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EVALUATION OF RADIO-TRACKING BY TRIANGULATION
WITH SPECIAL REFERENCE TO DEER MOVEMENTS

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Abstract: Four parameters out of the five investigated were found useful for studying white-tailed deer (Odocoileus virginianus) movements by triangulation with an automatic radio-tracking system. These were total area, greatest linear dimension, mean activity radius and distribution of activity radii, and appearance of the map. Random plots, which simulated deer movements, were used to determine the effects of varying the location of the animal's range in relation to the triangulation stations. Results show an increase in size of range and a loss in accuracy of location as the plots were moved out. An "hourglass-shaped" area of about 3,300 acres is considered to be within acceptable accuracy with a 0.5-mile base line and a \( \pm 0.5^\circ \) resolution. Point locations were obtained at 1-min intervals for selected time periods for three deer. These data were then sampled at intervals of 2, 3, 4, 5, 6, 10, 15, 30, and 60 min. Values for total area and greatest dimension decreased and the mean activity radius increased as the sampling interval became longer. A sufficient number of point locations can be maintained by using a short sampling interval or long observation period. Comparisons of home range size were made among individual deer and between a winter and an early spring period using the above four parameters. Spring ranges were significantly larger than winter ranges and movements in spring were longer with less concentration of activity. The differences between winter and spring behavior are probably related to higher spring temperatures and the disappearance of snow.

This paper reports on laboratory and field studies of some limitations and restrictions in using triangulation to locate animals and on certain aspects of white-tailed deer movements.

Various techniques have been employed in the quest for knowledge of animal movements. One of the latest and most refined of these, radio-tracking, consists of marking individual animals with miniature radio transmitters. Most current investigations involve the use of portable directional receivers to monitor the animal's position and movements by triangulation from two or more sites. The recent development of an automatic tracking system (Cochran et al. 1965) enables the research worker to obtain minute-by-minute positions by triangulation for many animals simultaneously. Data obtained by radio-tracking have been valuable in analyzing numerous aspects of animal ecology, such as census methods (Tester and Heezen 1965), breeding behavior (Marshall 1965), and home range (Tester and Siniff 1965).

However, all radio-tracking techniques have certain limitations and restrictions which must be considered in experimental design, data analysis, and interpretation. Marshall (1963:175–176), Cochran and Lord (1963), and Verts (1963) all mention limitations in accuracy of radio locations, and Marshall and Kupa (1963) and Slade et al. (1965) used systematic approaches to investigate the magnitude of the errors encountered. No attempt was made in these studies to relate the amount of error found to different parameters of home range. For some aspects of these and other studies (Craighead et al. 1963) the accuracy of triangulation is not of extreme importance as the purpose of the radio location is to allow the investigator to come into visual range of the animal to make observations on movement and behavior.

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2 Present address: Michigan Department of Conservation, Caro.
An investigation based on data from the automatic radio-tracking system at Cedar Creek (Cochran et al. 1965) was conducted to evaluate (1) the effects of simulated variation in the relationship between tracking stations and the area used by a deer, and (2) the effects of varying sampling intervals on several parameters of range and movement. A second part of the investigation involved the use of these parameters, under the restrictions and limitations determined earlier, to compare winter and spring movements of deer.

In any animal-tracking system using triangulation there may be discrepancies between the true locations and those found by triangulation. Angular errors and the location of the point in relation to the triangulation towers have a major influence on the magnitude of this discrepancy. Angular errors are defined as follows:

1. **System error** is the angle between the system-determined bearing and the true bearing of the animal. System error may be caused by wind twisting the antennas, temperature changes, inaccurate referencing of the antenna, etc.

2. **Reading errors** are those made in reading and recording the bearings. Cochran et al. (1965:100) determined that combined system and reading errors were no greater than ± 0.3° with good signals on a calm day, and ± 0.5° with good signals on a windy day.

