Breitenmoser, U., Breitenmoser-Würsten, Ch., Zuleta, G. A., Bernhart, F., and O'Donoghue, M. (1993). A method to estimate travel distances of fast moving animals. Biotelemetry : 318-326.

Keywords: 3CA/Canada Lynx/dispersal/Kluane Lake/Lynx canadensis/method/movement/tracking

Abstract: We present a method to estimate daily travel distance (DTD) of lynx *(Lynx canadensis)* by means of telemetry. Lynx were located every 15 minutes for a maximum of 8 hours. Three observers simultaneously took 2 bearings each. A fourth person analyzed the locations on a computer and guided the observers. Later, the data were re-analyzed, and non-significant displacements excluded. DTD in summer was 12,9-13,5 km. From tracking series in winter, we derived a correction factor and estimated the real distance traveled to be about 20.1-21.1 km. By splitting the continuous location series into intervals of decreasing length. We determined a model to compute DTDs. At a rhythm of 1 location/minute, the DTD would be 20.5km.

Biotelemetry XII
August 31-September 5, 1992
Ancona, Italy

A METHOD TO ESTIMATE TRAVEL DISTANCES OF FAST MOVING ANIMALS[1]

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ABSTRACT

We present a method to estimate daily travel distances (DTD) of lynx (Lynx canadensis) by means of telemetry. Lynx were located every 15 minutes for a maximum of 8 hours. Three observers simultaneously took 2 bearings each. A fourth person analyzed the locations on a computer and guided the observers. Later, the data were re-analyzed, and non-significant displacements excluded. DTD in summer was 12.9-13.5 km. From tracking series in winter, we derived a correction factor and estimated the real distance travelled to be about 20.1-21.1 km. By splitting the continuous location series into intervals of decreasing length, we determined a model to compute DTDs. At a rhythm of 1 location/minute, the DTD would be 20.5 km.

INTRODUCTION

Straight line distances between consecutive locations of a radio-tagged animal are often used to describe the animal's movements. If locations are taken each day, these stretches will represent the real distances travelled only in particular situations, such as for migrating birds. For resident, but highly mobile animals, capable of reaching each part of their home range within a few hours, day-to-day displacements will largely underes-

[1] Publication no. 16 from the Kluane Boreal Ecosystem Project.

timate their actual movements. Reducing the time span between 2 consecutive locations would improve the estimation, but how short a time interval would represent the real distance travelled?

During an ongoing study of the boreal forest ecosystem in the SW Yukon Territory, Canada (Krebs et al. 1992), lynx (Lynx canadensis) were tracked in the snow to estimate kill rates per distance travelled. To attain realistic information on the movements of lynx in summer as well, we developed a method to estimate travel rates by means of radio-telemetry. We estimated the daily travel distances by locating single individuals continuously over a fixed time period. To reach this goal, we had to (i) set up a field procedure suitable for locating even a moving animal with high accuracy, (ii) cut down the monitoring intervals to a level where the straight line distance between 2 consecutive locations would approximate the real travel distance, and (iii) gain information about the difference between the straight line and the real distance travelled.

STUDY AREA AND EQUIPMENT USED

The field work was carried out in the boreal forest of the Kluane Game Sanctuary east of Kluane Lake in southwestern Yukon Territory (138°W/61°N). The area is quite flat, but radio tracking was difficult because of the numerous steep eskers. Only the Alaska Highway, the abandoned Old Alaska Highway and mining roads provided access to the study area of about 300 km^2. We moved around by car and mountain bike in summer, and by snowmobile in winter. Telemetry equipment used was by Telonics and YAESU. Bearings were taken by means of hand-held H-antennas.

