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The Raccoon (*Procyon lotor*) on St. Catherines Island, Georgia. 4. Comparisons of Home Ranges Determined by Livetrapping and Radiotracking

JOERG-HENNER LOTZE[1]

ABSTRACT

Home ranges of 49 raccoons (*Procyon lotor*) from St. Catherines Island, Georgia, each captured at least five times, are compared with home ranges of nine radiotagged raccoons. The mean of final estimates of home range sizes of 35 males (51 ± SE 68 ha.) was significantly different from that for 14 females (6 ± SE 10 ha., $t = 2.42$, $p < 0.05$). The limited female trapping success is related to both a higher mean time interval between captures and a higher mean number of captures per station of capture than for males. Home range size seemed to increase with number of captures using both mean convex polygon and mean circular estimates as well as regression analyses. The estimates of home range of a male raccoon captured 103 times changed in shape, location, and size each year in the four-year study period and did not approach the final estimate of 254 ha. asymptotically. The mean yearly radiotracking home range estimate of seven males (65 ± SE 18 ha.) was not significantly different from that for two females (39 ± SE 16 ha.). For females, the mean home range based on radiotracking was significantly different from the mean home range based on recaptures ($t = 3.86$, $p < 0.05$). Home ranges determined by radiotracking did not always coincide closely with home ranges determined by recaptures for the same animals during the same time periods.

INTRODUCTION

The importance of the raccoon (*Procyon lotor*) as game and as a competitor for human food has justified many studies of the raccoon (Sanderson, 1951; Stains, 1956; Johnson, 1970; Urban, 1970). The raccoon is a highly successful species that is still expanding its range today (Sanderson, 1960; Sutton, 1964; Aliev and Sanderson, 1966). Its potential importance as an indicator species for the monitoring of environmental zoonoses and pollutants has received attention recently (Bigler et al., 1975a, 1975b.

The predominantly nocturnal activities of the raccoon have limited most field studies of the behavior of raccoons to interpretations of indirect observations. Bider, Thibault and Sarrayin (1968) learned the time of activity of raccoons by studying their tracks on sand transects. Many field studies of raccoon movements and population dynamics have used marking and recapturing techniques (Stuewer, 1943; Johnson, 1970; Urban, 1970; Sonenshine and Winslow, 1972). Problems in the study of mammalian movements were reviewed by

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Sanderson (1966). The techniques of radiotelemetry have permitted more frequent determinations of the locations of individual raccoons and have thus avoided some of the problems of livetrapping studies (Tester and Siniff, 1965; Mech, Barnes and Tester, 1968; Schnell, 1969; Schneider, Mech and Tester, 1971). Nevertheless, even the most advanced radiotracking data may be difficult to interpret (Tester and Siniff, 1965; Schneider, Mech and Tester, 1971).

Comparatively little information is available on home-range dynamics of raccoons. Except for female raccoons making temporary use of den cavities, no defended territory beyond that of a vacillating personal distance maintained between individuals and family groups was reported for raccoons (Stuewer, 1943; Tevis, 1947; Sharp and Sharp, 1956; Schneider, Mech, and Tester, 1971).

The present study of raccoons from St. Catherines Island, a barrier island off mainland Georgia, contrasts home ranges as manifested by livetrapping 591 raccoons and by radiotracking nine raccoons. Home range sizes of adult males and females are described and compared in terms of convex polygon and circular home range models. The significance of behavioral differences between males and females and of the varying ecological conditions on St. Catherines Island during the four-year study period are discussed in terms of problems of evaluating home ranges. The details of home-range data for a raccoon captured 103 times are compared with home range data of raccoons less frequently captured.

STUDY AREA

St. Catherines Island is a barrier island of 5762 hectares (ha.) about 8 km. from the mainland of Georgia. It is about 16 km. long, 6 km. wide, and has a maximum elevation of 8 m. Extensive tidal marshes and meandering tidal channels exist between the island and the mainland. The unconsolidated marine and nearshore sediments of St. Catherines Island were deposited during the Pleistocene and Holocene periods and consist of three basic landforms: erosion remnants, marsh constructions, and beach ridges (Thornbury, 1965). Climatological conditions on the island are moderate and less extreme than those of the adjacent mainland (Somes and Ashbaugh, 1973). More than 100 years ago, extensive forested areas in the center of the island were cleared for cotton and rice crops, whereas forested areas were until recently altered by controlled grazing, fire, and logging (Somes and Ashbaugh, 1973). The island is now managed primarily as a natural area preserve in cooperation with the American Museum of Natural History. The vegetation of St. Catherines Island includes 2965 ha. of tidal marshes, 153 ha. of wet meadows, 132 ha. of upland meadows, 99 ha. of scrubland, 2241 ha. of forest, 3 ha. of herbland, and 8 ha. of aquatic vegetation (Somes and Ashbaugh, 1973).

Field surveys conducted by the American Museum of Natural History have shown that, except for birds, the vertebrate fauna of St. Catherines Island is depauperate. Among mammals, raccoons (*Procyon lotor*), deer (*Odocoileus virginianus*), and squirrels (*Sciurus carolinensis*) now predominate. Deer were especially abundant on the island during 1973 and early 1974 but declined in numbers during the winter of 1974-1975. Starvation due to the acorn crop failure in 1974 may account for the decline. However, an outbreak of listeriosis, a disease known to occur among raccoons (Gifford and Jungherr, 1947) and deer, and very difficult to diagnose, was noted among the gemsbok (*Oryx gazella*) being bred on the island (James Doherty, personal commun.). Rabies, canine distemper, and other diseases are known from raccoons in the southeastern states (Bigler et al., 1975a), but have not yet been demonstrated from St. Catherines Island. Feral pigs (*Sus scrofa*) and cattle (*Bos taurus*), common throughout the island just prior to 1976, had caused widespread habitat alterations. However, most were removed from the island during 1976 and 1977 (probably 80 percent, including more than 1000 pigs and 200 cattle). Their removal resulted in significant increases among ground-inhabiting species of small mammals (as judged from limited trapping, observations by R. G. Zweifel of animals found under pieces of wood, and observations by mammalogists of numbers of mice seen crossing roads at night).

ACKNOWLEDGMENTS

Field studies by the author during 1976 and 1977 on St. Catherines Island were made possible by a grant from the Edward John Noble Foundation to Dr. Sydney Anderson, Chairman, Department of Mammalogy, the American Museum of Natural History. These studies and subsequent data analyses were conceived with the continual advice and cooperation of Dr. Sydney Anderson and Dr. Robert A. Martin, Department of Biology, Fairleigh Dickinson University. Dr. Martin as graduate advisor and Dr. Ivan Huber, Department of Biology, Fairleigh Dickinson University, and Dr. Anderson as committee members greatly assisted in the preparation and review of the manuscript. The raccoon data upon which this study is based were gathered by the concerted efforts of many individuals: Dr. Anderson and Mr. Barry Koffler of the American Museum of Natural History; Mr. William Berliner of Yale University; Dr. Howard J. Stains, Mrs. Ellen Hardin, Mr. Dennis Harman, and Mr. Wayne Lee of Southern Illinois University; Mr. Charles Anderson of the University of Kansas; Ms. Gale Andersen of Fairleigh Dickinson University; and Mr. Allen Northrup and Mr. Gary Simpson of the University of Vermont. The field assistance of Mr. John Woods, Superintendent of St. Catherines Island, is greatly appreciated. Access to the computer system at the American Museum of Natural History was arranged by Dr. Anderson and by Mr. Robert Koestler of the Interdepartmental Laboratory. Access to the computer system of the City University of New York was arranged through the Biology Department of City College. Advice concerning certain questions on statistics and computer programming was kindly given by Dr. Robert Rockwell, Department of Biology, City College and by Mr. Fred North, Acquisitions Librarian, the American Museum of Natural History. Island maps used in this study were prepared by Dr. Anderson and by Dr. Richard G. Zweifel, Chairman, Department of Herpetology, the American Museum of Natural History. Final manuscript suggestions by Mr. Charles Anderson were very helpful.

MATERIALS AND METHODS

LIVETRAPPING

From April 1974 to March 1977 several investigators intermittently trapped raccoons on St. Catherines Island, Liberty County, Georgia. Live traps (26 cm. by 31 cm. by 82 cm.) were baited with canned cat food or table scraps. For convenience, traps were placed at least 0.16 km. apart and within 10 m. of rarely traveled dirt roads. Early in the study, traps were distributed with the intention of capturing as many raccoons from as many different representative habitats on the island as possible within each study period. Most of the later trapping was concentrated on the northern end of the island (north of 3503.0 N of the 1000 Meter Universal Transverse Mercator Grid, fig. 1). Except where noted, this study concerns the northern end of the island.

A chi square test (using a 0.5 km. grid) indicated that the placement of traps as described above along the roads of the northern end of the island was not random (fig. 1). A different trapping strategy would probably have yielded different, although not necessarily more valid, results (Sanderson, 1966).

Experiences influencing behavior of raccoons were repetitive trapping, contact with humans, and periodic anesthetization with ketamine hydrochloride (10 mg. per kg. body weight, Bigler and Hoff, 1974). This was used in order to collect yearly data on age as determined by wear on the teeth (Grau et al., 1970), measurements, sexual characteristics (Sanderson, 1961), and weight. Raccoons were detained for a maximum of 48 hours and were released at the sites of capture.

