Computer Analysis of Animal-Movement Data Obtained by Telemetry
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every clump of trees or bushy thicket while sometimes they seemed to spring magically from nowhere. Some of them ran ahead of the line while many were entirely confused and dashed back through the noisy driving line. . . . At the finish . . . all the deer that had been moving ahead of the drive line broke cover by the dozens and streaked between the counters. . . ."

The behavior of Deer No. 502 during the drive appears to be similar to that described above. This doe approached the drive line twice and turned back each time. On the third attempt she ran between the drivers and then raced northward for nearly a mile before slowing. We believe that this extensive movement outside her normal range was caused by panic or fright due to the noise made by the drivers. This animal's radio was noticed by a driver as the deer approached the drive line. The driver shouted to the others, and the doe "spooked" away from the line.

Deer No. 503 was apparently "surprised" by the drivers and made a short dash through the line, probably with several other deer, and then stopped its flight, without moving outside of its normal range. Its radio was not noticed.

Both deer were within their regular ranges by late evening. The disturbing effects of the drive appear to have been very short-lived since we could not detect any difference in the range of movements or the activity patterns of the deer immediately following the census. Probably deer react similarly to hunting, and we hope that the radio-tracking system can be used to evaluate responses to hunting in the future.

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COMPUTER ANALYSIS OF ANIMAL-MOVEMENT DATA OBTAINED BY TELEMETRY

Donald B. Siniff and John R. Tester

The recent development of the automatic radio-tracking system described in the first of this trilogy of articles (1) has made it possible to continuously monitor movements and activity of many animals carrying miniature radio transmitters. The system, which became operational in January, 1964, is capable of producing so many locations or fixes in a short period that it is not practical to manually process the data. This final article describes the analysis procedures using high-speed digital computers which have been developed for automatic map construction and distance computation of animal-movement data obtained by telemetry.

The radio-tracking system, located at the Cedar Creek Natural History Area, 30 miles north of Minneapolis, determines and records on 16 mm film a potential of 1920 fixes per animal in 24 hours, and is capable of tracking 52 animals simultaneously. Transferring data from film to a base map requires 6 to 8 man-hours for a 24-hour record of one animal's activity. Several species of mammals ranging in size from cottontail rabbits (*Sylvilagus floridanus*) to white-tailed deer (*Odocoileus virginianus*) have been instrumented and tracked for varying periods. Even though we have not monitored more than 20 animals at one time, manual data processing has proved impractical.

Sampling the film record may be satisfactory in some situations. In Tester and Heezen's analyses of the response of radio-tagged white-tailed deer during a drive census, they plotted minute-by-minute positions of the deer during "critical" periods and sampled the film record at 10-minute intervals at other times (3). This study pointed out numerous advantages of knowing the positions of marked animals minute-by-minute and prompted us to explore the potentials of digital computer analysis.

Many biological questions dealing with such diverse subjects as home range, territory, predation, disease, evaluation of census techniques, and animal reactions to food, cover, and weather are being studied with data generated by this tracking system. This necessitates a type of analysis that will provide useful information for specific problems and yet be broad enough to take full advantage of the available data. We have prepared a program for analysis of the animal-tracking data on the University of Minnesota's CDC 1604 computer and accessory equipment consisting of a CDC 160A computer and X-Y plotter. This discussion of the program and its options, the type of decisions made by the computer, and the nature of the input and output data are intended as a guide for use of the program and for developing modifications or new programs for similar analyses with other computers.

Data format

Data generated by the automatic tracking system consist of a bearing or azimuth from each of the two tracking towers and time. By interpretation of signal quality it is possible to assign to each "fix" a code corresponding to the suspected behavior of the animal, much as Marshall and Kupa (2) did in correlating signal changes with known grouse (*Bonasa umbellus*) activity. Ultimately we plan to correlate motion pic-

