THE CEDAR CREEK AUTOMATIC RADIO TRACKING SYSTEM

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The effects of physical and biological factors on the activity patterns and movements of animals are of major interest to biologists. Much speculation has arisen on the stimuli for specific motile responses. However, published reports on the influence of physical and or biotic factors in the environment on activity patterns and movement are relatively infrequent and usually treat the subject qualitatively rather than quantitatively.

A primary requisite to understanding these aspects of animal behavior is knowledge of the exact location at all times of the animal under investigation. Our experiences with portable radio tracking receivers showed that several persons could not continuously monitor the position of even one animal under natural conditions. Since we planned to investigate motile responses of numerous individuals of several species the need for some automation in the tracking system was apparent. No system was commercially available or even designed which would provide this type of continuous information. The development of automatic tracking equipment has been one of the primary objectives of a research project titled "A study of the motile responses of animals to physical and biotic factors in the natural environment," sponsored by the Louis W. and Maud Hill Family Foundation of Saint Paul, Minnesota.

The original specifications for the system were established on the basis of current and proposed biological objectives. These requirements provided a basis for discussions between biologists and engineers and for numerous field tests of portable tracking equipment. Modification in the specifications were based on these tests and on the experiences of other workers (Cochran and Lord, 1963; Marshall et al., 1962 and Marshall and Kupa, 1963.)

The following specifications were established:

1. Bearing accuracy—plus or minus 0.5°.
2. Range—dependent upon species and varying from approximately 0.5 mile for cottontail rabbits (Sylvilagus floridanus) to 10.0 miles for white-tailed deer (Odocoileus virginianus).
3. Interval between fixes—minimum of one per minute; continuous operation.
4. Number of individuals—1 to 50.
5. Data output—instantaneous visual display plus simultaneous permanent record.
6. Data processing—format of recorded data to be compatible with key or tape punch equipment for computer analysis and plotting.

Study Area

The area selected as the site for these investigations is the Cedar Creek Natural History Area located in Anoka and Isanti counties approximately 30 miles north of Minneapolis. This area, of 4,500 acres is now owned and administered by
the University of Minnesota. The topography is nearly flat except for scattered ice-block depressions. Terrestrial habitat varies from active sand dunes on upland areas to white cedar (Thuja occidentalis) bogs in certain lowlands. Upland areas typically have sandy soils and lowland areas are usually poorly drained with muck or peat soils. The upland vegetation has been roughly categorized into tall grass prairie, deciduous angiosperm savanna and forest and mixed conifer-angiosperm forest (Bray, Lawrence and Pearson, 1959). Lowland areas are characterized by bog lakes, marshes, dense thickets of alder (Alnus rugosa) and bog birch (Betula pumila) and stands of aspen (Populus tremuloides), tamarack (Larix laricina) and white cedar. The wide range of habitats present in the Cedar Creek Natural History Area, availability of excellent maps and aerial photographs, plus its proximity to the main campus of the University make it ideal for the purposes of the present study. In addition, the area has a permanent weather station and a modern laboratory with living facilities.

**Equipment and Methods**

The loop-type transmitters used in this study are similar to those described by Cochran and Lord (1963). This report will not cover design details of the transmitters; however, typical types and their performance in this system are given in Table 1.

The range and accuracy of this system depend to a great extent on the design of the receiving antennas, their supporting towers and associated bearing-indicating devices. For a given transmitter, the system range increases with greater receiving antenna gain and height (Lord and Cochran, 1963). In general, the resolving power of an antenna increases linearly as it is made larger whereas the difficulties in supporting and positioning it increase at a much faster rate. The compromise chosen for this system consists of two yagi antennas spaced two wavelengths (36 feet) with a maximum forward gain of 15 db. Figure 1 illustrates the directional pattern of this array and compares it with other common antennas. The yagis are hurricane-proof, Telrex Model OS 516/41, and have excellent mechanical and electrical stability. The connecting boom is of cross-braced aluminum alloy construction. The actual array weighs about 225 pounds and is rotated by a heavy duty rotator, Telrex Model BT-599 RIS, at 4/3 rpm. These mechanical features are essential to insure a maximum of accuracy. The arrays are mounted on 70-foot and 100-foot towers spaced 0.5 mile apart.

