Seasonal Home Ranges of Raccoons, *Procyon lotor*, Using a Common Feeding Site in Rural Eastern Ontario: Rabies Management Implications

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Thirteen adult Raccoons (*Procyon lotor*) (six females, seven males) that fed at a garbage dump north of Kingston, Ontario were radio-tracked from 21 June to 16 October 1995 to assess their seasonal home ranges and movements. Average Minimum Convex Polygon (MCP) summer and fall home ranges for the collared Raccoons were 78.4 ha (SD=46.2 ha) and 45.6 ha (SD=29.7 ha), respectively. Average grid cell summer and fall home ranges for the collared Raccoons were 143.3 ha (SD=40.0 ha) and 116.9 ha (SD=24.9 ha), respectively. Summer ranges of the Raccoons were significantly larger than fall ranges using both the MCP method (P=0.05) and the grid cell method (P=0.073). Yearling Raccoons travelled an average summer maximum distance from the dump of 2608 m (SD=1964, n=3), more than double the distance of adults (≥2 yr) at 1239 m (SD=547, n=10). The population density for the study area in late August 1995 was estimated at 1 Raccoon/12 ha based on an effective area surrounding the dump of 234 ha. Home range and movement data may be useful to design a strategy to control Raccoon rabies in Ontario.

Key Words: Raccoon, *Procyon lotor*, rabies, communal feeding, disease transmission, field study, home range, telemetry, Ontario.

Raccoon (*Procyon lotor*) rabies was first reported in Ontario, Canada, during July 1999 (Wandeler and Salsberg 1999; Rosatte et al. 2001). Point infection control methodologies are currently being used (since 1999) in Ontario to contain the outbreak to a small area (Rosatte et al. 2001). As well, a Raccoon rabies model is being developed in Ontario to assist with the control of the disease by predicting the rate of spread of Raccoon rabies both temporally and spatially. Knowledge on Raccoon home ranges, movements and population dynamics in Ontario is needed to develop and validate the rabies model so that it reflects the actual sequence of events that occur during a Raccoon rabies epizootic/enzootic (Broadfoot et al. 2001).

The spatial distribution of food is known to influence contact rates in Raccoons (*Procyon lotor*) (Seidensticker et al., 1988). Clumped food resources such as garbage dumps may increase potential contact rates of Raccoons as these resources cause members of a population to congregate from a wide area. This in turn may influence rabies transmission in the population (Seidensticker et al. 1988). Range of movements of Raccoons using common feeding sites may be a useful indicator of potential rabies spread. Such information can be used to design effective baiting strategies to vaccinate these animals against rabies as well as provide input for the development of rabies models.

Home ranges of Raccoons tend to shift due to seasonal changes in behavior and therefore must be calculated separately for each season (Kauffmann 1982).

Summer is the family rearing period when lactating mothers and their offspring travel together and it is also the main dispersal period for yearling males (Mech et al. 1968; Fritzell 1978). Fall is a time when the juveniles may disperse and Raccoons prepare for the coming winter dormancy period (Shirer and Fitch 1970). In this study, home range was defined using criteria of White and Garrott (1990) as the area within which the animal normally moved in a specified time frame, in this case the summer and fall of 1995.

In this study, movements of Raccoons using a common feeding site in rural eastern Ontario, Canada, were determined by radio-telemetry to assess the size of their summer and fall home ranges. The same Raccoons on which contact data were obtained in the Totton et al. (2002) study were used. In addition, two Raccoons, caught at a smaller feeding site (compost heap) were tracked periodically to determine their daytime resting sites. The population density of Raccoons in this study was also measured as it influences home range and contact rate.

