532) over different habitats. — **B**: The mean (± S.E.) habitat composition of core areas of home ranges (n = 6), determined using radio-tracking vs. GPS-positioning.

(χ^2 = 4.86, df = 6, p = 0.562; Fig. 5a). Both frequency distributions differed from the distribution of random fixes (GSP–random: χ^2 = 17.22, df = 6, p = 0.009; radio–random: χ^2 = 15.18, df = 6, p = 0.019). We also compared the habitats of core areas (radio–GPS_{tot}) and found no difference in habitat composition (Fig. 5b). The 90% and 95% confidence areas were 106 ha and 154 ha, respectively. They were thus 15–22 times larger than the habitat patches.

Discussion

Location error and routes lengths

In the present study, the mean location error was 281 m. Zimmerman and Powell (1995) found a similar error (mean 279 m, range 10–440 m, 95% confidence distance 766 m) in their study of black bears (*Ursus americanus*), and Garrott *et al.* (1987) reported a location error of 74–1025 m in their study of the mule deer (*Odocoileus hemionus*). Palomares *et al.* (2000) found a 95% confidence distance of 207 m when they studied habitat use of the iberian lynx (*Lynx pardinus*), the corresponding figure in the present study being 704 m. Kauhala *et al.* (1993) found a mean location error of only 180 m in their study of raccoon dogs (*Nyctereutes procyonoides*). The error was < 80 m in 63% of the cases, the corresponding figure in the present study being 300 m. The two previous studies were done using transmitters hidden in the field, and the location error was smaller than that in the present study. In this study, the 'hare' moved, which may have caused larger error (Schmutz & White 1990). Studies where the transmitter is not moving, may thus give an overly positive picture about the accuracy of locations.

Since the location error in the present study varied considerably between persons, the same persons should do the radio tracking for a given study, for instance, when data of the same animals are collected during different seasons/years or from different areas. If that is not possible, the location error of different persons should at least be tested and taken into account when results are analysed.

Location error also varied between seasons, being greater in summer than in winter. The overall precision of location is best when the distance between the transmitter and the receiver is < 1000 m (Schmutz & White 1990). In this study, the distance was equal in summer and winter, and thus, does not explain the seasonal difference in the location error. The movements of the animal may also cause location error, the rate of movement and location error being positively and linearly correlated (Schmutz & White 1990). In this study, the 'hare' moved faster in winter (0.9 km h^{-1}) than in summer (0.6 km h^{-1}) and one would expect larger error in winter. One explanation to the larger error in summer may be that the vegetation in summer may affect the radio signal (White & Garrott 1990).

Radio-tracking resulted in routes that were 1.5 times the length of the true routes. The actual location error was even larger but taking the locations at 15-min. intervals shortened the route and counteracted location error. A correction factor (in this study 0.67; the true route = 0.67 × radio route) should be used if nightly movements of animals were studied using radio-telemetry. Also Rouys *et al*. (2001) found that radio-tracking distances walked (by bison) needed to be corrected before further analyses.

Home ranges and habitat use

The imaginary home ranges in this study were approximately the size of the true home ranges of mountain hares in Finland (K. Kauhala *et al*. unpubl.), and radio-tracking resulted in home range sizes similar to those obtained from GPS-data. The effect of location error on the size of the core area seems particularly small. The effect of the number of locations (difference between GPS_{tot} and GPS_{15} home ranges) on the size of the 100% harmonic mean home range was, however, larger (Fig. 4). The lack of statistical significance in that case may be due to small data (n = 6). Sample size affected less on OCP, total (95%) home range and core area. This means that when the number of locations varied between 25 and 40, the sample size was adequate to give reasonably reliable home range sizes, probably except the 100% harmonic mean home range.

Since a minority of radio-locations (22%) were in the correct forest patch, one must be careful when using single fixes from radio-tracking data for habitat analysis, especially when habitat patches are small. The results were better when we examined the distribution of fixes in larger habitat patches. It is also possible that false positive and false negative errors have balanced each others out, and produced unbiased estimates of habitat use (Samuel & Kenow 1992). The ratio of location error to the size of habitat patches is essential when habitat use is studied using radio telemetry (Nams 1989). Nams (1989) found, however, that even when location error is great in relation to the size of habitat patch, one can test habitat selection by increasing sample size.

The position of radio home ranges was rather correct; radio home ranges overlapped > 50% of the GPS-home ranges. Radio telemetry gave also a good picture of the habitat composition of core areas. Thus, habitat use should be estimated using home ranges and their core areas rather than using single fixes; even when the location error of single fixes is large in relation to the size of the habitat patches, the position and habitat composition of core areas may be rather correct. Rouys *et al*. (2001) found that also in activity studies of animals, single fixes often did not represent the actual activity, but the mean time spent active calculated from radio-tracking data was reliable.

Conclusions

Radio locations are only estimates of an animal's true position, and the location error should always be tested in studies based on radio telemetry (White & Garrott 1990). The acceptable error depends on the aims of the study; in this study even a rather large error gave reasonably correct home range sizes. If the aim of the study is to find out the length of the daily route of the animal, location error tends to result in too long routes. We suggest that if movement patterns of small or medium-sized mammals are studied, GPS-transmitters would be the best solution to obtain reliable results. Another possibility is to test the error and use a correction factor. If one studies habitat use of the animal, location error should be compared to the size of the habitat patches to estimate the reliability of the results, or GPS-transmitters should be used. Since estimates of the habitat composition of the core areas gave reliable results despite the large location error, habitat use should be studied by examining home ranges rather than single fixes.

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