Island-wide trapping success, indicated by the following formula

$$\frac{\text{Number of raccoons captured per week}}{\text{Number of trap days per week}} \times 100$$

(Calhoun and Casby, 1958), varied widely during the four years in which home range data were gathered for individual raccoons (figs. 2,

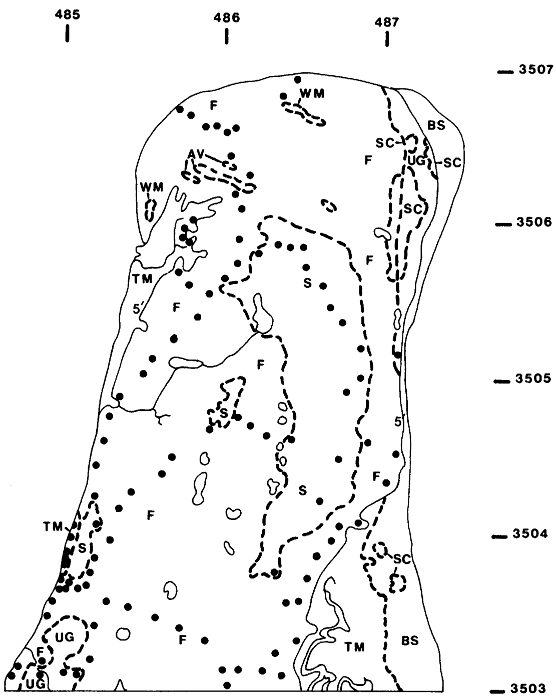

FIG. 1. Northern end of St. Catherines Island, Liberty County, Georgia. Solid dots indicate positions of all trap stations from 1974 to 1977. Grid markings are for the 1000 m. Universal Transverse Mercator Grid.

Abbreviations: AV, aquatic vegetation; BS, beach sand; F, forest; S, savanna; SC, scrubland; TM, tidal marsh; UG, upland grassland; WM, wet meadow. Ponds, streams, and contour lines at 2 m. above sea level are indicated by light lines.

3). A marked population crash occurred within a five-week period in the winter of 1974-1975. Thereafter, the population increased, but did not attain the earlier density by March 1977 (Hudson, 1978).

During the four years of study, 1504 captures for 591 individual raccoons were recorded (table 1). During 1975, the percentage of males among the raccoons captured per month increased markedly from the period of January through March to that of April through July (fig. 4). No such increase was noted in 1976.

The time interval between captures averaged greater for females than males (fig. 5), although the difference was not statistically significant. In general, the time between successive captures for individual raccoons averaged between 20 and 45 days for the first six captures.

The mean number of captures per trap station of capture was calculated for 49 raccoons captured more than five times each from the northern end of St. Catherines Island. Raccoon no. 696 was captured 103 times at 33 stations or 3.13 times per station of capture. With an increase in the number of captures per raccoon, the captures per successful station increased (fig. 6). Although the mean number of captures per successful station was always higher for females than males, a statistically significant difference ($t = 2.82$, $p < 0.05$) was only noted with 10 or more captures per raccoon.

RADIOTRACKING

Nineteen raccoons were fitted with radio collars. Collars were composed of dental acrylic surounding a transmitter core and averaged 125 g. in weight. Hand carried receivers and yagi antennas were used to track raccoons. Sensitivity of the equipment varied under local conditions and techniques and results varied from observer to observer. Errors of plus or minus 10 degrees of the actual signal bearing were noted in some readings. Raccoons were radiotracked for varying lengths of time between 1975 and 1977 both during the day and at night. A mean of $1.8 \pm$ SE 0.34 locations per day per raccoon was obtained for the seven adult males and two adult females that were successfully radiotracked for more than one week. When possible, the observer (who made readings from within 500 m. of a radiotagged raccoon) walked to within 100 m. of the raccoon for greater accuracy. Exact daytime resting sites were often determined in this manner. Observations of captive and free ranging raccoons indicated that the collars did not seem to interfere with normal activities once individuals had become accustomed to the collars.

HOME RANGE ANALYSES

The "convex polygon" method (Jennrich and Turner, 1966) is used here as an estimate of actual home range size, position, and shape.

It involves drawing the smallest convex polygon which encompasses all capture points or all points determined by radiotracking for any individual. For raccoon no. 696 the home range was determined for each of four calendar years. For 49 raccoons (including no. 696) captured more than five times each, home range estimates were based on all captures during two to four years. No home range determinations were attempted for 542 raccoons captured fewer than

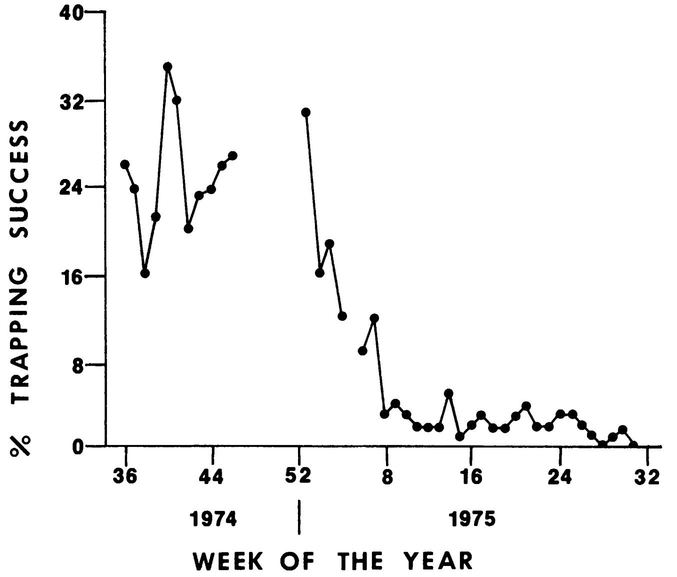

FIG. 2. Raccoon trapping success on St. Catherines Island, Georgia from 1974 to 1975.

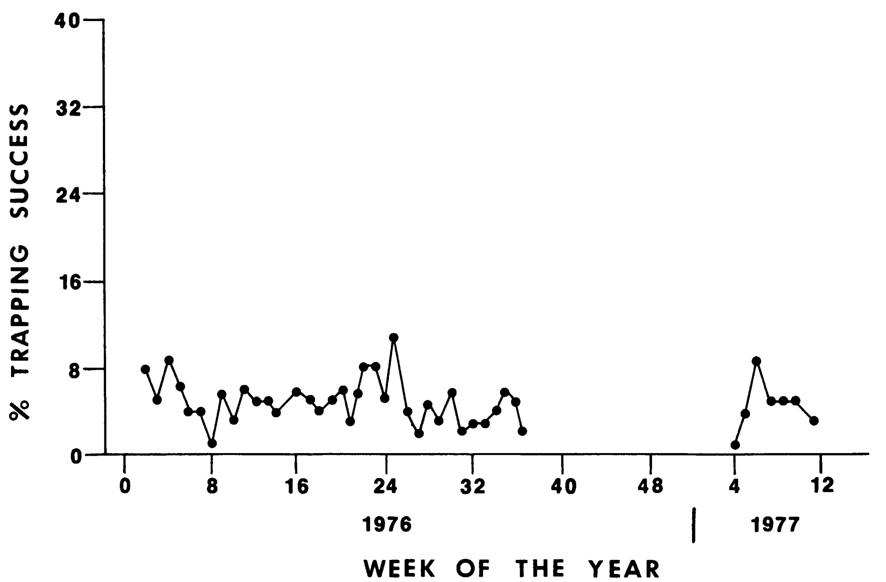

FIG. 3. Raccoon trapping success on St. Catherines Island, Georgia from 1976 to 1977.

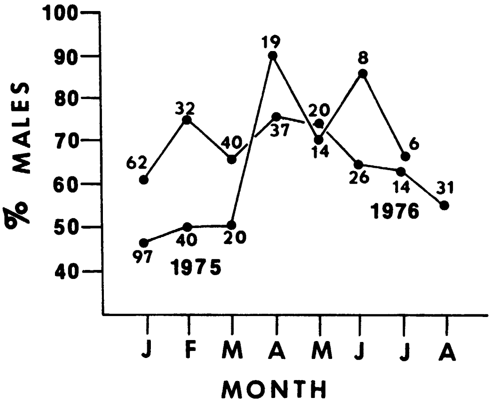

FIG. 4. Percentage of males among raccoons captured during each month during 1975 and 1976 on St. Catherines Island, Georgia. Total number of individuals captured per month is indicated.

five times each. Home ranges for nine radiotagged raccoons were based on all radiolocations in one year. For these raccoons, a separate home range estimation was based on all captures during the time of radiotracking.

An index of "potential home range size" is a circle with a radius equal to the distance from the geometric center of all capture points to the capture point farthest from this center. This was calculated for each of the 49 raccoons captured more than five times each. The geometric center of all capture points or of marginal points describing a convex polygon is regarded as a practical abstraction and not necessarily as a center of activity (Metzgar, 1973).