The angular position of the antenna on the 100' tower is obtained from a slotted disk which is securely fastened to the 2-inch heavy-duty pipe that turns the antenna. This 14-inch diameter disk has 360 slits milled radially 1-inch into its edge. As the disk rotates, the slits pass between a light source and a photo-cell creating 1° electrical pulses which are amplified sufficiently to activate a relay at the tracking laboratory. Radially in from the 1° slits are holes spaced every 10°; another photo-cell and light source provide 10° relay closures. A cam on the disk closes a microswitch between 3560° and 0040°; this closure, in series with a set of contacts on the 10° relay, activates a 0° (or 360°) relay. In this way 360 one-degree pulses, 36 ten-degree pulses and one 360° pulse are obtained. The 100 foot tower is structurally very stable. Tower twist from wind loading is negligible and the degree disk and photo-cell assembly are mounted directly under the rotator. However, the 70-foot tower is a triangular guyed-type which twists up to three degrees with heavy wind loading. If the degree disk assembly were located at the top, it would measure the antenna's angular position relative to the tower which in itself may turn up to 3° relative to the desired ground reference. For this reason, the antenna rotation is transmitted by a 1" pipe down the center of the tower to the degree disk and photo-cell assembly.
Table 1. Transmitters developed for the study of animal movements using the Cedar Creek radio tracking system.

<table>
<thead>
<tr>
<th>Animal</th>
<th>Antenna type</th>
<th>Weight</th>
<th>Battery life</th>
<th>Recordable range</th>
<th>Maximum range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Deer</td>
<td>whip</td>
<td></td>
<td>2 yr.</td>
<td>5 mile</td>
<td>not tested</td>
</tr>
<tr>
<td>Deer</td>
<td>loop</td>
<td></td>
<td>1 yr.</td>
<td>4 mile</td>
<td>not tested</td>
</tr>
<tr>
<td>Red Fox</td>
<td>loop</td>
<td>110 g</td>
<td>1 yr</td>
<td>3 mile</td>
<td>3.5 mile</td>
</tr>
<tr>
<td>Cottontail</td>
<td>loop</td>
<td>32 g</td>
<td>4 mo.</td>
<td>2.0 mile</td>
<td>2.5 mile</td>
</tr>
<tr>
<td>rabbit</td>
<td>loop</td>
<td></td>
<td>9 mo.</td>
<td>2.5 mile</td>
<td></td>
</tr>
</tbody>
</table>
Figure 1. Antenna Patterns

A. A Single 5 Element Yagi

B. Two 5 Element Yagis Spaced Two Wavelengths

C. A Simple Loop

D. Expanded Plot Showing Deep Null Characteristics; Signal Plus Noise vs. Angle
mounted firmly at the base. The torsional loading introduced by the pre-amplifier slip rings is so small that no significant twist is produced in this pipe. The measured angular position of this pipe is thus a true indication of the antenna orientation relative to the ground, regardless of tower twist.

A pre-amplifier, Ameco Model PV-50, is located at the center of the antenna boom to preclude deterioration of the signal to noise ratio from losses in the co-axial cable leading down the tower. At the base of the tower the signals are further amplified and converted to 16 mc by an Ameco Model CN-50 converter for transmission over several thousand feet of co-axial cable to the tracking laboratory. At the tracking laboratory signals from both towers are amplified and converted to the 200 kc to 550 kc frequency band by International Type KB-1 converters. The outputs of these converters are fed in parallel to banks of U.S. Government surplus BC-453 receivers which can be tuned within the frequency range from 200 kc to 550 kc. These receivers are arranged in 52 pairs with each pair tuned to a specific frequency representing the frequency of an animal transmitter in the field. One of the pair receives signals from the 100 foot tower while the other receives signals from the 70 foot tower. The 200 kc to 550 kc frequency range covered by these receivers represents 52900 kc to 53250 kc due to the three prior conversions. With 5 kc transmitter frequency separation, it is possible to have 75 channels in this range, 52 of which may be received simultaneously.

The outputs of the receivers are coupled to Mullard Type DM-70 visual indicator tubes. Two indicators are connected to each receiver. One is located at the receiver and serves as an output indicator for operator tuning while the other is photographed as described below. Headphones may also be used to monitor a receiver.

Permanent records of the received signals, as displayed by the indicator tubes, are made by photography. Sixteen pairs of indicator tubes are connected individually to 16 receiver pairs. Four additional indicators are provided for antenna bearing information. These 36 indicator tubes are mounted in a darkroom in the tracking laboratory where they are photographed on 16 mm film which moves continuously through a special "shutterless" camera at the rate of 100 feet per 24 hours. Two similar indicator sets and cameras complete the recording system for the 104 receivers.

Time is recorded on the film by illuminating a clock which is located near the bank of indicator tubes. Illumination is by a short flash of light every two minutes.