METHODS

Field procedure: To obtain quick and accurate locations, 3 persons took bearings simultaneously from different points ("stations") and reported them by walkie-talkie to a fourth person, who analyzed the data on a lap-top computer. We applied the program Locate II (Nams 1990) to estimate the locations from a minimum of 3 bearings, using the maximum likelihood estimator (Lenth 1981), which provides a 95%-confidence-ellipse for each location (Fig.1). The immediate analysis of each location was crucial to adapt our tactic to the situation of the lynx. We also noted for each location whether the lynx was active or not by interpreting the fluctuations of the signal strength, and the pulse rate of transmitters with activity switches. The following strategy proved to be rational during the field work: 1. Each person took 2 bearings for every location (Fig.1). If the first and the second bearing differed for >5°, a third was taken. 2. The bearings were taken at the same time; a short delay was sometimes enough to produce an improper location if the animal was moving. 3. The angle between the 2 outermost bearings had to be 90° to get a good estimate of both coordinates (Fig.1). It was important to anticipate a lynx' further movements to reach the next adequate station in time. 4. To improve the accuracy, we tried to work as close to the lynx as possible. Therefore, we started out with a lynx not too far away from a road. Most lynx seemed not to care about our presence, but sometimes, an animal obviously altered the route because one of us was standing in its way.

The interval between 2 locations was 15 minutes. This was the minimal time-span needed to take the bearings, compute a location, and reach a new station, if required. The maximum length of a series was 8 hours (Tab.1). After this period, all batteries (and also the people) were exhausted. When a lynx walked too far from the roads, we had to quit earlier, as the locations became too inaccurate.

Analyses of data: The field data contained some locations with large error areas (series # 1 or 19; Tab.1). Inaccurate locations strongly influenced travel distance and speed of a series. To check for such errors and to avoid a bias due to improper locations, we subsequently re-analyzed the field data at home, and excluded non-significant displacements, using only significant ones for the interpretation. We defined a significant displacement as the distance between 2 consecutive locations, if the 95%-confidence-ellipse of the second fix did not include the first one. We laid down the following rules for the re-analysis of the data: 1. A location was accepted if its error ellipse did not include the former fix ("a" in Fig. 2), and rejected if it did ("d" in Fig.2). In the latter case, the interval between 2 consecutive locations became 30 minutes (or longer if >1 location was rejected). 2. Locations were pooled (a new fix was computed from all bearings) with a medium location time if their error ellipses included each other's fixes, but no more neighbouring fixes ("c" in Fig.2). 3. Fixes were computed from the pooled bearings, but accepted as several distinct locations in the same spot ("zero-displacement") if the error areas included all fixes but the lynx was inactive. We called such a cluster of locations a "bed" ("b" in Fig.2).

From the re-analized data, we computed the total distance travelled per series, mean distance per hour of the day, mean speed per time active, and the hypothetical daily travel distance (DTD). We corrected the local time for -2 hours in summer and for -1 hour in winter, so that the data are presented in solar time. DTDs from the continuous locations were compared with the results of "time trials". For a time trial, a radio-marked lynx was flushed from a bed, and was monitored until it settled down again. Then the lynx's tracks were followed step by step between the 2 known locations.

RESULTS

Distribution of data and activity: From June to August 1991, we made 22, and in February 1992, another 5 continuous location series from 7 different lynx (3 adult females, 3 adult males and 1 yearling male, M630; Tab.1). The field data represented a total of 611 locations within 151 hours. 19% of the locations were found to be not significantly distinct from the previous ones. We accepted 494 locations within 146.5 hours as significant displacements. The re-analysis of the field data reduced the total length of all consecutive displacements from 100.378 km to 77.522 km (Tab.1). The summer data were about equally distributed throughout the day, but the winter data were concentrated during the daylight hours from 0800-1500 (Fig.3). We were only able to realize 5 series during the winter. Cold temperatures and strong winds in February 1992 often thwarted field work. Lynx were active in 63.7% (active: n = 305; inactive: n = 191; unknown: n = 31) of the continuous locations in summer, and 71.7% (active: n = 59; inactive: n = 24) in winter. The distribution of activity from the summer series (Fig.4) showed a minimum activity of 20% from 0900-1000, and a peak activity of 87.5% from 1700-1800. However, the pattern of activity was not very distinct - probably a consequence of the long lasting daylight during the summer at this northern latitude.