The combination of angular error and location of the animal in relation to the towers determines the greatest distance the radio-location can be from the true location. A figure, called an *error polygon*, can be drawn on the basis of these two factors which shows the bounds within which an animal will be for a particular radio-determined location. This figure is bounded by two adjacent lines which are drawn 0.5° on either side of the recorded bearing from one triangulation station intersecting two adjacent lines drawn similarly from the other triangulation station (for example, 101.5° and 102.5° from the 70-ft tower and 305.5° and 306.5° from the 100-ft tower in Fig. 1). The recorded location is defined as the point of intersection of degree bearings. For the error polygon in the example above, the recorded location is the dot labeled 102° × 306°.

The size and shape of error polygons (Fig. 1) change from one location to another in relation to the towers. These changes in polygon size and shape result in corresponding changes in the maximum distance a true location could be from a radio-determined location. This error increases in any direction from the optimum location, which is the 90° intersection of the bearing lines at the perpendicular bisector of the base line. Size of the error polygon can be decreased by reading the bearings to a smaller unit, for example, the nearest 0.5°, 0.25°, or 0.1°. However, angular error still determines the lower limit of error. For example, in reading to the nearest 0.1°, if the true reading was 1.7° we would know that in the worst case we might find readings in the range 1.2° to 2.2° as determined by the 0.5° system error; if we rounded to the nearest degree, the range would be from 1.0° to 2.0° and the angular error could be as large as 0.7° in this case. Size of the error polygon would then also have to be increased if it were to include all possibilities. It is important to realize that the problems of error in the Cedar Creek automatic tracking system as discussed above represent “worst-possible case” situations. In reality, system error is usually less than implied here.

Many other factors may contribute to the discrepancy between the true location and recorded location, especially for moving animals. These factors include the effect of
assigning a specific set of location data to the nearest minute, the interval which elapses between the time when one antenna points at an animal until the other antenna points at the same animal, and signal refraction by vegetation.

The site of the study was the Cedar Creek Natural History Area, about 30 miles north of Minneapolis. This 4,500-acre area, administered by the University of Minnesota, contains diverse habitats. Pierce (1954:61) states that "the upland plant communities form part of a complex mosaic of oak and pine forest, and deforested fields, in a general matrix of lowland swamps, bogs and marshes." He lists six upland

Fig. 1. Relative sizes and shapes of error polygons at selected locations in relation to the two tracking towers. Any true location within an error polygon would be recorded at the center of that polygon.
types, all but one of which contain one or more species of oak (*Quercus*) as a major component, and six lowland types. The lowland types include tamarack (*Larix laricina*) swamp, cedar (*Thuja occidentalis*) swamp, alder (*Alnus rugosa*) swamp, cedartamarack (*Thuja–Larix*) swamp, swamp hardwoods, and marsh.

We wish to express our appreciation to Dr. W. H. Marshall and Alvar Peterson of the Cedar Creek Natural History Area for use of the facilities and for field assistance. Personnel of the Radio Tracking Project, especially D. B. Siniff, W. W. Cochrnan, V. B. Kuechle, L. D. Mech, and A. B. Sargeant, generously assisted in both field and laboratory aspects of the investigation and made valuable criticisms of the manuscript. B. Fashingbauer and J. M. Idstrom of the Carlos Avery Game Research Center, Minnesota Division of Game and Fish, provided live-traps and captive deer for tests of radio transmitters and immobilizing drugs and contributed advice on field problems.

**METHODS**

Six deer were live-trapped and fitted with radios between January 1–April 23, 1964. The radios were modifications of the design used by Tester et al. (1964). One design incorporated a whip antenna from 24–36 inches in length. The transmitter was mounted on the outside of a double leather collar with batteries placed diametrically opposite to provide balance to hold the antenna upright. The batteries were connected to the transmitter by two phosphor bronze leads insulated by polyvinylchloride (PVC) tubing and placed between the two layers of leather. Batteries were potted in Ecco-bond brand (Emerson-Cummings) epoxy resin and the transmitter in Perm brand dental acrylic. A second design, with the batteries and transmitter potted together in acrylic, used a 2-inch-wide copper strip antenna taped on the outside of a leather collar.