Means of final home range sizes of male and female raccoons were calculated. Another measure of home range size is the asymptote (if

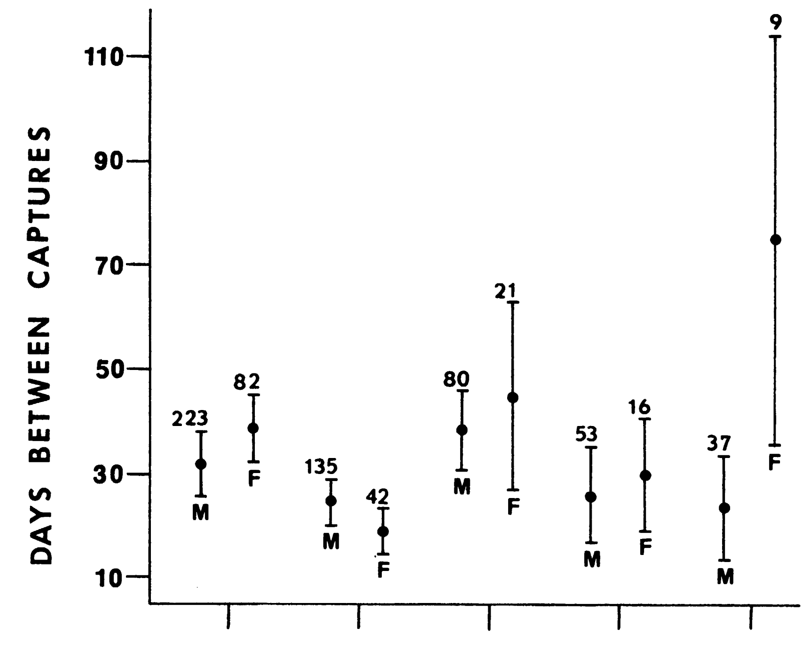

FIG. 5. Mean time interval in days between each successive capture for male (M) and female (F) raccoons on St. Catherines Island, Georgia from 1974 to 1977. Sample sizes and +/− one standard error of the mean are indicated.

present) determined from the relationship between cumulative mean home range estimates and increasing numbers of captures for the 49 raccoons captured more than five times each (Metzgar and Sheldon, 1974). Regressions of home range size on number of captures per individual were also calculated.

Although 1504 captures for 591 individual raccoons were obtained during this study, captures (especially of females) were insufficient for analyses of the effects of age, reproductive conditions, general physical conditions, and season of the year on home ranges.

RESULTS

Home Ranges Based on Trapping Data

The most detailed home range data for a

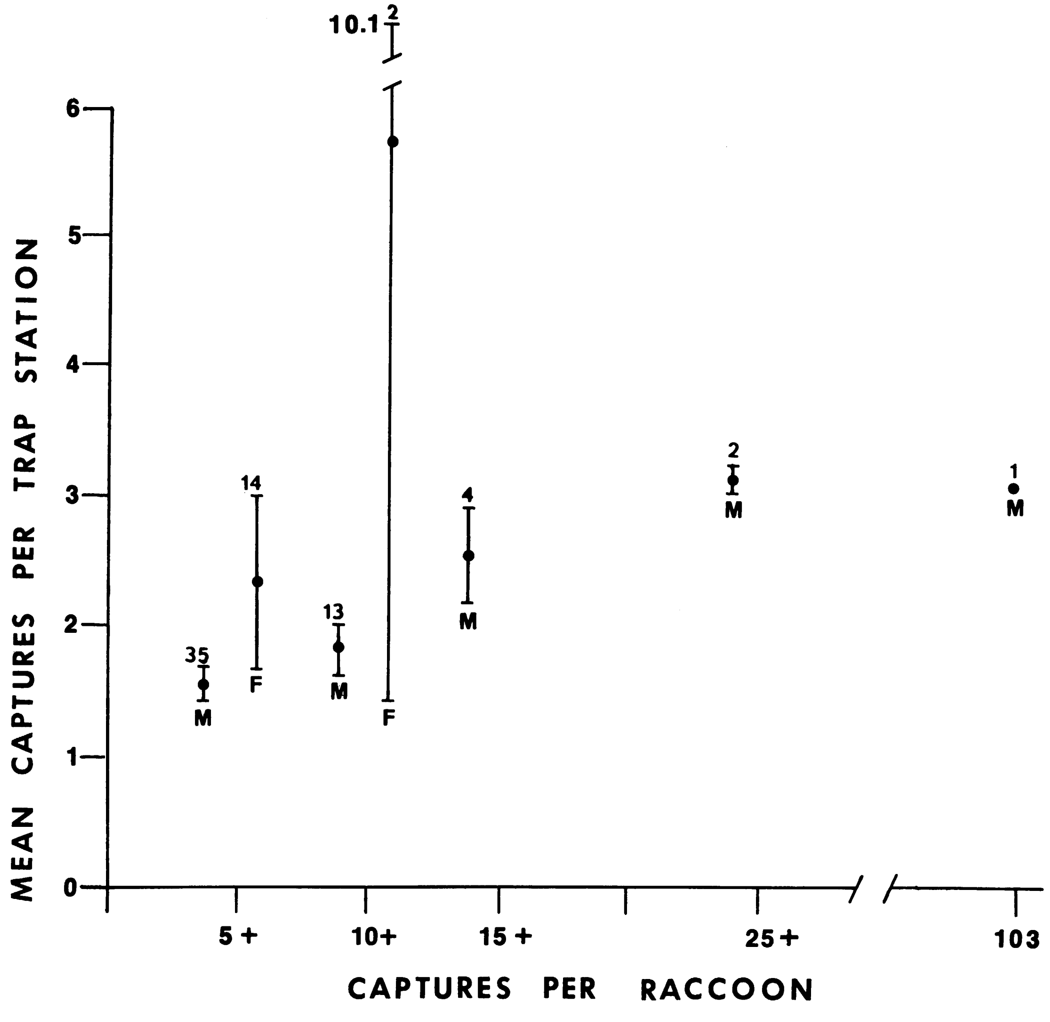

Fig. 6. Mean number of captures per station of capture for male (M) and female (F) raccoons on St. Catherines Island, Georgia from 1974 to 1977. Sample sizes and +/− one standard error of the mean are indicated. Samples are of animals captured at least the number of times indicated. For example, 5+ means all animals captured five or more times.

TABLE 1
Summary of Captures of Raccoons on St. Catherines Island, Georgia from 1974 to 1977

	Male	Female	Total	Percentage of Males
		Number of Different Individuals Captured[a]		
1974	182 (182)	109 (109)	291 (291)	63
1975	85 (54)	80 (58)	165 (112)	52
1976	119 (101)	73 (61)	192 (162)	62
1977	32 (18)	15 (8)	47 (26)	68
Total	(355)	(236)	(591)	60
		Total Number of Captures		
1974	501	212	713	70
1975	164	121	285	58
1976	284	104	388	73
1977	98	20	118	83
Total	1047	457	1504	70

[a]The number in parentheses indicates the number of new captures.

raccoon from St. Catherines Island is for raccoon no. 696, an adult male. From April 27, 1974, until March 14, 1977, he was captured 103 times. Computations after each capture (after captures had occurred at three points) during those four years indicated that the estimates of home range increased somewhat irregularly and that the increase was not asymptotic (fig. 7). Separate cumulative estimates of his home range in each of the four years also did not increase asymptotically (fig. 8). For raccoons captured more than 10 times each, cumulative estimates of multi-yearly home range areas for some individuals were asymptotic, but for others they were not (fig. 9). Although raccoon no. 696 was trap-prone, cumulative home range estimates for him (figs. 7, 8) are well within the range of patterns for other raccoons (fig. 9).

The shape and size of the home range of raccoon no. 696 shifted each year (figs. 10, 11). The shift from an elongate home range along the shore of the island to a more rounded home range in the center of the island was gradual. The home range of raccoon no. 696 in 1974 occupied 89 ha. In the next year, after the population crash, it occupied only 73 ha. In 1976 and 1977, the estimates were again higher, 111 and 112 ha., respectively. Overall trap placement patterns from 1974 to 1977 in the northern end of the island (figs. 10, 11) indicated that numerous other traps outside of each year's home range polygon were well within his potential range. For other raccoons on St. Catherines Island, insufficient capture data did not permit satisfactory yearly home range estimates (comparable to those for raccoon no. 696) to be made.

The final home ranges (convex polygon, mean ± standard error of the mean, in hectares) for 49 adult raccoons with at least five captures each were computed. The mean home range size was 38 ± 9. The mean value for 35 males, 51 ± 68, was significantly different ($t = 2.42$, $p < 0.05$) from the value for 14 females, 6 ± 10 (fig. 12).

The greater the number of captures, the higher the mean home range size of males seemed to be (fig. 12). No comparable increase in estimates of mean home range size of females was noted. However, no significant differences were noted between highest and lowest estimates for either sex. A regression of home range (Y) on number of captures (X) was significant ($F_{1,47} = 18.4$ $p < 0.01$, fig. 13). However, regressions calculated after log and