Travel distances and speed: The accumulated total distance for the re-analyzed summer series was 68.608 km in 127.5 hours (speed per time active = 0.845 km/h), for the winter series 8.914 km in 19 hours (0.654 km/h). The mean speed per time active was higher for the summer series (0.913 km/h, n = 22) than for the winter series (0.720 km/h, n = 5), but the difference was not significant (Man-Whithey U-test, P = 0.318). The DTD was 12.706 km when computed for all series, 12.918 km for the summer, and 11.254 km for the winter series, respectively. As the number of locations per hour was not exactly equally distributed throughout the day (Fig.3), we also calculated the DTD from the values for each hour of the day. The DTD calculated from the mean displacements per hour was 13.204 km for all series together, and 12.916 km for the summer series.

With an increasing number of locations/day, an asymptotic value for the DTD should be reached. This can be shown from continuous location series. We split the series into each possible interval of 15-minute steps (15, 30, 45, 60 minutes, etc.) and projected the DTDs from the mean values of each interval, starting at 8 hours (*3 = DTD) down to 15 minutes (*96 = DTD). This analysis resulted in a DTD of 13.536 km from the 15-minute distances (0.141 km/15 min). We then plotted the DTD against the increasing number of locations per day (Fig.5). The increasing DTDs followed the logarithmic function $y = a + b * \ln(x)$, where a = -1.267, and b = 2.999 (r = 0.991, P < 0.001; Fig.5).

Thus, the DTD of lynx in summer from the continuous location series ranged from 12.916 to 13.536 km. These values were much higher than the minimum DTD computed as a straight line between the daily routine locations (Fig.6). From summer 1991 and February 1992, an additional 230 locations were available to calculate the displacement of the lynx within the last 24 hours. The mean minimum DTD was 2.490 km (sdev = 1.801 km, range = 0.037-13.022 km). This illustrates, how different the minimum DTD was from the real distance travelled by lynx per day.

We compared our data from the continuous location series with a set of time trials. During the time-active of 9 trials, lynx travelled 9.739 km in 596 minutes, or 1.017 km/h (range = 0.745-1.456 km/h, sdev = 0.228 km/h). The correction factor (cf) to estimate the real travel distance from the 15-minute straight line displacements would then be 1.25 for the over-all speed of 27 series, or 1.56 for the speed of the winter series. Consequently, the true DTD of lynx in summer would be 16.145-16.920 km (cf = 1.25) or 20.149-21.116 km (cf = 1.56).

DISCUSSION

To compare the data from continuous location series with those from time trials, we had to work with the travel speed. Nevertheless, there are 2 problems with the speed. (1) The speed from the time trials could be above average, as the animals were flushed. (2) Though we would suppose that lynx walk more slowly in the snow than on bare ground, and indeed found a lower speed in winter, the difference was not significant. The best way to calibrate the 15-minute straight line distances would be to track a lynx parallel to a continuous location series, and to compare the accumulated straight line distances with the real distance travelled instead of the speed. To do this, however, requires additional equipment and manpower.

In spite of the uncertainty about the speed, the true DTD estimated from the summer data (20.149-21.116 km) would fit rather well the estimations from the logarithmic function model. At a hypothetical frequency of 1 location/minute (1440 fixes/day), the DTD computed from this model would be 20.5 km, and at a frequency of 1 location/30 seconds, 22.6 km, respectively.

Even without knowing the actual correction factor, our method provided a realistic idea about travel distances, and, furthermore, information on activity patterns and habitat use. The main difficulty, however, was the accuracy of the field data. Research on predators often implies working with hand-held telemetry systems in a large study area. Use of fixed stations (towers) and extensive testing of the triangulation system (White & Garrot 1990) in the study area is often impossible. We have to work towards an improvement of this simple method of radio-tracking. We summarize the major problems met during the field work and the analyses of the data in order to help to avoid these pitfalls, and to encourage for further work.

1. Procedures to estimate telemetry locations and errors (overview in Saltz & White 1990; White & Garrott 1990) help us to obtain control over the accuracy of a location. We used the 95% error ellipse from the maximum likelihood estimator to detect imprecise locations. We did, however, not know whether all locations with a small error area were really correct. A systematic bias of the bearings (e.g. reflections) could produce a wrong location with a small error area. The relationship between the size of the error area and the difference between the estimated and the true location needs testing. Working close to the animal solves part of the problem. But then, it is sometimes hard to determine one's own map location, and the risk of disturbing the animal's behaviour increases. We had some lynx that were more tolerant of our presence than others. Working with one of these improved the result and was more exciting.