Movements of the six deer were monitored with the automatic tracking system which utilizes two rotating, directional, receiving antennas. These antennas, mounted on towers (one 70 ft, one 100 ft high) ¼ mile apart, received signals in a 3-peak, 2-null pattern which are automatically recorded on film along with the degree bearing of each antenna. The antennas are oriented with the 0° bearing toward the other tower (Fig. 1). To determine the position of a transmitter at a particular time, the investigator places the film in a film viewer, turns to the appropriate time mark, aligns the signal with the antenna bearing mark and counts the degrees (Cochran et al. 1965: 99). This operation is repeated for the other antenna. The date, identification number of the animal, time, and bearing from each tower, plus a correction factor for improper referencing, are punched on computer cards for compilation and analysis.

All data were processed with a digital computer using programs described by Siniff and Tester (1965) and Tester and Siniff (1965). One program calculates distance traveled and average rate of travel between successive points, distance traveled for the time covered by the data, acreage based on the number of grid squares occupied, and a frequency distribution of the number of fixes per grid square. The other program determines the geometric center, or center of activity (Hayne 1949), measures the distance from this center of activity to each point (Calhoun and Casby 1958), and computes the mean activity radius and the variance. Number of points, X and Y coordinates of each point, variance, and the distance to the activity center appear in the printed output. In addition,
maps are drawn by an x-y plotter for each set of data.

Effects of an animal's using different portions of the study area in relation to the towers were tested by simulation, using three random plots. These were prepared by arbitrarily choosing a starting point, then drawing 60 pairs of numbers from a table of random numbers. Of each pair one number, between 001 and 360, represented the bearing of the line and the other number, between 00 and 20, represented the distance along this bearing in millimeters. Twenty mm was chosen as the upper limit because, at the desired scale of 1 inch = 400 ft, a distance of 20 mm = 314 ft. A speed of 314 ft/min = about 3.5 mph, which is assumed to be about the usual upper limit of traveling speed for an undisturbed deer. Therefore the plot was assumed to represent 60 min of activity of a deer traveling in a random direction for 1 min at a speed between 0 and 3.5 mph, stopping at the end of 1 min, turning a new random direction and again traveling for 1 min at a speed between 0 and 3.5 mph, etc. Although the three plots do not represent actual deer movements, they do appear very similar to plots of the movements of the radio-tagged deer. We feel they can be used to test the effects of moving from one location to another with respect to the base line better than actual deer movements because the simulated plot can be measured for the same parameters in the same manner as a computer plot. A map was drawn with radiating lines from each tower at 1° intervals. Eight stations, four on a 90° angle and four on a 45° angle to the base line spaced 0.5 mile apart, were chosen on this map (Fig. 2) and the random plots were centered by eye on each. The nearest degree bearing, as measured from the map, from each tower was then recorded for each point on the random plot. This was repeated for each plot at each station shown in Fig. 2. These data were then punched on cards and run through the computer on both programs.

The effect of different locations was observed on the following five parameters:

(1) Total area determined by connecting the most extreme perimeter points. This is assured by turning the maximum angle possible from the preceding line and still pass through a point. A dot grid was used to obtain the area within the boundary. (2) Linear range or greatest dimension obtained by measuring the distance between the two most-distant points (Burt 1940 and Holdenried 1940). (3) Total distance traveled obtained by summing the distances between successive point locations (Siniff and Tester 1965:106). (4) Mean
activity radius and frequency distribution of activity radii obtained by determining the center of activity and measuring the distance from this center to each point. (5) Appearance of the map as evaluated subjectively.

Each of these parameters had one or more of the following attributes: (1) it could be easily obtained from the radio-tracking data by the use of the computer; (2) it could be used for comparing different animals or time periods; and (3) it is already accepted by other workers.

A two-way analysis of variance was used to test for differences between stations and between plots, with the three random plots used as treatments, and the stations as blocks. Parameters 1, 2, and 3 above were considered appropriate for this type of analysis, and were the only ones tested. For each test in which the difference among blocks (representing stations) was shown to be significant, Dunnett's test for comparing means with the control (Steel and Torrie 1960: 111–112) was used to determine which means were significantly different. The mean of the three actual plots was considered as the control and the mean of the three computer plots at each station was compared with it.