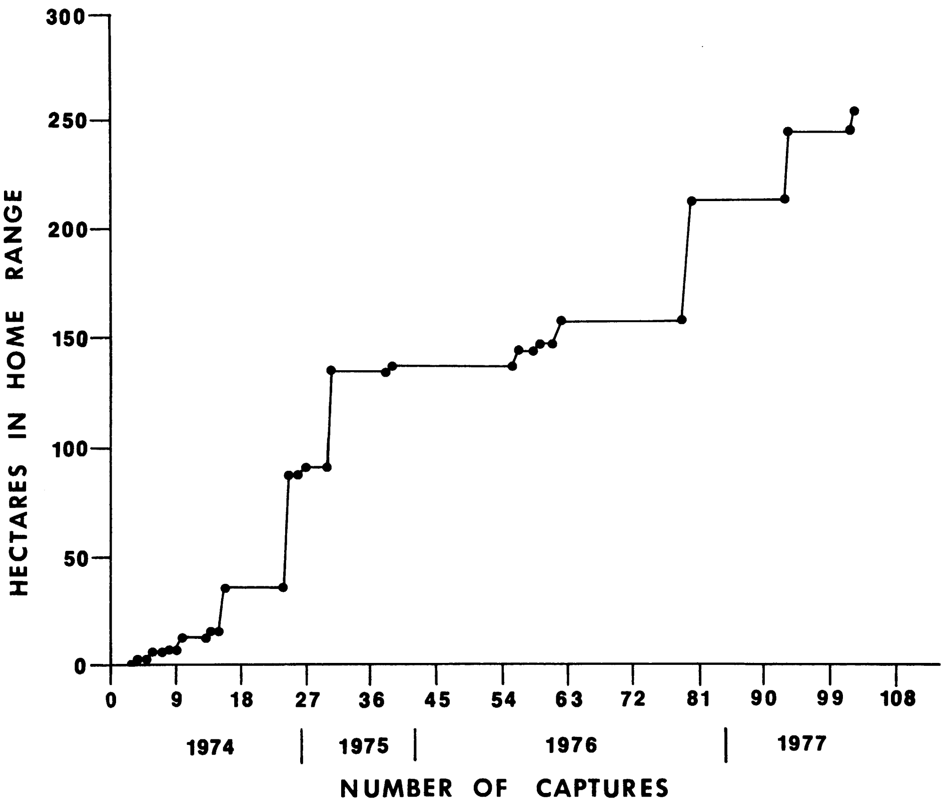

FIG. 7. Cumulative convex polygon estimates of home range size of raccoon no. 696 on St. Catherines Island, Georgia from April 27, 1974 to March 14, 1977.

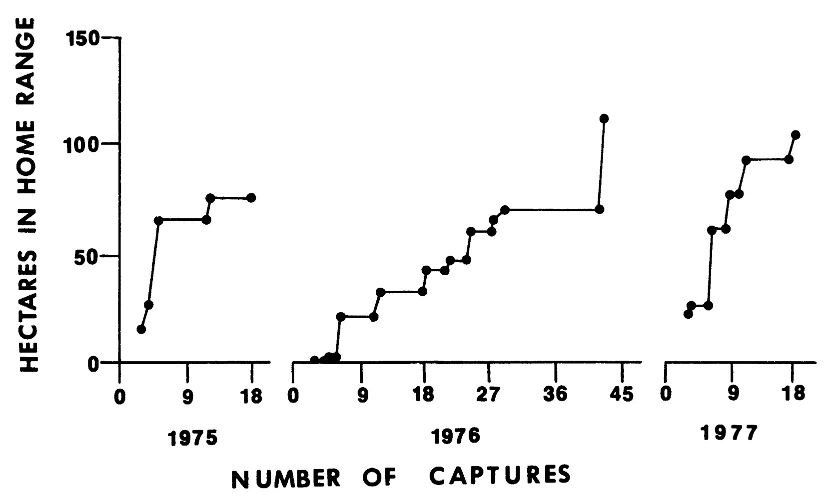

FIG. 8. Cumulative convex polygon estimates of home range size of raccoon no. 696 on St. Catherines Island, Georgia during 1975, 1976, and 1977. Data for 1974 are included in figure 7.

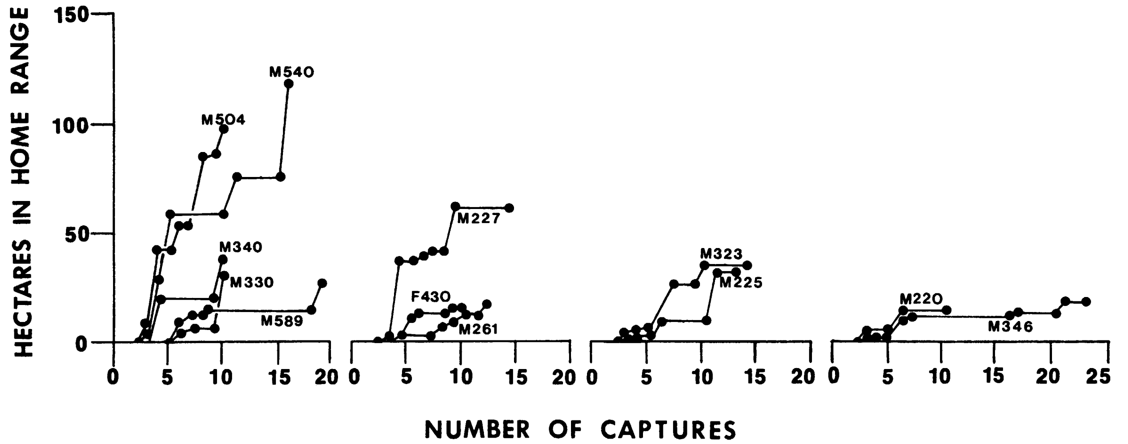

FIG. 9. Cumulative multi-yearly convex polygon estimates of home range sizes of individual raccoons on St. Catherines Island, Georgia. Raccoon identification numbers are indicated for males (M) and females (F).

natural log transformations of Y and/or X also were significant. Regression coefficients were positive in all cases.

The mean circular "potential" home range estimates for males and females (fig. 14) were not significantly different, nor were highest and lowest values for either sex. A regression of home range size (Y) on the number of captures (X) was not significant. Only regressions of log Y on log X and ln Y on ln X were significant ($F_{1,47} = 5.70$, $p < 0.05$ for both regressions, fig. 15). Regression coefficients were positive in both cases.

The mean home range estimate (cumulative convex polygon) of males increased from 11 ha. after three captures per male to 49 ha. after seven captures per male (fig. 16). The estimate for females did not show a significant increase. An asymptote of 40-50 ha. for males and 8-10 ha. for females was thus indicated.

HOME RANGES OF RADIOTAGGED RACCOONS

Yearly home range estimates (convex polygon, mean ± standard error of the mean, in hectares) of seven radiotagged adult male raccons was 65 ± 18 (n = 9) and for two adult females were 39 ± 16 (n = 2). Corresponding estimates of multi-yearly home ranges based on convex polygons of captures were available for five of these males.

Raccoon no. 261 had a multi-yearly trapping home range of 18 ha. His radiotracking home range of 37 ha. included most of the area of the trapping home range but also extended into the untrapped western marsh area (fig. 17).

Racoon no. 227 had a trapping home range of 61 ha. His radiotracking home range of 47 ha. included only one-fourth of the area of this trapping home range and extended into northern and southern areas where no traps were placed (fig. 18). His radiotracking home range did not coincide closely with the trapping home range based on the seven captures during the time of radiotracking.

Raccoon no. 540 had a trapping home range of 120 ha. His radiotracking home range of only 13 ha. included a fraction of the area of this trapping home range and included only a fraction of the area of the trapping home range based on the nine captures during the time of radiotracking (fig. 19). The southern part of the radiotracking home range was sparsely trapped.

Raccoon no. 589 had a trapping home range of 26 ha. His 1975 and 1976 radiotracking home ranges of 19 and 29 ha., respectively, included less than one-half of the area of this trapping home range. However, they included most of the area of the trapping home ranges determined by captures during the time of radiotracking in each year (fig. 20). His radio-

FIG. 10. Home range of raccoon no. 696 during each year from 1974 to 1977. Solid dots indicate the trap station positions during each year. A small circle and square indicate the geometric centers of all capture points and of all marginal points of the polygon for each year, respectively. Other features of the island map are as indicated in figure 1.

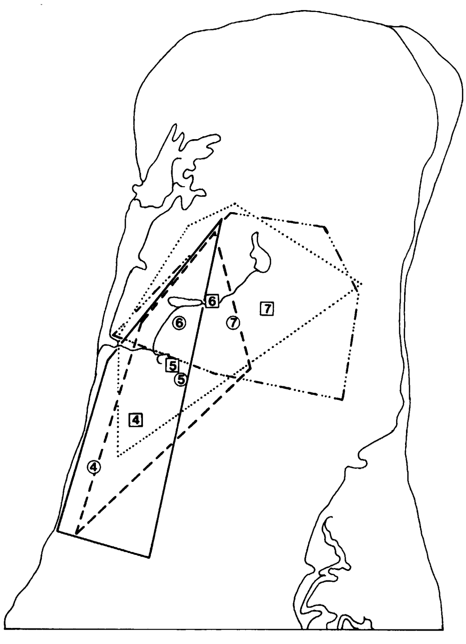

FIG. 11. Composite of the home ranges of raccoon no. 696 during 1974 (solid line), 1975 (dashed line), 1976 (dotted line), and 1977 (dashed and dotted line) on St. Catherines Island, Georgia. A small circle and square indicate the geometric centers of all capture points and of all marginal points of the polygon for each year, respectively. The enclosed numbers 4 to 7 differentiate symbols for 1974 to 1977, respectively. Other features of the island map are as indicated in figure 1.

tracking home ranges extended well into the untrapped western marsh area.

Raccoon no. 696 had a multi-yearly trapping home range of 254 ha. During 1976 and 1977, his trapping home ranges were estimated at 111 and 112 ha., respectively, whereas his radiotracking home ranges were estimated at 64 and 177 ha., respectively (fig. 21). In 1976, the radiotracking home range area included the entire trapping home range based on nine captures during the time of radiotracking. However, this radiotracking home range included less than one-half of the trapping home range based on all captures during that year and extended well into the untrapped western marsh area. During 1977, the radiotracking home range included most of the area of the trapping home range based on all captures during that year but also extended well into the southeast where no traps were placed.