2. We needed independent monitoring of the activity of the lynx. There were 2 problems with the determination of the activity. (1) Interpreting the fluctuation of the signal strength (which had proved to be a reliable method to determine the activity of Eurasian lynx; Bernhart 1990) and the status of the activity switch of the transmitter did not always produce the same results. If there was a discrepancy, we favoured the fluctuation of the signal, which resulted in a higher proportion of activity. (2) Lynx seemed to change their status of activity in a fast rhythm. As a consequence, we some-

times had displacements between 2 consecutive locations, though both locations were recorded as "inactive". On the other hand, we also had "zero displacements" between 2 "active" locations. According to our rule that insignificant distinct locations should be ignored if the lynx was active, we excluded or pooled these locations although they might have been correct.

The estimator used to compute the locations as well as the method to monitor the activity should be tested in the study area by means of beacons (White & Garrot 1990). In large areas, however, it is often not possible to do this. Most projects using telemetry have limited manpower and modest equipment. Even our method to estimate the travel distance of lynx, although no sophisticated technique was used, involved a considerable amount of manpower and telemetry equipment.

ACKNOWLEDGEMENTS

We thank E. Hofer for her help with field work, P. Jackson for proofreading the manuscript, and the Yukon Territory Government for lending us walkie-talkies. Funds were provided by the Swiss National Foundation for Scientific Research (postdoctoral fellowship to U. Breitenmoser), Argentinia's Council for Scientific and Technological Research (postdoctoral fellowship to G.A. Zuleta), and the Natural Sciences and Engineering Research Council of Canada (NSERC) through a Special Collaborative Project to C.J. Krebs and associates (see Krebs et al. 1992).

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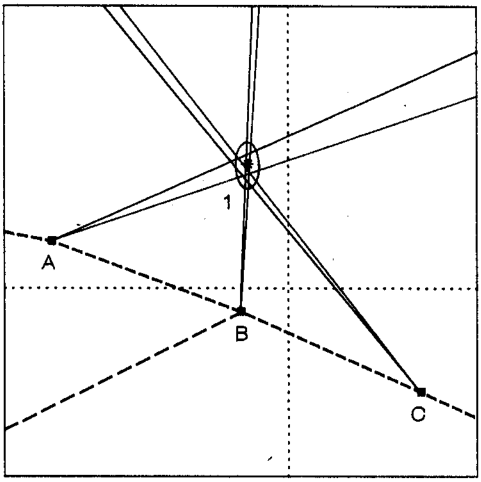

Fig.1. Lynx location. Three observers (A, B, C) simultaneously took two bearings (solid lines) each. The location (*) was computed by means of the program Locate II (Nams 1990), using the maximum likelihood estimator. The ellipse represents the 95% confidence area for the location. Broken lines = roads, dotted lines = coordinate grid. The map shows an area of 1000 x 1000 metres.

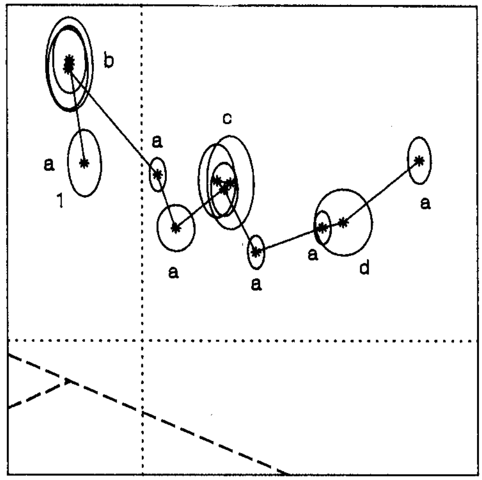

Fig.2. Thirteen consecutive locations (*) with error areas (95% confidence ellipse). Solid line = route of the lynx, starting at 1 (same location as in Fig.1); a = significant distinct locations; b = bed (lynx passive, for explanation see text); c = pooled locations (lynx active); d = excluded location after a non-significant displacement. Broken lines = roads, dotted lines = coordinate grid. The map shows an area of 700 x 700 metres.