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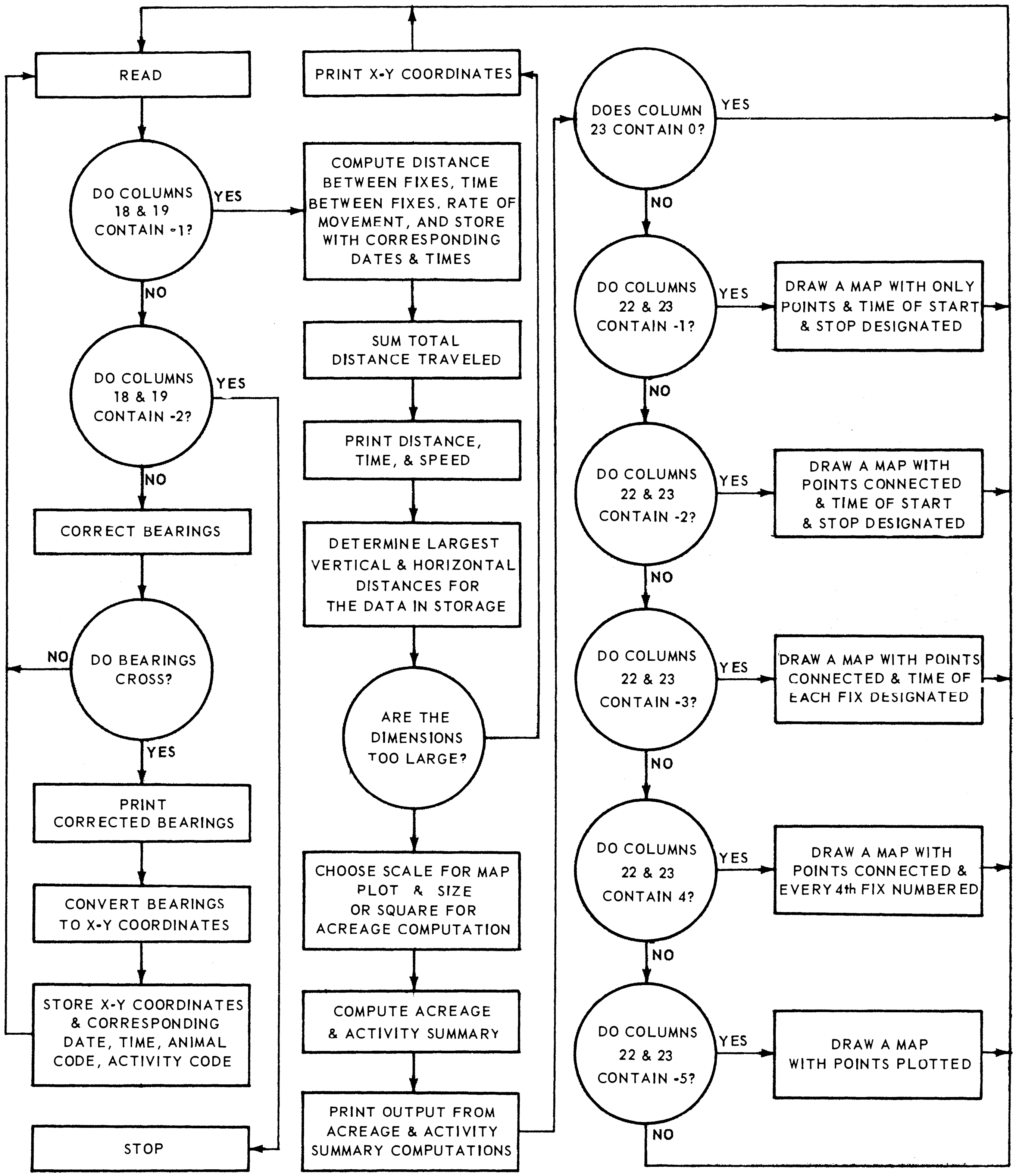


FIG. 1. Block diagram of the program for computing distance parameters and for drawing movement maps.

FIG 2. Format of the printed computer output for analysis of animal tracking data (See text for explanation)

Animal	Month	Day	Time	100 Ft	70 Ft	Count
112	8	1	1943	183.0	2.0	1
112	8	1	2038	183.0	2.0	2
112	8	1	2048	185.0	3.0	3
112	8	1	2055	188.0	5.0	4
.	.	.	.	.	.	.
.	.	.	.	.	.	.

				Distance Traveled		Distance Per Unit Time			Time
Day	Month	Time	Interval	Miles	Feet	Miles/Hr	Feet/Min	Activity	Difference in Minutes
8	1	1943	2038	0		0	0	3	55
8	1	2038	2048	.252	1330.01	1.51138	133.00105	5	10
8	1	2048	2055	.093	488.87	.79363	69.83921	2	7
8	1	2055	2108	.208	1099.97	.96152	84.61364	2	13
.	.	.	.	.	.	.	.	.	.
.	.	.	.	.	.	.	.	.	.