General Comparison of Home Range Sizes Based on Trapping and Radiotracking

Home range size (convex polygon, mean ± standard error of the mean, in hectares) of male raccoons based on radiotracking (65 ± 18, n = 9) was not significantly different from trapping estimates based on at least five captures (51 ± 68, n = 35) or on at least 10 captures (74 ± 79, n = 13) per raccoon. For female raccoons, the home range size based on radiotracking (39 ± 16, n = 2) was significantly different from that based on at least five captures (6 ± 10, n = 14, $t = 3.86$, $p < 0.05$) but not from that based on at least 10 captures (7 ± 11, n = 2) per raccoon.

One other study (not yet completed) has compared estimates based on trapping and radiotracking. David Worley, a graduate student at the University of South Florida, Tampa, did this at the Archbold Biological Station of the American Museum of Natural History in Highlands County, Florida, in 1975 and 1976.

DISCUSSION

"Home range" has many conceptual as well as practical definitions in the literature on the movement of mammals (Sanderson, 1966). The convex polygon estimate of home range based on recapture data (Jennrich and Turner, 1966) is considered by some to be the most conservative and appropriate two dimensional method (Layne, 1954) and by others to be an outdated method (Mohr and Stumpf, 1964). The method seems to make good use of two dimensional information on point locations of an individual over a period of time without either over- or under-utilizing data. The problems of including unused areas within such a polygon, excluding used areas, and differentiating between areas variously important to an individual exist with all methods of approximating a home range (Brant, 1962; Sanderson, 1966) except perhaps sophisticated radiotracking methods (Schneider, Mech and Tester, 1971).

Ecological conditions on St. Catherines Island varied significantly during the four-year study period. The raccoon population crash during the winter of 1974-1975 (figs. 2, 3) was a significant event and may have affected home ranges of raccoons on St. Catherines Island. The poor condition of the racoons handled during that winter and the fact that the population crashed within only five weeks suggest that an outbreak of canine distemper had occurred but was not diagnosed at the time (Frank Hayes, personal commun.). The degree to which starvation due to the 1974 acorn crop failure triggered or contributed to the severity of such an outbreak or whether the disease was actually listeriosis, canine distemper, or something else is not known. The decline in trapping success does not seem to reflect a sudden decrease in activity of raccoons in response to weather. Winters on St. Catherines Island are comparatively mild, unlike winters in more northern latitudes (Stuewer, 1943; Schneider, Mech and Tester, 1971; Mech, Barnes and Tester, 1968). As Calhoun and Casby (1958) pointed out, density of traps and the number of days traps are left out will modify trapping success. In spite of these variables and the opportune placement of traps on St. Catherines Island, the trend in the trapping success index is clear, although magnitudes may be somewhat uncertain.

A decrease in the percentage of males

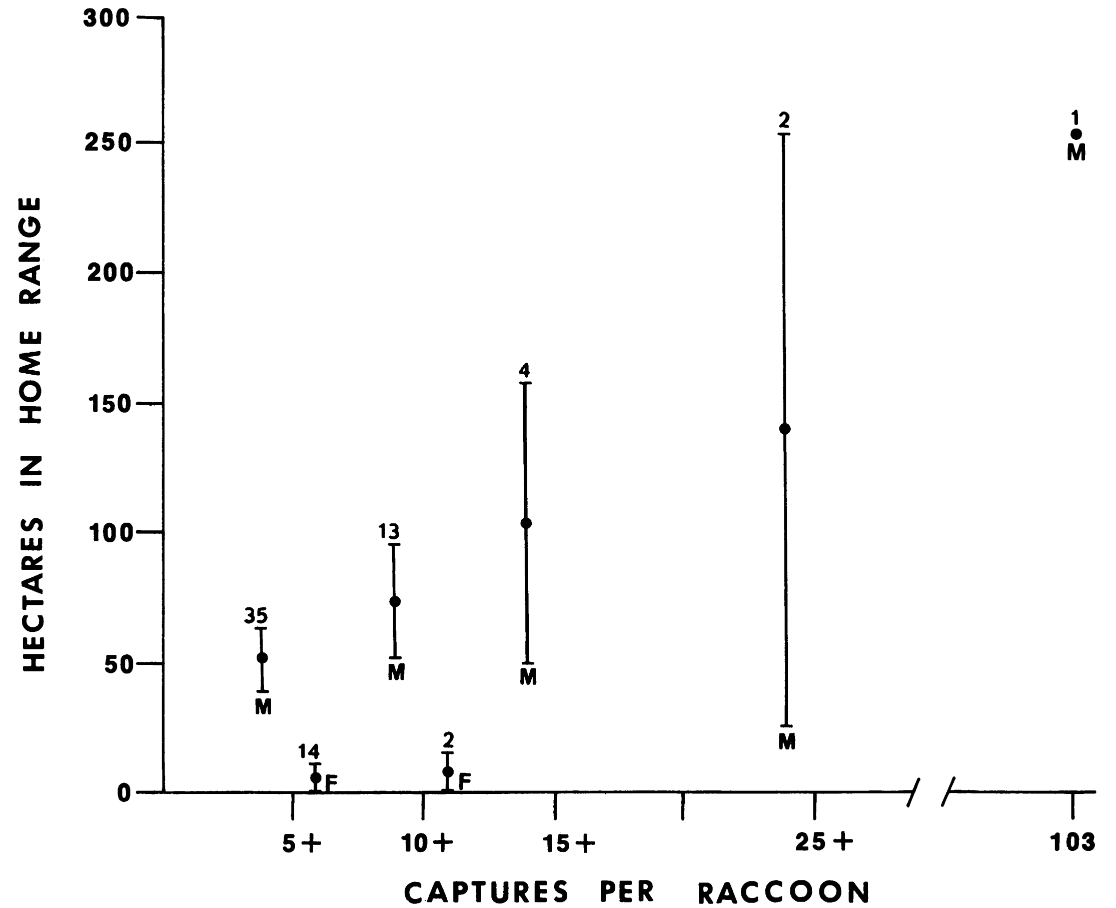

FIG. 12. Mean home range sizes (convex polygon estimates) of male (M) and female (F) raccoons on St. Catherines Island, Georgia from 1974 to 1977. Sample sizes and +/− one standard error of the mean are indicated.

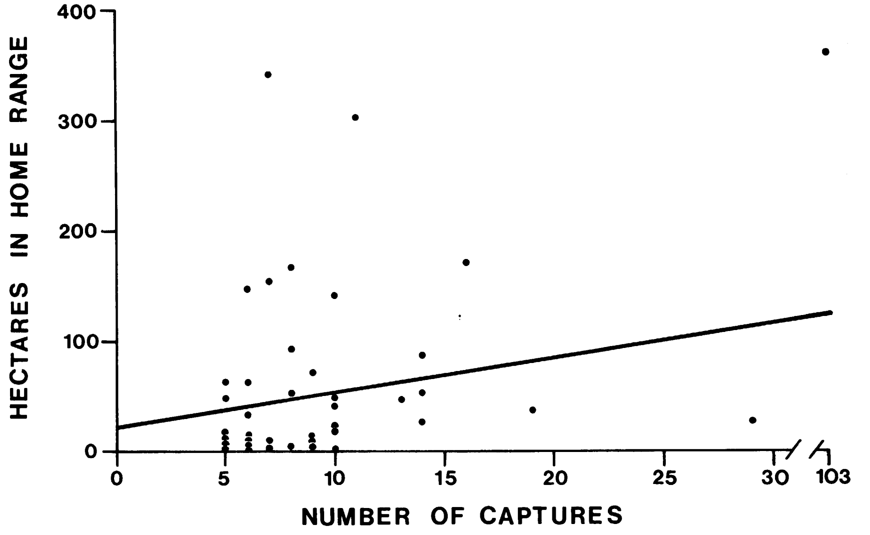

FIG. 13. Regression of home range size (convex polygon estimates) on number of captures for raccoons from St. Catherines Island, Georgia from 1974 to 1977. The regression equation is Y = 22.6 + 3.2X.

among raccoons captured was noted in the year following the population crash of the winter of 1974-1975 (table 1). This agrees with the conclusion of Sanderson (1951) that as raccoon numbers decline, an increase in the proportion of females in a population may be noted. He also noted that the percentage of female raccoons in a harvest increased as the size of the harvest increased. Males may be more vulnerable to factors causing natural mortality and to trapping and hunting than females because of the males' generally greater activity (Stains, 1956). Underlying causes of a change in sex ratio as a population is stressed are poorly understood (Sanderson, 1951). The yearly percentages (52-68) of males trapped on St. Catherines Island are in agreement with percentages reported in other studies (Stuewer, 1943; Sanderson, 1951; Stains, 1956; Johnson, 1970). Female raccoons rarely outnumber males in a population (Sanderson, 1951; Johnson, 1970). In 1975, the year after the population crash, the monthly percentage of males captured increased markedly (fig. 4). Johnson (1970) also noted monthly variations in sex ratios in samples of raccoons from Alabama and attributed them to increased activity of males with the onset of the breeding season. He noted that the mean date of conception of raccoons in Alabama was April 17 and that the mean date of birth was June 18. Comparable dates for St. Catherines Island are not yet known. It is possible that the 1975 data for raccoons on St. Catherines Island reflect such an increase in activity of males. However, no significant variation in monthly percentage of males captured was noted during 1976, the second year after the population crash. As noted, the higher percentage of females captured early in 1975 could be a reflection of the stresses on the population at the time.