After testing the results of the simulation study, we chose the station with the largest mean judged to be not significantly different from the control and, at this point, measured the longest dimension of the error polygon. Locations of several polygons of this length were determined and connected by a smooth curve. We considered this line to be the outer limit of acceptable accuracy and that all plots within this line should be comparable. Using this limitation, data from wild deer were then used for additional studies.

To obtain data for the sampling interval tests we chose time periods when deer were within the zone of acceptable accuracy described above and when the signals were clear and regular enough to obtain a fix approximately every minute. These criteria were difficult to meet, and there are some gaps in the data, especially for deer 503.

The data were read and tabulated from the film at approximately 1-min intervals. Because the receiving antennae revolve at a rate of 1½ rpm, the signals do not always fall on the minute. Thus, to obtain data for a specific time, the signal nearest the minute was read. These minute-by-minute data were then sampled with a card sorter at intervals of 2, 3, 4, 5, 6, 10, 15, 30, and 60 min. The sampling interval was begun on the hour; therefore, the points from one sampling interval to a multiple of that interval were comparable (that is, the 15-min interval contained every third point of the 5-min interval, etc.).

Starting times for several sampling intervals were varied in an attempt to evaluate this possible bias. For each sampling interval, there are as many possible starting times as minutes in the interval. Therefore, for each 5-min or smaller interval checked, we used each of the possible starting points and for each 15-, 30-, and 60-min interval we chose four starting times by drawing numbers from a table of random numbers. The fifth starting time was the "on-the-hour time" used at all sampling intervals.

Location data were compiled from some of the radio-tagged deer and the above parameters were used to compare winter and early spring movements and to compare movement among deer and among days. A 15-min sampling interval was used. Six deer were equipped with radios throughout the study period; however, because of incomplete records, data from only three were used in the comparison.

For the two 4-day periods of comparison, 1200 January 23 to 1200 January 28 and
1200 March 27 to 1200 March 31, an attempt was made to obtain data for each deer for each day. Data from 1200 January 25 to 1200 January 26 were omitted from the analysis because of disturbance caused by a deer drive (Tester and Heezen 1965:103). The attempt to obtain continuous data was not entirely successful; however, in each case data were obtained for one animal for all 4 days. Each sample day was the 24-hour period from 1200 on one calendar day to 1200 the next calendar day. This time interval was chosen because reports summarized by Montgomery (1963:423) indicated that deer are least likely to be active at 1200.

RESULTS AND DISCUSSION OF TESTS

The results of each of the different tests indicate parameters which can be used for studying animal movements. However, the ultimate choice of the parameter(s) and the sampling interval to use for any study depends upon the objectives of that study. If detailed knowledge of the range of an animal is desired, the parameters and the sampling used should be different than for a gross study comparing several animals over periods of weeks or months.

Area (By Connecting Perimeter Points)

Fig. 3 shows that the apparent total area increases as the random plots are moved outward from the base line. This is a direct result of increase in the size of the error polygon as distance from the base line increases. Because only the peripheral points are considered in calculating area, the chances for an increase are greater than for a decrease, that is, if due to error only one or two recorded perimeter points fall farther out than the true points and all the rest fall farther in, it is possible that the area of the plot will still increase. Only 3 out of 24 computer plots have areas smaller than the actual plot (Fig. 3).

Although the curves in Fig. 3 are variable and some show a sharp deflection, no point on the abscissa could be visually chosen to logically separate acceptable and unacceptable areas. However, analysis of variance does show a significant difference (P < 0.05) among the means. Dunnett's test shows no significant difference between the mean of the actual areas and the means of each of the following: ½-mile and 1-mile observations for both 90° and 45° and 1½-mile observations for 90°. The most distant station judged to be not significantly different is 1½ miles at 90°. The length of the error polygon is about 800 ft at this station. Therefore, error polygons 800 ft long were used to separate the areas of acceptable and unacceptable displacement. Connecting the error polygons of this dimension gave the "hourglass-shaped" acceptable area which covers about 3,300 acres (Fig. 2). The minute-by-minute deer data were then sampled at the selected time intervals and areas of use were determined for each
interval (Fig. 4). A general decrease in area can be noted for each increase in time interval. As the sampling interval increases, the number of point locations per plot decreases; therefore, there is a greater probability that an area included in the minute-by-minute sample will be missed.