Animal 112 Activity Code	8/1/1941 to 8/2/458 Total Minutes for Each Activity	Animal 112 Number per Square	8/1/1941 to 8/2/458 Frequency
0	0	0	8087
1	11	1	8
2	73	2	4
3	311	3	1
4	0	4	0
5	10	5	0
6	152	6	0
7	0	7	0
8	0	8	0
9	0	9	0
		10	0
		11	0
		12	0
		13	0
		14	0
		15	0

Total Area in Acres Equals 5.20
Size of Square Used Was .4 Acres

ture records of animals with signal characteristics.

The data are read from the film using a microfilm reader, recorded on a form, and then transferred to machine punch cards. Each card, representing one location for a specific time for one animal, also contains observer and animal codes so that each is an independent unit of data. For input to the computer, each block of data is followed by a control card which determines the specific operation to be performed, e.g., the type of map to be drawn or whether a printed output only is desired.

Computing program

The block diagram (Fig. 1) shows the operations and logic sequence for the program, the order of the various outputs, and the functions of the control cards. First, the data are read, then correction factors (which are sometimes necessary due to adjustment of the system) are applied to the bearings and the corrected bearings are printed out. These bearings are then converted to X-Y coordinates and stored in the computer memory. When the corrections and conversions have been completed for the entire data deck, the computer reads the control card which transfers control to the portion of the program that calculates the distance in miles and in feet, time in minutes, rate in miles-per-hour and feet-per-minute between successive fixes, and then totals the distance traveled during the specified period. The above information with the appropriate activity code is printed for each fix in the format shown in Fig. 2.

Further computation approximates the acreage over which the animal has traveled during the period represented by the block of data. The program parti-

TABLE 1

Dimensions for Determining Map Scale and Size of Square for Acreage Computation

Maximum dimension in miles	Map scale	Square size in acres
0.00–0.68	1 inch = 400 feet	0.1
0.69–0.89	1 inch = 0.10 mile	0.1
0.90–2.24	1 inch = 0.25 mile	0.4
2.25–4.49	1 inch = 0.50 mile	1.6
4.50–9.00	1 inch = 1.00 mile	6.4

tions the coordinate surface containing the set of data into squares, and the areas of all squares that include one or more positions or fixes are summed; squares including more than one fix are only counted once. The computer chooses the size of the square for a given set of data on the basis of the maximum dimensions of the area covered by the animal during the period. The frequency of the number of squares containing 1, 2, 3, . . . 15+ positions and total acreage are printed. We believe that this type of data will be useful in studies of intensity of use within the home range.

The final printed output (Fig. 2) lists the total time in minutes for each type of activity during the period of the data. For example, in Fig. 3, animal No. 112, a red fox (*Vulpes fulva*), spent 11 minutes at Activity 1, 73 minutes at Activity 2, and 311 minutes at Activity 3, etc.

Plotting program

After the printed output is complete, the plot portion of the program directs the drawing of a map of the animal's movements. The system of X-Y coordinates mentioned above defines one antenna tower as the point 5.0, 5.0. All measurement is in miles and is relative to this position.

The stored coordinate data are scanned and the greatest vertical and horizontal distances covered by the animal are determined. The map is oriented with true north at the top; the vertical scan determines the greatest north-south distance, and the horizontal scan determines the greatest east-west distance. The plotter can produce maps up to 10 inches square. Thus, the computer determines the greatest distance, either vertical or horizontal, and selects one of the five scales shown in Table 1. Square size to be used in the acreage computations is also determined from this measurement. For example, if the greatest vertical or horizontal distance is less than 0.68 miles, the map scale will be 1 inch = 400 feet, and the square size used in the acreage computation will be 0.1 acre.

Five types of maps can be produced. The type drawn by the plotter depends on the value of the negative number in columns 22 and 23 of the control card. Table 2 gives the options available from the various control cards. For example, a minus 5 in columns 22 and 23 pro-