In general, female raccoons were captured less often than male raccoons on St. Catherines Island. There may be various reasons for this. The mean number of captures per station of capture was always greater for females than males (fig. 6) and the time between captures was greater for females than for males (fig. 5). Thus different behavioral responses to the traps or to the trapping strategies may be involved. The mean number of captures per station of capture increased for both females and males as the number of captures increased (fig. 6). The value seemed to stabilize at about three captures per station of capture for males. However, the value for females did not seem to stabilize in the small sample available.

Although it is generally assumed that home range size increases as population density decreases (Sanderson, 1966), the home range size of raccoon no. 696 decreased after the population crash of the winter of 1974-1975. However, in 1976 and 1977 the estimates were larger than for 1974, the year of the greatest population density. Although the sample size for 1975 was smaller than in 1974 and 1976, it was comparable to that of 1977.

Changes in shape, size, and location of the yearly home ranges of raccoons other than raccoon no. 696 (figs. 10, 11) during the four-year study period could not be adequately determined because of insufficient recaptures, but may have occurred.

From the general literature on the movement

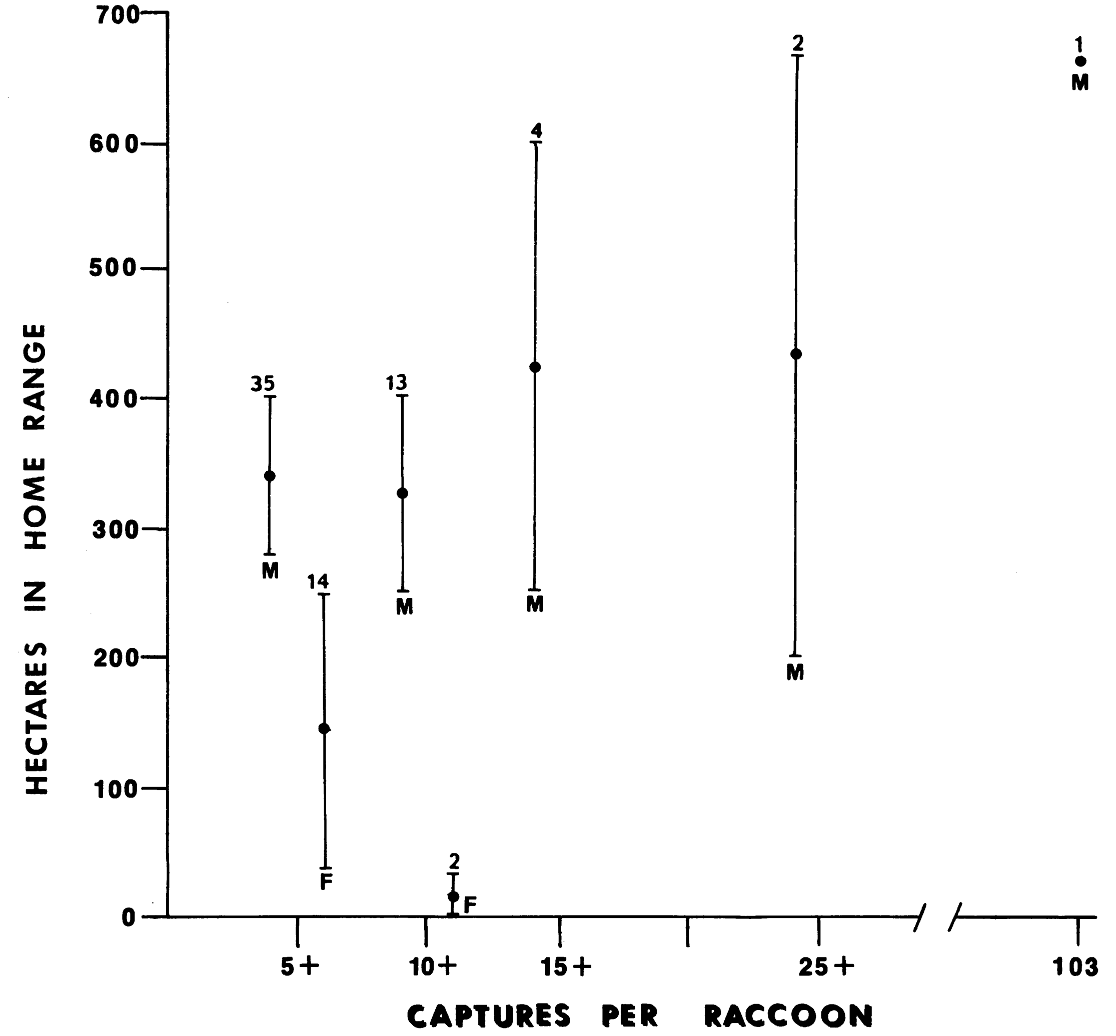

FIG. 14. Mean home range sizes (circular or "potential" estimates) of male (M) and female (F) raccoons on St. Catherines Island, Georgia from 1974 to 1977. Sample sizes and +/− one standard error of the mean are indicated.

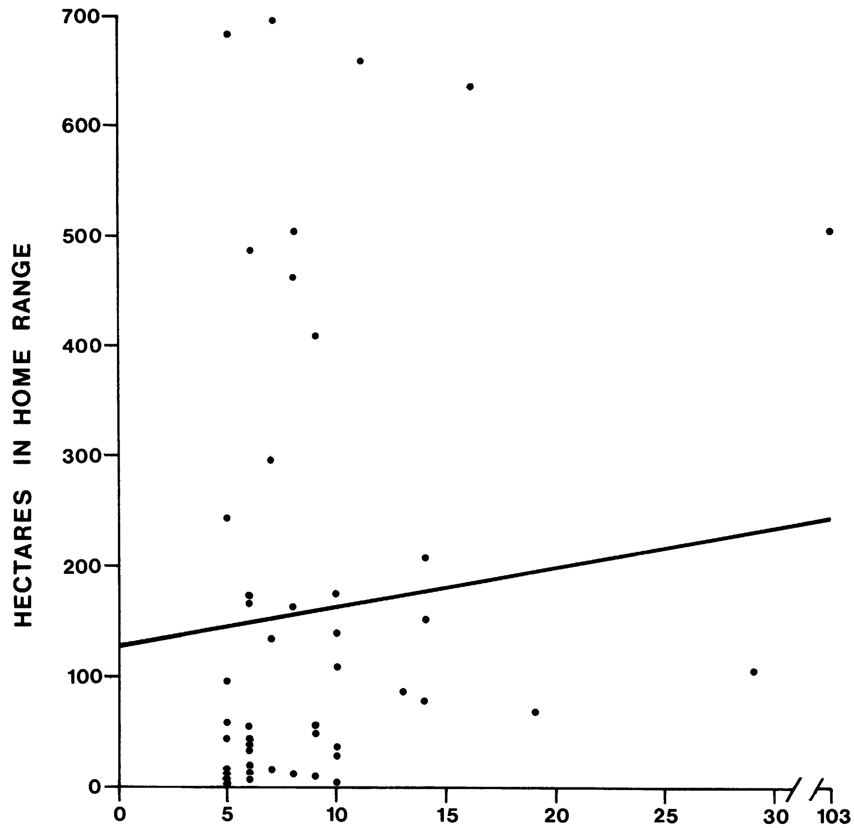

FIG. 15. Regression of home range size (circular or "potential" estimates) on number of captures for raccoons from St. Catherines Island, Georgia from 1974 to 1977. The regression equation is $Y = 127.6 + 3.7X$.

of mammals, it is not clear what number of captures or other point locations constitutes an adequate sample for the determination of a home range (Sanderson, 1966). Although many studies report estimates based on fewer than 10 captures per individual, it is generally conceded that the greater the number of captures considered in making an estimate, the more realistic that estimate will be, and that the estimate will eventually approach an asymptote. Sanderson (1966) noted that comparisons of different estimates of home ranges based on point locations are hampered by the wide variability in the number of captures, the intervals between successive captures, and the intervals between the first and most recent capture from one individual to another. For practical purposes, it is often assumed that the recapture data for individuals are minimum estimates of home ranges and that these estimates may be compared cautiously despite variabilities in the basic data. The inherent problems in the collection and analyses of data on point locations are similar regardless of the length of the period of study. One can determine home ranges for any convenient time period (Fritzell, 1978).

Estimates of home range sizes of individual raccoons on St. Catherines Island do not necessarily approach an asymptote with an increase in number of captures (figs. 7-9). The data were so variable that without evidence from another source (such as radiotracking) little significance can be attached to asymptotes approached by data for some raccoons (fig. 9). Such additional evidence was available for only five raccoons (see below). The periodic increases in the cumulative home ranges of raccoons (figs. 7-9) could result from seasonal changes in home range parameters but may also result from an insufficient number of captures. Although other studies assume that beyond a certain specified "minimum" number of captures a significant change in the estimate of a home range size is not likely to occur (Hayne, 1949; Stickel, 1954; Metzgar and Sheldon, 1974), the data of the present study did not indicate such a minimum number. In studies of territorial species, the concept of a minimum number of observations is useful (Odum and Kuenzler, 1955).