A U.S. Government surplus audio filter is provided for each receiver to improve the signal to noise ratio and increase the system range. However, because of slight random frequency changes in the transmitters caused by temperature change and animal activity, a receiver must be tuned hourly when its filter is switched in. With the filter switched out the receiver bandwidth is about 500 cps which is sufficient to contain a signal for periods of several days without tuning.

After standard photographic development the data on the film must be read and tabulated. The operator moves the film through a micro-film reader until the selected signal null from one antenna is aligned under the vertical reference line on the viewing screen. He then determines the bearing for this signal by reading the degree under the reference line on the viewing screen. The bearings from each antenna for an individual animal are determined and recorded in this manner. Next, the time of the fix is determined by looking at the nearest clock image. Approximately 6 hours are required to read, tabulate, and plot all the data for 24 hours of movement of one animal.
The original plans for this system include a process for semi-automatic transfer of the bearing information from the film to punch tape. Although this equipment is not yet completed, the film format is arranged so that data now being collected can later be reduced in this manner. Most of the time required in extracting the data from the film is consumed in counting the degrees and tabulating the bearings and time. The semi-automatic equipment will eliminate these steps by monitoring time and degrees on counters as the film is moved through the viewer. These counters will provide input to a Flexowriter. At the touch of a button, the time and bearing corresponding to the portion of the film lying exactly under the reference line on the viewer will be recorded by the Flexowriter on punch tape and as typewritten data.

An auxiliary system is provided for taking fixes without waiting for the film to be developed. This consists of electro-mechanical counters actuated by pulses from the 1° relay. The 0° pulses reset the counters. The operator monitoring the signal presses a micro-switch at the instant he hears the appropriate signal null. The switch closure instantly stops the counter at the degree reading which represents the angular position of the antenna corresponding to the direction of the signal null. This procedure is repeated for the other antenna and its counter. The counters, accurate to the nearest degree, are then read and the bearings plotted on a map.

Performance

Most of the 4500 acre study site and some adjacent areas are adequately covered by the system. Triangulation on animals beyond three miles from the towers or along the baseline is of limited usefulness because the bearings cross at such an acute angle that a bearing error of one degree represents a large map location error. Fig. 2 shows a plot of numerous fixes taken on a transmitter carried by a man following a predetermined path. These plots illustrate the accuracy of the system under typical conditions.

Tests were made to determine the effect of signal refraction or diffraction by vegetation as reported by Marshall (1963). No such effects were observed with this system.

Power line noise is experienced periodically. The noise is associated with normal insulator breakdown, loose connections, and a variety of other accidents incurred by power poles and lines due to the weather changes. In severe cases this noise may reduce system range by factors of two or three. The local power company has been most cooperative in promptly correcting these conditions.

Field Studies

The tracking system described above became operational in November, 1963. To date, May 1964, movements of the following animals have been continuously recorded: 12 red fox (Vulpes fulva), 5 white-tailed deer, 6 cottontail rabbits, and 9 snowshoe hares (Lepus americanus).

Specific biological investigations on each species are being carried out by four biologists employed on the project. These investigations vary from routine analysis of home range and activity patterns to detailed studies of interspecific (competition, predation) and intraspecific behavior (territory, family group dispersal).
Figure 2. Actual and radio-determined positions of a man carrying a radio transmitter, Cedar Creek Natural History Area, Minnesota, March 1964.

Legend:
- X Radio-determined location
- Actual location
- Building

Scale: 1 inch = 400 feet
The objectives of each investigation must be clearly defined because of the vast amount of position data on each animal. For certain projects locations are recorded and plotted at specified time intervals, such as every 15 or 30 minutes. For other projects all positions for a given time period, such as dawn or dusk, are plotted.

Need for some automation in data processing is obvious. The Flexowriter system will, when completed, read and print position data approximately 10 times as fast as the manual operation. The punch tape produced by the Flexowriter will serve as computer input. Programs are now being written for automatic plotting of movement data on outline maps through the use of digital computers and an x-y plotter.

The potential of the automatic tracking system is illustrated by a comparison with a portable, manually operated directional receiver. A total of 112 locations of adult male red fox Number 151 were obtained over a 35-day period using the portable receiver by driving from the laboratory to the general area occupied by the fox and obtaining bearings from two or three sites. Approximately three fixes were taken each 24 hours. Obtaining the fixes and plotting the data required about four hours per day.

In contrast, 116 fixes showing the movements of the same fox for 24 hours were obtained from the film record and plotted in approximately six hours. Not only is the quality of data improved and the quantity greatly increased but the amount of time required to obtain it is much reduced.

ACKNOWLEDGEMENTS

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LITERATURE CITED