Study Area and Methods

Trapping took place at a private garbage dump (44°34'N, 76°20'W) and at a compost bin on the grounds of the Queen's University Biological Station 40 km north of Kingston, Ontario (44° 35'N, 76° 19'W). The area surrounding the dump consisted of farm land (livestock), forest, marsh, and cottages (most of which were only occupied during the summer). The entire

study area was about 460 ha. Fifteen Raccoons (eight females and seven males) were collared between 20 May and 27 June 1995. Raccoons were captured using Tomahawk #106 (Tomahawk Live-trap Company, Tomahawk, Wisconsin, USA), and Havahart #1079 (Havahart Live Trap Company, Niagara Falls, Ontario, Canada) live-traps. All Raccoons were ear-tagged (numbered size 1 and 2, National Band and Tag Company, Newport, Kentucky), vaccinated against rabies (Imrab® inactivated rabies vaccine, Merieux, Inc., Athens, Georgia, USA) and canine distemper (Fromm D, modified live virus, SOLVAY animal health, Inc., Mendota Heights, Minnesota, USA). They were immobilized by intramuscular injection of ketamine hydrochloride (Rogar/STB Inc., London, Ontario, Canada) and xylazine hydrochloride [Rompun] (Bayvet, Rexdale, Ontario, Canada) [30 mg/kg body weight ketamine, 10:1 ratio ketamine:rompun]. We determined their sex and extracted a first premolar tooth for age determination by cementum analysis (Johnston et al. 1987). Each animal was then fitted with an adjustable radio-collar [151 to 152-Mhz] (Lotek Engineering Inc., Newmarket, Ontario, Canada) and released at its point of capture.

The radio-tracking system consisted of a four-element Yagi antenna, 151 MHz (FM) transmitters mounted on whip antenna collars (Lotek Engineering, Newmarket, Ontario), one programmable hand-held receiver (Lotek model SRX-400; Lotek Engineering, Inc., Newmarket, Ontario) that operated in the 151-152 MHz range, one hand-held compass, and a four-wheel drive pick-up truck. Animals were given at least seven days to acclimatize to their collars before radio-tracking began, in accordance with White and Garrott's (1990) recommendations. The tracking period lasted from 21 June to 16 October 1995 with attempts being made to locate each Raccoon two to three times per week. Since only one telemetry receiver was available, sequential rather than simultaneous bearings had to be taken. A maximum interval between first and last bearings of 10 min was set to minimize telemetry error caused by animal movement (except for bearings taken during the day when the animals were inactive, at which time the interval may have been longer). In a study by Gert and Fritzell (1996), 23% of the locations came from triangulations with between-bearing intervals in excess of 8 min. For this reason, the 10 min cut-off was deemed reasonable for this study.

Continuous radio-tracking (i.e., location of the animals at least every 15 min (Harris et al. 1990)) was not feasible with only one receiver; therefore, for this study, discontinuous tracking was performed. Location estimates were made for each animal three or four times between dusk and dawn at roughly 2-h intervals, and once during the following afternoon to determine daytime resting sites. The tracking schedule was constructed by randomly selecting six of the collared animals

trapped at the dump for one given tracking night. The remaining Raccoons were then tracked on the next scheduled night. A different set of Raccoons was randomly chosen for the following tracking night and so on. Dates of tracking nights were randomly selected for each week.

Three types of location estimate techniques were used: scanning, triangulation, and homing. Scanning involved tuning into the collar frequencies of the dump animals while the researcher sat in the middle of the dump area. Data from telemetry accuracy tests indicated a mean transmitter-receiver distance of 240 m± 30 m (n=20) when the signal was picked up at a gain of 10. A Raccoon was therefore considered to be in a radius of this distance from the center of the dump area if its signal was detected from there at a gain of 10 or less. Most of the locations for the dump animals were obtained by triangulation. This technique involves taking directional bearings from two to three different receiver sites at known locations and using these to estimate the true location of a remote transmitter on the animal's collar (White and Garrott 1990).