As the number of captures per raccoon increased, the mean home range of males increased (fig. 12). This suggests that for male raccoons on St. Catherines Island, home range

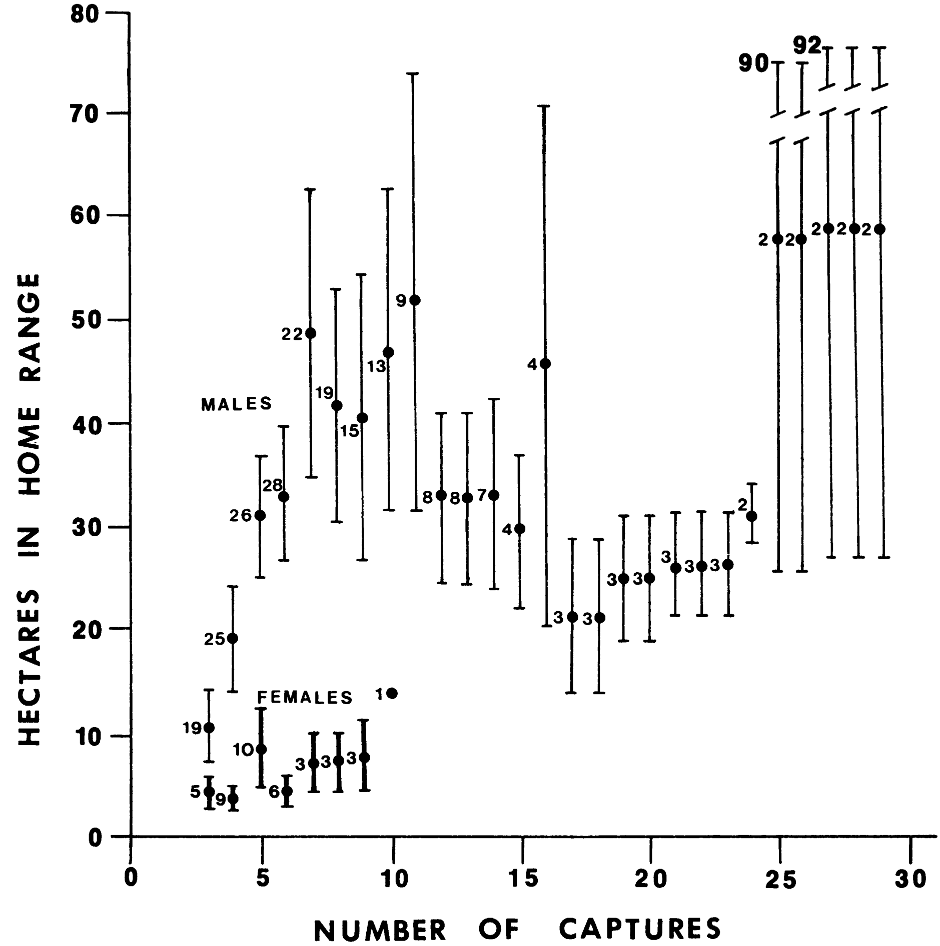

FIG. 16. Cumulative means of convex polygon home range sizes of male and female raccoons after succeeding captures on St. Catherines Island, Georgia from 1974 to 1977. Sample sizes and +/− one standard error of the mean are indicated.

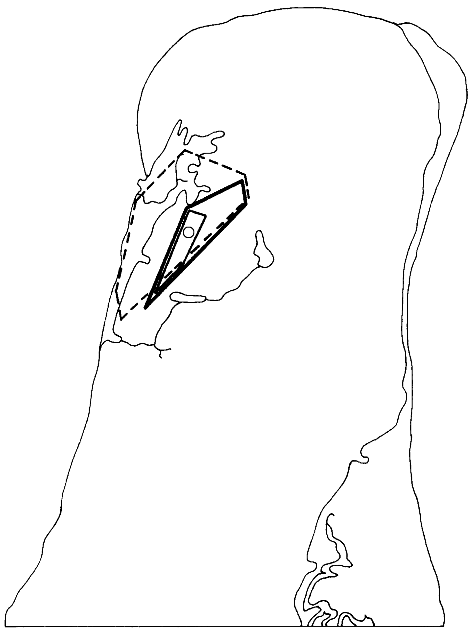

FIG. 17. Home ranges of raccoon no. 261: based on 15 captures from 1974 to 1977 (heavy line); based on 316 radiolocations during 103 days of 1976 (dashed line); and based on five captures during radiotracking (light line). The small circle indicates the geometric center of all capture points. Other features of the island map are as indicated in figure 1.

estimates should be regarded as minimum estimates. Although a concomitant increase was not noted for the smaller sample of females, a larger sample might show an increase. Since regressions (convex polygon estimates on number of captures) based on both untransformed and transformed data for all raccoons (male and females pooled) yielded positive regression coefficients and since all regressions were significant, it seems that home range size does continue to increase with the number of captures per individual. However, there is no basis for assuming that such an increase is asymptotic (see Sokal and Rohlf, 1969, p. 476, for an explanation of the tests).

In studies of home ranges, it has been found that the translation of point location data into a circular home range estimate (Stuewer, 1943; Calhoun and Casby, 1958; Maza, French and Aschwanden, 1973) is often useful as an index or estimate of potential home range size and for comparisons between populations and species. Mean circular home range sizes of raccoons on St. Catherines Island were always several times larger than corresponding mean estimates based on convex polygons (figs. 12, 14). The circular estimates do not clearly indicate that mean home range size estimates increase as raccoons with fewer captures are excluded from the sample. Since only regressions following log and natural log transformations were significant, there may nevertheless be some basis for assuming that there is an asymptotic increase in circular home range size with an increase in number of captures per individual. However, this method is considered of limited value to the present study because it under-utilizes available information in size and shape of home ranges.

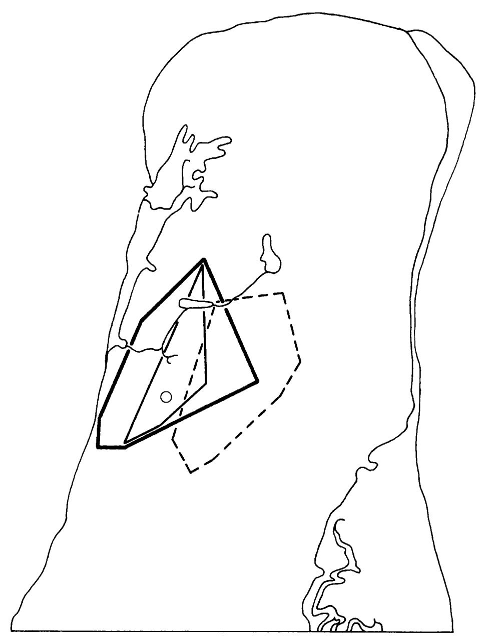

FIG. 18. Home ranges of raccoon no. 227: based on 14 captures from 1974 to 1975 (heavy line); based on 22 radiolocations during 42 days of 1975 (dashed line); and based on seven captures during radiotracking (light line). Symbols are as indicated in figure 17.

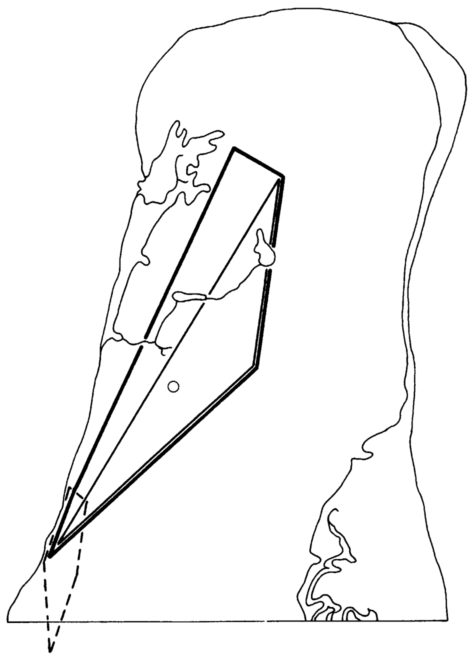

FIG. 19. Home ranges of raccoon no. 540: based on 16 captures from 1975 to 1976 (heavy line); based on 67 radiolocations during 56 days of 1975 (dashed line); and based on nine captures during radiotracking (light line). Symbols are as indicated in figure 17.

The apparent curvilinear relationship between mean home range size and number of captures for male raccoons indicates an asymptote (fig. 16) which is well within the range of estimates based on means of final home range sizes of males with at least five and 10 captures (fig. 12). Although both methods depend on convex polygon determinations of individual raccoon home ranges, the close agreement of estimates is considered significant.

Radiotracking techniques in part offer the possibility for validating estimates of home ranges based on trapping of individuals. Although yearly radiotracking home ranges of raccoons no. 261, no. 589 during 1975 and 1976, and no. 696 during 1976 approximately encompassed the home range polygons based on captures during the radiotracking interval only, this was not the case for raccoons nos. 227, 540, and 696 during 1977. This lack of coincidence was unexpected because the larger number of point locations from radiotracking should theoretically have encompassed the trapping home range polygons. Apparently, the radiotracking home range polygons did not adequately describe home ranges in some cases.