The probability of a given area being missed for a given sampling interval is dependent upon the length of time the animal spent there. However, because most animals probably use the same area over and over, locations with greater biological significance will be visited many times or the animals will spend a long time there. Therefore, if the period under observation is long (several days, a week, or a season), the sampling interval can be long (20 min, 60 min, etc.) without missing many biologically significant areas. Conversely, because there is likely to be a "loss of area" as the time interval for sampling increases, when the observation period is short (a few hours or days), the sampling interval must be short (1 to 5 min).

Ultimately, the observation period and sampling interval used depend upon the biological question to be answered. Some questions can best be answered by data from a long period, others by detailed information from a short period. It is likely that few problems will necessitate minute-by-minute movement data for a month or longer. As for any problem, the sample should be sufficiently large to answer the question; anything more is wasteful of time and effort.

The ranges of the acreage estimates shown in Fig. 4 tend to increase as the sampling interval increases. This may be caused by the decrease in the number of point locations at the larger time intervals. Because the sampling is started at different times, the areas included and excluded change. An example of this is the extreme range of acreage estimates for deer 504 at the 15-min interval. At the lower end of the range, none of the five original perimeter points is included in the plot. At the upper end of the range one of the original five points is included plus three points which were close to the original boundary. The areas omitted in the smallest estimate were those covered by long movements of less than 15-min duration. The range of estimates would tend to become smaller as the number of point locations was increased by shortening the sampling interval or lengthening the observation period.
Linear Range

The linear range, or greatest dimension, is related to the total area as indicated in the tests. Fig. 5 shows a general increase in range length as the distance from the towers increases. However, the linear range has a greater variation than the total area because the former is dependent upon only two points. As with total area, no arbitrary point can be chosen to separate areas in which this parameter is acceptable or unacceptable. Analysis of variance reveals a significant difference ($P < 0.05$) among the means. Dunnett’s test shows the difference between the mean of the actual and the means of the ½-mile, 1-mile, and 1½-mile observation for both 90° and 45° to be non-significant at the 0.05 level. Therefore, the line enclosing the acceptable area could be drawn using the error polygon at the 1½ mile at 45° station as the base as this is the most distant station judged not significantly different. However, no line was actually drawn for this parameter because it is used in conjunction with total area and the measurement is valid within the acceptable region for total area.

The sampling interval tests (Fig. 6) show somewhat less decrease in linear range than the same tests for total area. The ranges of lengths are generally shorter than obtained for total area. Again, note the large range of observations for deer 504 at the 15-min sampling interval (Fig. 6). The extreme range of observations for deer 503 at 60 min is caused by the small number of point locations, which varies from 3 to 5 for different samples depending on the starting time. The same conclusions hold for linear range as for total area, and the sampling intervals acceptable for either parameter would be usable for the other.

![Fig. 5. Linear range obtained for three random plots at selected locations.](image1)

![Fig. 6. Linear range obtained for three deer for selected sampling intervals.](image2)
Distance Traveled

The increases in total distance traveled (Fig. 7) follow about the same graphic patterns as those for total area. Analysis of variance shows the difference among the means of the random plots to be significant ($P < 0.05$) and Dunnett’s test indicates that the differences between the mean of the actual and the means of the $\frac{1}{2}$-mile and 1-mile observations at 90° and 45° and the 1$\frac{1}{2}$-mile observation at 90° are not significant. No significant difference was found among these stations for either total area or linear range. Therefore, it appears that distance traveled is as valid a measure as the total area, and is possibly more meaningful. However, in using the total distance traveled, some problems arise that do not occur with total area.

The major problem with the parameter of distance traveled is that most errors are additive, that is, if an error is made in reading the film, and the animal has not actually moved, the distance to the erroneous location and the distance back will both be added. If a deer is located near the midpoint between two degrees, a small amount of movement can change the reading by 1°. A few instances of this would be negligible; however, if a deer spent 2 hours browsing back and forth in such a location the indicated distance traveled could be much greater than the actual. These two types of error would affect the total area only if they occurred at the perimeter of the range and then only once for each location. The distance-traveled figure is affected at any location and every time the error is made. More tests using different types of data must be made to evaluate the distance-traveled parameter and to determine the area within which it can be used.