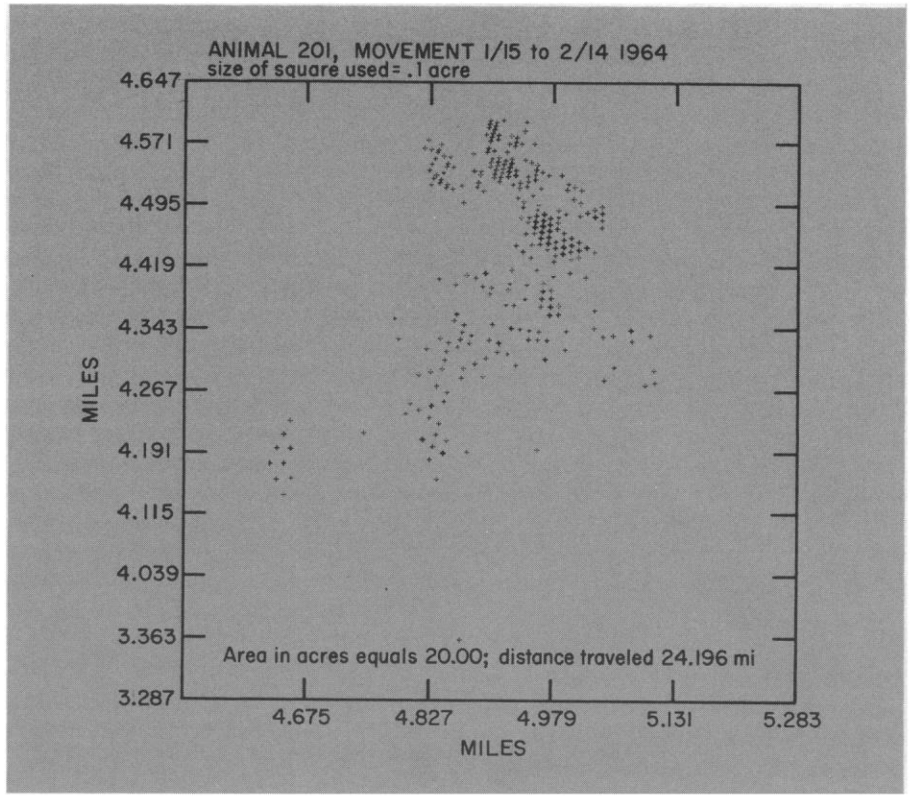
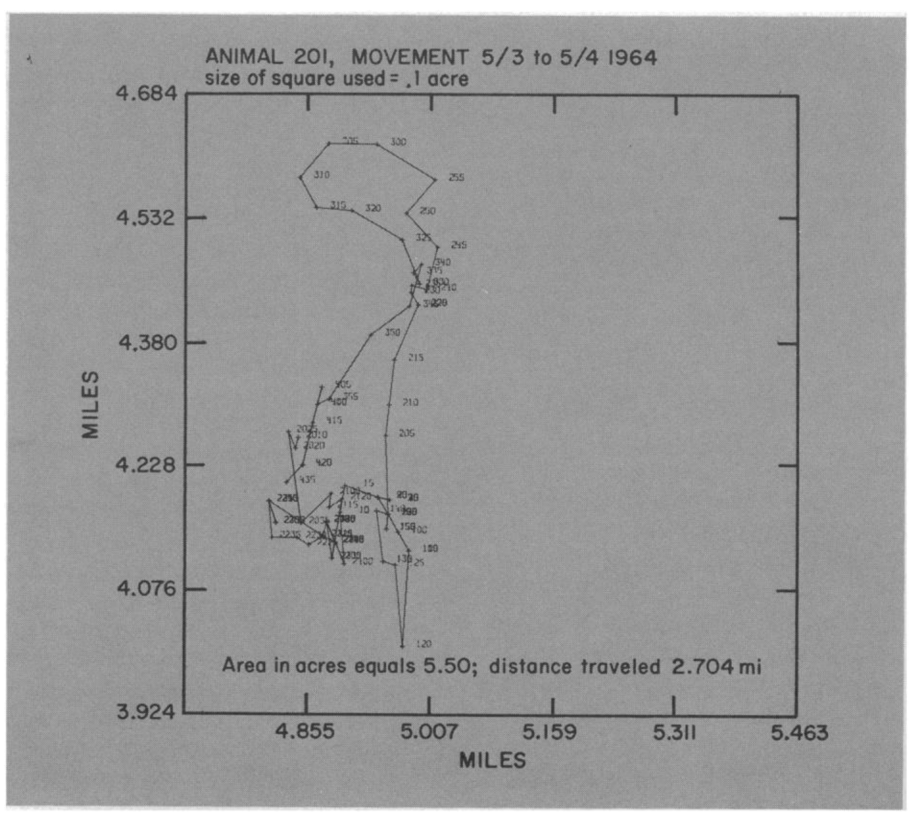


FIG. 3. Photo of map drawn by the X-Y plotter, showing each location for snowshoe hare No. 201 for 30 days from January 15 to February 14, 1964.