Since the total number of locations and the number of locations per unit time upon which radiotracking estimates on St. Catherines Island were based are larger than for recapture locations, radiotracking estimates of home ranges can be considered more accurate. Each sample of radiotracking data for any one animal was accumulated during a time period of less than one year, and home range estimates generated from these data should be smaller than those based on trapping data for a several year period. For male raccoons on St. Catherines Island, the mean home range size based on radiotracking data was, as expected, smaller than the mean trapping home range size based on at least ten captures but was larger than the estimate based on at least five captures per raccoon. This suggests that at least 10 captures per male are desirable for estimating home ranges. However, there were no significant differences between the estimates. For female raccoons, the mean home range size based on radiotracking locations was larger than the mean home range size based on at last five captures but also larger than that based on at least 10 captures per raccoon. This suggests that for female raccoons on St. Catherines Island, recapture data were insufficient for estimating home ranges. Had yearly estimates of home ranges been made for males and females captured more than five times each (over more than one year), these would have been even more doubtful than multi-yearly estimates. Thus classical marking and recapturing techniques at best yielded minimum estimates of home range sizes, shapes, and locations of raccoons on St. Catherines Island. Radiotracking offers the possibility of more frequent observations at regular intervals and hence more detail about home range dynamics. However, a

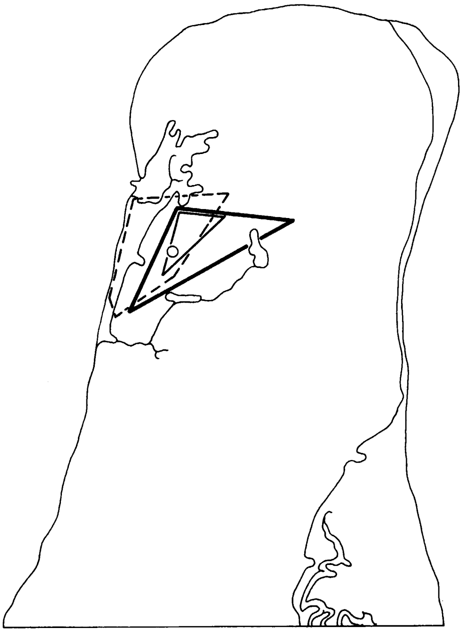

FIG. 20. Home ranges of raccoon no. 589. The heavy line is based on 29 captures from 1974 to 1976, in both maps. At left, estimates for 1975: based on 297 radiolocations during 119 days (dashed line); and based on 4 captures during radiotracking (light line). At right, estimates for 1976: based on 20 radiolocations during 19 days (dashed line); and based on seven captures during radiotracking (light line). Symbols are as indicated in figure 17.

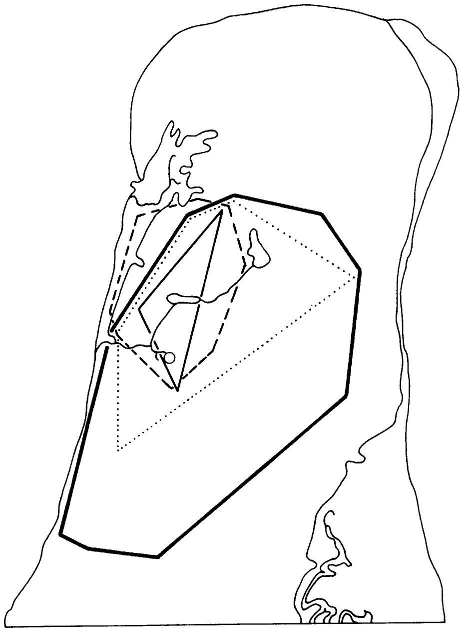

FIG. 21. Home ranges of raccoon no. 696. The heavy line is based on 103 captures from 1974 to 1977, in both maps. At left, estimates for 1976: based on 85 radiolocations during 19 days (dashed line); based on 43 captures (dotted line); and based on nine captures during radiotracking (light line). At right, estimates for 1977: based on 41 radiolocations during 46 days (dashed line); and based on 18 captures during radiotracking (light line). Symbols are as indicated in figure 17.

TABLE 2
Summary of Raccoon Home Ranges Studies in the United States

Author	State	Methods[a]	Raccoon Sex Age No.[b]	Number of Data Points Per Raccoon[c]	Duration of Study in Days Per Raccoon[c]	Home Ranges Size in Hectares Per Raccoon[c]
Cauley and Schinner, 1973	Ohio	R/ CVP	"several" of unknown age and sex	unknown	less than 730	$\bar{X}$ 8.3 R 0.2-20.2
Ellis, 1964	Illinois	R/ CVP?	M A 1	every 15 min. to 2 hours	1-10 days during 1-18 day study periods	A 42.9
			F A 3			R 13.9-41.0
			M J 2			R 10.9-77.3
			F J 1			A 54.6
Fisher, MS	Michigan	R/ CCP	M A 5	R 233-563	R 48-106	$\bar{X}$ 55.2
			F A 6	R 10-580	R 11-101	R 41.4-64.8
Fritzell, 1978[d]	North Dakota	R/ modified CVP	M A 9	$\bar{X}$ 210	up to 122	$\bar{X}$ 2560 R 670-4946
			M Y 11	$\bar{X}$ 109		$\bar{X}$ 1139
			F A 7	$\bar{X}$ 182		R 227-2160
			F Y 8	$\bar{X}$ 172		$\bar{X}$ 806 R 229-1632 $\bar{X}$ 656 R 222-1263
Hoffmann and Gottschang, 1977	Ohio	T/ C and modified CVP				CVP C
			M A 6	at least three	up to 772	$\bar{X}$ 15.8 $\bar{X}$ 52.3
			M J 9			$\bar{X}$ 2.8 $\bar{X}$ 11.7
			M Y 6			$\bar{X}$ 5.1 $\bar{X}$ 40.5
			F A 10			$\bar{X}$ 3.8 $\bar{X}$ 14.6
			F J 10			$\bar{X}$ 2.3 $\bar{X}$ 10.0
			F Y 5			$\bar{X}$ 4.6 $\bar{X}$ 30.2
		R/ modif. CVP	F J 1	unknown	$\bar{X}$ 13.2 Indiv. days over $\bar{X}$ 30.4 day transmission period but up to 192 days	$\bar{X}$ 10.5 in one day
			? ? 4	unknown		unknown
Johnson, 1970	Alabama	R/ CVP	M A 1	at least 31	120	A 99.2
			M J 1	43	83	A 49.4
			F J 1	at least 14	30	A 46.1

TABLE 2 (*Continued*)

Author	State	Methods[a]	Raccoon Sex Age No.[b]	Number of Data Points Per Raccoon[c]	Duration of Study in Days Per Raccoon[c]	Home R Size in Hectares Raccoon[c]
Mech, Tester and Warner, 1966	Minnesota	R/ CCP	M A 1	R 24-53 den locations	R 10-47	R 25.9-20(
			F A 1			
			? J 5			
Schneider, Mech and Tester, 1971	Minnesota	R/ CCP	F A 4	up to 9600	R 40-200	R 120-350
			M J 1	up to 1440	A 30	A 200
Schnell, 1969	Minnesota	R/ CCP	M A 2	unknown	unknown	R 422.1-476.
			F A 5			R 153.0-356.
Shirer and Fitch, 1970	Kansas	R/ CVP	? A 4	R 4-14	up to 548	R 5.3-34.0
			? J 3	A 29 each	A 123 each	A 110 each
Stuewer, 1943	Michigan	T and F/C	M A 19	$\bar{X}$ 7	up to 1095	$\bar{X}$ 203
				R 3-36		R 18.2-814.3
			F A 17	$\bar{X}$ 7.1		$\bar{X}$ 108.5
				R 3-19		R 5.3-376.4
			M J 27	$\bar{X}$ 3.4		$\bar{X}$ 108.5
				R 2-10		R 2.0-719.1
			F J 24	$\bar{X}$ 4.6		$\bar{X}$ 44.9
				R 2-18		R 2.0-323.0
Sunquist, 1967	Minnesota	R/ CVP	F A 1	total of 1800 locations for all four	$\bar{X}$ 9.0	R 63.9-95.5
			M J 3			
Sunquist, Montgomery and Storm, 1969	Minnesota	R/ CCP	M A 1 (blind)	minimum of 1 every 5 min.	two 7 day periods	A 2068
			M A 1 (normal)			A 775
Tester and Siniff, 1965	Minnesota	R/ CCP	M A 1	A 37-521	1 to 35 day cumulative patterns	A 517
Turkowski and Mech, 1968	Minnesota	R/ CCP	M J 1	A 2065	A 135	A 246.1
Urban, 1970	Ohio	R/ CVP	M A 3	R 84-105	R 16-58	$\bar{X}$ 88.2
			M J 4	R 15-124	R 12-66	$\bar{X}$ 18.2
			F J 2	R 74-97	R 26-42	

[a]R, radiotracking; T, trapping; F, footprint tracking; C, circular home range; CCP, concave polygon home range; CVP, convex polygon home range.
[b]M, male; F, female; A, adult; J, juvenile; Y, yearling.
[c]$\bar{X}$, a mean of values; R, a range of values; A, actual value; C, circular home range; CVP, convex polygon home range.
[d]Note: Also included in this article are data on mean monthly home range sizes and also bi-weekly home range sizes of parous females

greater number of radiotracking locations than 1.8 per day per raccoon should be obtained. Such studies were begun on St. Catherines Island in July 1977.

The techniques used to obtain point location data and to determine home range parameters of raccoons on St. Catherines Island are those used in other studies of raccoon home ranges throughout the United States (table 2). In part, the large variation in estimates of home range sizes of raccoons can be explained in terms of the tremendous range of habitats from which raccoons are known (Goldman, 1950). However, the number of data points per raccoon and the duration of studies (in days) per raccoon vary significantly between studies.

This study emphasizes that significant questions regarding home range size, shape, and location can be raised and that these need to be answered prior to more detailed ecological analyses (Sanderson, 1966). Validation of trapping home range data with radiotracking home range data is shown to be important as is the comparison of detailed data for at least one individual with data of more poorly understood individuals. This study also emphasizes that methods of collecting trapping and radiotracking data may have a significant bearing on conclusions drawn from those data.

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