Activity Radius

Because the location of the center of activity is geometrically determined, it may have no biological significance, and need not even fall within an area which the animal has visited. However, the center of activity, the mean activity radius, and the distribution of activity radii do give some measures useful in comparing animal ranges. An animal's daily ranges can be compared to detect shifts in location or movement pattern and ranges of different animals can be compared for the same day to detect individual differences or similarities.

Moving the plots outward causes the mean activity radii to increase (Fig. 8), much as the total area increased. The distributions of activity radii for random plot No. 2 were plotted for all stations (Fig. 9). These distributions show no obvious differences over the entire range, except for a slight flattening as the plots are moved outward; however, the peak occurs at the 400–600- or 600–800-ft frequency interval in every instance. Therefore, the mean activity radius, or the distribution of activity

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**Fig. 7.** Total distance traveled for three random plots at selected locations.
radii, can probably be used with some degree of confidence within the same region as the total area.

Increasing the sampling interval tends to increase the mean activity radius (Fig. 10). This increase is relatively small and is probably more a function of decreasing sample size than an increase in sampling interval. So, as with the other parameters, the sampling interval can be chosen to fit the observation period, that is, long sampling intervals for long observation periods and short sampling intervals for short observation periods.

**Appearance of the Maps**

A subjective approach was used in assessing the appearance of the maps. The number of recorded locations decreases and the possible distances from the true point to the representative recorded location on the computer plot increase, owing to a loss of resolution as the distance from the towers increases. Therefore, the shape, concentration of point locations, and routes of travel become more and more difficult to discern as the plots are moved away from the towers (Fig. 11).

As the sampling interval increases, the computer map becomes less and less representative of the movements made by the animal (Fig. 12). The lines connecting the point locations merely show a progression of points and cannot be said to trace the routes of travel. If resolution were high, if there were no errors, and if the sampling intervals were short enough, the lines would indicate the routes of travel. Although the true route used by deer 504 is unknown, the map at the 1-min interval probably approximates it better than any of the others; and the map at the 60-min interval is probably least accurate. If it is necessary to know all points visited by an animal, or if a given point was visited on a particular day, a short sampling interval

![Fig. 8. Mean activity radii obtained for three random plots at selected locations.](image)

![Fig. 9. Frequency distribution of activity radii for random plot No. 2 at stations 45° from the base line.](image)
would be imperative. However, long sampling intervals are satisfactory for general patterns of movement over an extended period.

CONCLUSIONS CONCERNING TESTS

The choice of appropriate parameters and sampling intervals within the limitations revealed by the preceding tests depends upon the objectives of the study. If one is comparing the movements of several deer between two or more periods, the parameters of total area, linear range, mean activity radius, and appearance of the maps are useful in giving a generalized but comparable picture of the ranges.

For studies involving short observation periods of a few days or different portions of days, the total area and linear range probably would have less significance than for long observation periods. The total distance traveled may be of use in short-term studies, especially if the movements are in the same locality during the entire observation period and are within the acceptable area (Fig. 4). The sampling interval should be short—probably no longer than 5 min and preferably 2 min.

These parameters would probably also be valid for other animals that exhibit rather haphazard movement patterns, doubling back repeatedly over the same area and only occasionally making long straight-line movements. For animals which make many long straight-line movements and few "wandering-type" movements, the total-distance-traveled parameter may be more valid than total area and linear range.

Certainly in the interest of efficiency the minimum number of fixes required for an accurate evaluation should be used. This may be accomplished by using the longest sampling period feasible, by intensively sampling a few days throughout the study period, or with any other sampling scheme which fits the objectives of the study.

RESULTS AND DISCUSSION OF DEER MOVEMENT STUDY

Deer location data were processed for January 23–28 to represent the winter period and March 27–31 to represent the early spring period. The latter period represents that time when the deer are not restricted by snow or cold weather but have not yet completely left the wintering area.