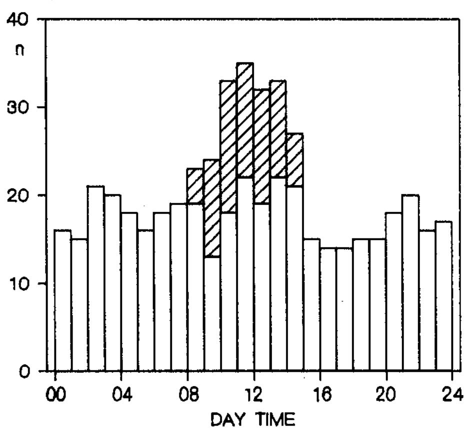

Fig.3. Distribution of significant distinct locations. Blank bars = summer (n = 421), and hatched bars = winter data (n = 73).

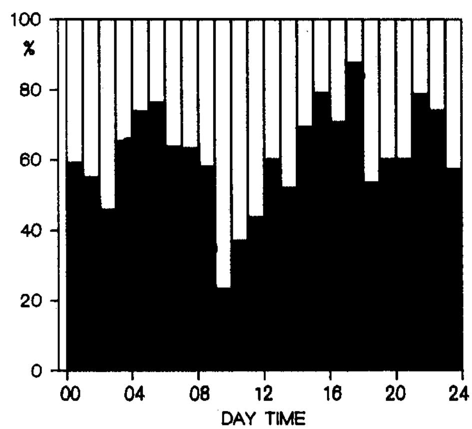

Fig.4. Relative activity of lynx during the continuous location series. Bars represent the active (black) and the inactive (blank) locations per hour in per cent. Summer data only.

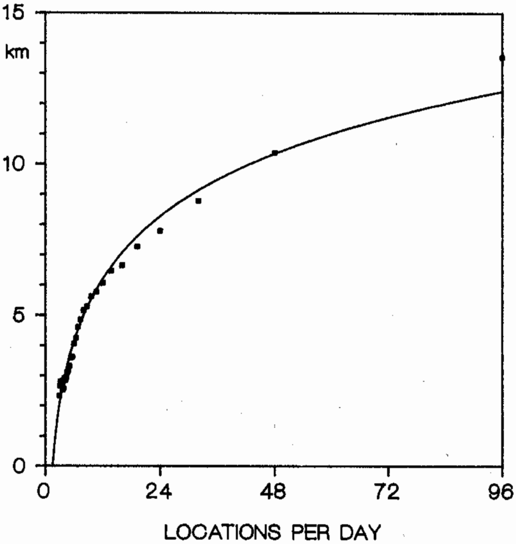

Fig.5. Daily travel distance (•) of lynx computed from an increasing number of locations per day and decreasing intervals. Distances per interval were calculated as mean values of the straight lines between all possible pairs of two locations, with the respective interval within every continuous location series. Curve = logarithmic smoothing of the data (y = a + b * ln(x)), where a = -1.267, and b = 2.999.

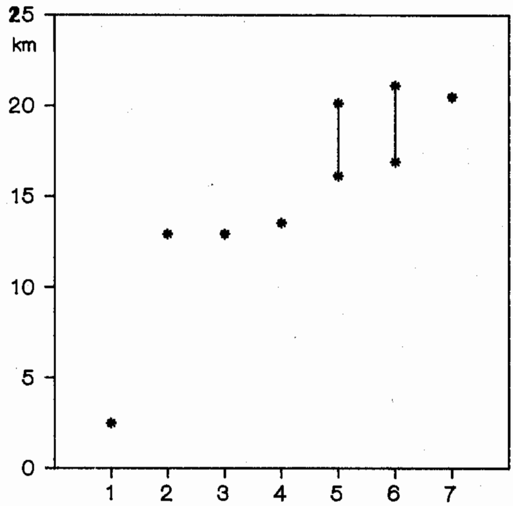

Fig.6. Comparison of daily travel distance of lynx estimated from different methods. 1 = straight line distances between day-to-day locations; 2-4 = continuous location series, 2 = speed per time active summer series, 3 = mean displacement per hour summer, 4 = mean 15-minute intervals; 5, 6 = method 3 and 4 multiplied with correction factors 1.25, and 1.56, respectively; 7 = computed for a frequency of one location per minute from the logarithmic function.