FIG. 4. Photo of map drawn by the X-Y plotter, showing the time for each location with consecutive locations connected for snowshoe hare No. 201 from 2010 May 3 to 0435 May 4, 1964.



duces a map with each position shown as an "X" (Fig. 3). A control card with a minus 3 in columns 22 and 23 produces a map with the points connected and the time of each fix written at each position (Fig. 4). A control card with a zero in column 23 is used if only the printed output is desired. The last set of data and its control card are followed by an end card which gives instructions to go to the end of the program and stop.

If a particular map scale from Table 1 is desired, one must first obtain a plot of the total set of data and then visually partition it into sub-areas corresponding to the dimension of the desired scale. After all the maps of each of the partitioned sets are drawn by the plotter, the large map can be pieced together.

Problems of interpretation

Although computer analysis eliminates much tedious hand work, many problems of interpretation remain. As examples, we will discuss several problems pertaining to the concepts of activity pattern and home range.

The distance traveled between fixes is computed as a straight line. This usually is not representative of the actual movement of the animal but will be a closer and closer approximation as the time between fixes decreases. However, the system has an inherent accuracy limitation of ±0.5 degree (1). Consequently, consecutive fixes may indicate small movements when none actually occurs. The magnitude of such errors depends on the animal's position and distance relative to the towers. These errors accumulate in estimates of total distance traveled and as the sampling interval between fixes decreases the apparent movement increases. It appears that a compensating factor exists, since no movement may be indicated by the system and yet the animal may actually be moving about in an area smaller than that represented by a one-degree change in azimuth. The extent of the actual bias is being evaluated.

We have tried to obtain an approximation of the area used by an animal by summing square areas of a selected size in which one or more fixes occur. It is obvious that without a large number of fixes we are only considering isolated squares drawn about each position. This does not give an adequate estimate of home range. However, as the number of fixes increases, the "used" squares begin to suggest a more definite area until they block out a clearly defined region of use which appears to give a rather close approximation of acreage.

A problem of shape is also associated with the number of fixes. It is likely an animal with a home range which demonstrates a strong "central tendency," with a distribution of fixes radiating outward in all directions, will be adequately represented. However, an animal with a pattern of movement along several lines considerable distances apart may not be as well represented.

Regardless of the shape of home range, there is the additional problem of sampling interval. The number of fixes which can be obtained for the acreage approximation is a direct reflection of the length of the period over which they are taken. Therefore, the number of possible new locations increases with time. Thus if a home range estimate is desired for a relatively short period, it may be that this method will not give the best approximation since not enough time would have passed for a definite area to be blocked out. However, at present it is difficult to define what a realistic period is, and if we could adequately define it, there is still the question of exactly how the area of occupancy should be outlined. These considerations illustrate the difficulty of interpretation of telemetry data with reference to home range. This great increase in information forces a more careful evaluation of what is meant by "home range." It is not our purpose here to propose new definitions but only to show how present techniques have forced such an appraisal.

Aside from the problems concerned with the definition of home range, we hypothesized the frequency distribution of the number of fixes per square would be valuable as an index of usage. However, this frequency is affected by the distance of a given square from the towers. The farther from the towers an animal is, the farther it must move for the system to register a 1-degree change. Thus, a square far from the tower cannot contain as many possible fixes as a square of equal size close to the towers. Since this bias is consistent with the distance from the towers, a weighting factor may be applicable.

These problems of interpretation indicate some of the complications caused by computer analysis. As more animals are instrumented and more data considered, other problems may become evident. Although at this writing no solutions are apparent, we believe that more research on the distributions generated and on the time factor as it influences these distributions will lead to satisfactory evaluations and pertinent contributions.

TABLE 2

Control Card Formats and Resulting Output

(Illustrating method of selecting any one of five possible map types or printed output only)

Card Column . . . 18 19 20	21 22 23 . . .	Instruction
−1	0	Printed output only
−1	−1	Map with points only, write time of start and stop.
−1	−2	Map with points connected, write time of start and stop.
−1	−3	Map with points connected, write time at each point.
−1	−4	Map with points connected, write index number at every 4th point.
−1	−5	Map with points only.
−2	0	Stop

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