The total area (Table 1) and linear range (Table 2) both show marked increases from winter to spring. Analysis of variance reveals a significant difference \( (P < 0.05) \) between the means for winter and early spring for both total area and linear range. Deer 502 and 503 have little or no overlap

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**Fig. 11.** Appearance of maps for random plot No. 2 at stations 45° from the base line. A—actual plot; B—1/4 mile; C—1 mile; D—1 1/2 miles; E—2 miles.
in either length or area. However, deer 504 has spring daily ranges which are smaller in area and shorter in length than the largest winter daily ranges of either 502 or 503.

Increases and decreases in area and in linear range are not consistent between parameters for different days. This can be noted for deer 502 for March 28–29, 29–30, and 30–31, when total area decreased but the linear range increased. Thus, the two parameters complement each other, and when both are observed, a better picture of the home range can be obtained. The actual change in shape and size for both

Fig. 12. Appearance of map for deer 504 for selected sampling intervals, April 8, 1964.
periods can be seen in Figs. 13 and 14. Mean activity radii values shown in Table 3 agree very well with the total area and linear range figures, with generally larger values in the spring than in the winter. The frequency distributions of activity radii in Fig. 15 do not reveal striking changes between winter and early spring. Peaks tend to remain in about the same location, but the distributions become somewhat flattened and have more extreme values in the spring. This also indicates longer movements with less concentration of activity.

Figs. 13 and 14 show the appearance of maps for the winter and spring periods and the line separating the areas of acceptable and unacceptable accuracy. During the winter period (Fig. 13) only two points fall outside the area of acceptable accuracy, whereas during the spring period (Fig. 14) a few points fall outside of this area every day for deer 502 and 504. The error polygons in the regions of 170° to 190° from either tower are so large that the accuracy is not acceptable. Because deer 502 and 504 spent some time in this region each day during the spring sample, an arbitrary point (represented by solid square in Fig. 14) was chosen to represent this movement. The point is a conservative estimate of the area covered while deer were within the region between 170° and 190°. The winter series of maps shows movement concentrated into small areas with few long trips. The spring series indicates more long trips and fewer concentration areas.
The winter period studied (January 23–28) was cold, but not extreme, with a high of 30 F and low of -13 F. Snow depth varied from 3–5 inches which is about 5.5 inches below the 1949–63 average (U. S. Dept. of Commerce 1949–64). The spring period had typical early spring weather with a high of 35 F and a low of 4 F. This was immediately preceded by a short period of warmer weather with a high of 45 F. At this time the ground was free of snow in the open fields and deciduous woods.

Winter movements and daily ranges of the three deer are larger than those reported by Norberg (1957) for the same study area. The largest home range he reported (5.0 acres) was smaller than the
smallest area we found (6.2 acres for deer 503 for January 24–25). The range in temperatures on days which he sampled, 35 F to -11 F, was very similar to the winter temperatures during this study. However, the snow was deeper during Norberg’s study, varying from 11–22 inches in depth. He found the largest range when the snow was 11 inches deep and the smallest ranges, 0.05, 0.07, and 0.06 acre, when the snow was 22, 21, and 20 inches deep, respectively. Snowfall undoubtedly affects the mobility of these deer within their winter range. The snow depth which limits movement probably conforms with Day’s (1963:106) findings that when the deer sinks 15 inches or more into the snow pack, most movement is confined to existing trails.

The ranges found were generally smaller than those reported by Progulske and Baskett (1958) for Missouri. They found daily ranges varying from less than ½ section where the animals moved in a circular or zig-zag pattern to nearly linear shapes with straight-line movements of 2½ miles. There is a strong similarity between these movements and the ones shown in Fig. 13.