Ser	Lynx	Time Start-End	Field Data # min	# loc	Dist. (km)	Mean E.Area	Act in %	Re-Analyzed Data # min	# loc	Dist. (km)	Speed (km/h)	Mean E.Area
Summer												
1	M630	1000-1430	270	17	4.437	0.651	37.5	225	8	1.872	1.331	0.135
2	F595	0500-1300	480	33	3.079	0.008	48.5	480	27	2.835	0.731	0.009
3	F595	2100-0100	240	17	2.593	0.055	75.0	240	11	2.160	0.720	0.037
4	F595	1300-2100	480	33	4.238	0.022	81.3	480	33	5.660	0.871	0.022
5	F260	1200-1600	240	17	2.123	0.011	75.0	225	13	1.851	0.658	0.009
6	F260	2000-0200	360	25	6.712	0.253	76.0	345	15	4.162	0.952	0.082
7	F260	1600-2200	360	25	4.258	0.092	75.0	345	21	3.382	0.784	0.016
8	M500	0630-1400	450	31	2.444	0.019	38.7	450	25	2.155	0.742	0.010
9	M285	1700-2400	420	25	2.776	0.041	33.3	420	19	1.952	0.837	0.006
10	M500	1015-1700	405	28	5.637	0.065	84.6	397	21	3.636	0.649	0.048
11	F180	0430-0900	270	19	3.786	0.101	75.0	255	13	3.159	0.991	0.071
12	F180	2100-0330	390	27	5.699	0.196	72.0	375	18	4.438	0.986	0.037
13	F595	1315-2115	480	33	1.930	0.004	54.6	480	28	1.605	0.368	0.003
14	F180	0600-1215	375	27	2.688	0.022	34.8	367	25	1.281	0.602	0.004
15	M285	0730-1215	285	19	5.155	0.161	50.0	285	17	3.670	1.545	0.066
16	M630	2100-0500	480	32	7.429	0.064	34.4	480	30	6.230	2.265	0.041
17	F595	2100-0500	480	32	7.428	0.166	41.4	480	27	5.167	1.561	0.053
18	M500	1315-1530	135	10	1.942	0.025	66.7	135	5	0.670	0.447	0.028
19	F260	1230-1715	285	13	2.616	0.503	100.0	270	9	2.207	0.490	0.017
20	M285	0100-0700	360	25	4.653	0.011	88.0	345	22	4.459	0.881	0.008
21	M285	0215-0600	225	15	4.783	0.342	73.3	210	9	2.632	1.026	0.055
22	M630	0200-8000	360	25	3.312	0.014	87.0	360	25	3.425	0.656	0.017
Total			7830	528	89.718		61.5	7649	421	68.608	0.845	
Mean			356	24	4.078	0.128	63.7	348	19	3.119	0.913	0.035
Winter												
23	M285	1005-1445	280	18	2.887	0.026	72.2	240	15	2.346	1.146	0.008
24	F595	0930-1400	270	19	1.560	0.003	73.7	240	17	1.417	0.427	0.002
25	F180	0800-1015	135	8	1.847	0.034	87.5	135	8	1.847	0.938	0.033
26	M285	0945-1315	210	15	0.907	0.005	46.7	195	13	0.750	0.494	0.002
27	M735	0830-1400	330	23	3.459	0.045	78.3	330	20	2.554	0.593	0.023
Total			1225	83	10.660		71.1	1140	73	8.914	0.654	
Mean			245	17	2.132	0.023	71.7	228	15	1.783	0.720	0.014
Total			9055	611	100.378		62.9	8789	494	77.522	0.812	
Mean			335	23	3.718	0.109	65.2	326	18	2.871	0.877	0.031

Tab.1: Continuous lynx locations during summer 1991 (11.6.-11.8.91) and winter 1992 (10.2.-23.2.92) in the Kluane research area. Ser = series; # min = length of series in minutes; # loc = number of locations; Dist. = total travel distance per series = accumulated straight line distances between consecutive locations; Mean E. Area (error area) = mean 95% confidence ellipse (km²) for locations per series (maximum likelihood estimator; LocateII, Nams 1990); Act in % = percentage of locations lynx active. Speed = displacement per hour (km/h) for the time where the lynx was active.