The factor causing an expansion or contraction of the range is probably climatological, as both deer 502 and 503 contracted their range between January 23–24 when there was a snowfall of 2 inches and a drop of about 12 degrees in both maximum and minimum temperatures (Fig. 13 and Tables 1, 2, and 3). This consistency of trend in range expansion or contraction does not hold during the spring period. Fig. 14 and Tables 1, 2, and 3 show both expansion and

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**Table 3. Mean activity radii for three deer for winter and early spring periods, 1964, on the Cedar Creek Natural History Area in east-central Minnesota.**

<table>
<thead>
<tr>
<th>Season</th>
<th>Deer 502</th>
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<td>(\bar{z})</td>
<td>(s^*)</td>
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<tr>
<td>January</td>
<td>23–24</td>
<td>917</td>
<td>262,378</td>
</tr>
<tr>
<td>Winter</td>
<td>24–25</td>
<td>503</td>
<td>30,007</td>
</tr>
<tr>
<td></td>
<td>26–27</td>
<td>442</td>
<td>72,374</td>
</tr>
<tr>
<td>March</td>
<td>27–28</td>
<td>564</td>
<td>32,827</td>
</tr>
<tr>
<td>Spring</td>
<td>28–29</td>
<td>1,932</td>
<td>728,389</td>
</tr>
<tr>
<td></td>
<td>29–30</td>
<td>1,664</td>
<td>1,004,339</td>
</tr>
<tr>
<td></td>
<td>30–31</td>
<td>1,021</td>
<td>129,016</td>
</tr>
</tbody>
</table>
contraction on the same days for different deer. This points out the necessity of larger samples than two or three deer to show conclusive evidence of trends in range size in response to specific climatological factors.

A general comparison of winter and early spring data shows a definite increase in range size which was probably related to higher temperatures and the disappearance of snow.

A salient point in considering the data given here is the tremendous advantage the researcher has in using the automatic tracking system to study deer movements. Michael (1965:49) lists the following six factors which cause bias in a "mark and observe" type of study: (1) number of observations, (2) distribution and frequency of observer’s activities, (3) density of vegetation, (4) visibility of marking device, (5) total number of deer in group, and (6) location of roads. All six of these factors are eliminated as sources of bias when deer movements are determined by the automatic radio-tracking system. Factors 1 and 2 still plague studies using portable radio-tracking systems (hand-held receivers), and factors 1, 2, and 6 apply to mobile radio-tracking systems (receivers mounted on trucks or automobiles). Both portable and mobile systems were used in some phases of the deer study (results not reported here) at Cedar Creek. Both have advantages and disadvantages when compared to automatic equipment. However, the automatic system makes detailed movement studies possible if the proper limitations are observed. It also allows unbiased sampling of movements in relation to vegetation, roads, and other deer, but not in relation to the triangulation stations.

LITERATURE CITED


BROWSE USE BY CATTLE AND DEER IN NORTHERN IDAHO

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Abstract: White-tailed deer (Odocoileus virginianus) and cattle on the same forest range in northern Idaho utilize browse for the larger part of their food supply. Browse species used by white-tailed deer in the study area in order of importance were: garden snowberry (Symphoricarpos rivularis), redstem ceanothus (Ceanothus sanguineus), mallow ninebark (Physocarpus malvaceus), roses (Rosa gymnocarpa, R. spaldingii), birchleaf spirea (Spirea betulifolia), Saskatoon serviceberry (Amelanchier alnifolia), and creambush rockspirea (Holodiscus discolor). For cattle the order of intensity of use was: garden snowberry, birchleaf spirea, mallow ninebark, creambush rockspirea, redstem ceanothus, Saskatoon serviceberry, and roses. Use by cattle of browse species during the summer was not detrimental to the food supply of the deer.

In northern Idaho much of the low-elevation forest is yearlong range for white-tailed deer and spring–summer–fall range for cattle. The understory of these forests is dominated by shrubs; forage grasses and forbs are less abundant (Table 1).

Several studies in northern Idaho have indicated that white-tailed deer subsist almost entirely on browse (DeNio 1938, Basile 1954, Pengelly 1954, Roberts 1956). Because forage grasses are insufficient, cattle that use these same ranges also use browse for a great part of their food supply. In 1959, the Idaho Cooperative Wildlife Research Unit initiated a research program to define the extent of use by cattle of browse plants that are also important foods for white-tailed deer.

The program was carried out in the Hatter Creek enclosure, a research area of ap-