Accuracy tests were performed to determine the error associated with locations estimated by triangulation in this study. Bearing accuracy has two components: bias (the average difference between the true bearing and the bearing estimated by the receiving system for a series of receiver-transmitter locations), and precision, which is the standard deviation of these errors (White and Garrott 1990). The bias was 9º and was significantly different from 0º (t=3.61, n=63, P<0.001; one sample t-test (Zar 1996)). Therefore 9º was subtracted from all bearings. Precision of the system was ± 20º.

Screening criteria derived from telemetry accuracy tests were applied to all bearings to eliminate errors due to signal bounce. All bearings which did not intersect with other bearings taken on the same transmitter were removed. All bearings taken from receiver sites associated with large errors (high levels of signal bounce) were removed from subsequent analysis. Also, bearings taken when the transmitter-receiver distance was >2000 m were removed. In addition, all locations involving distances between transmitter and receiver of over 1 km were inspected for plausibility.

A computer program called TRIANG was used to estimate animal locations from triangulated bearing pairs and to calculate the distance between receiver and transmitter for each bearing. TRIANG did not compute animal locations when three bearings were taken. In this case, locations were determined by plotting the bearing angles in AutoCAD and estimating the centre of the triangle created by the intersection of the bearings.

Locations for two of the collared Raccoons were usually obtained by homing (White and Garrott 1990). Locations of animals determined by homing are not affected by error in the telemetry system; however, they

are affected by the researcher's ability to pinpoint the den location on a map (White and Garrott 1990). All locations determined by homing in our study were plotted by hand on 1:10 000 maps of the area to ±50 m to obtain Universal Trans Mercator Co-ordinates (UTMC).

Home ranges were estimated using the minimum convex polygon (MCP) method (Mohr 1947), since this is the only home range method that is strictly comparable between studies (Harris et al. 1990). Ranges for both seasons were combined to compare degree of overlap between seasons. Because it is advantageous to use more than one home range estimate technique (Voigt and Tinline 1980), the grid cell method of home range analysis (Siniff and Tester 1965) was also used. Size of the grid cells was chosen to reflect radio fix accuracy based on the results of accuracy tests. In order to enclose the uncertainty area associated with scanning the dump for transmitter signals (and this was larger than the area associated with triangulation) a grid square would have to measure 480 m on each side. Therefore this was the size of grid square (23 ha) used in estimating grid cell home ranges. The grid was oriented by centering a grid square over the dump site.

Summer home ranges were calculated from telemetry data collected in June, July, and August; September and October fixes were used to calculate fall home ranges. Two female Raccoons were excluded from the analysis because insufficient locational fixes (<16) were acquired during the study. A Mann-Whitney U test (Zar 1996) and Statistica Version 6.0 software (StatSoft Inc., Tulsa, Oklahoma) were used to test for statistical differences in Raccoon home range size. Raccoons were grouped into regular and occasional dump visitors based on the number of nights each animal was seen at the dump out of a total of 35 observation nights in a concurrent behavioral study (Totton et al. 2002). Raccoons were defined as regulars if they were observed at the dump on >51% of all observation nights and occasionals if they were seen at the dump on ≤51% of the observation nights. Since only one telemetry receiver was available, and hence discontinuous locational fixes had to be obtained, detailed analysis of the movement patterns of raccoons in this study was not possible.

Trapping to estimate the Raccoon population size took place at the dump from 28 August to 19 September 1995. At this time of year, juveniles are larger and easier to trap and handle than they are earlier in the summer (Seidensticker et al. 1988). The number of Raccoons in the study area was estimated using a modified Petersen Index (Begon 1979). Density of the dump population was not based solely on the area of the trapping site (garbage dump = 2.3 ha) because it was evident from telemetry data that some Raccoons were travelling from a much wider area to feed at the dump. Instead, using the number of Raccoons

calculated by the methods above, estimates were made of the crude density of the population as defined by Seidensticker et al. (1988) based on the average maximum width of the dump Raccoons' summer (MCP) home ranges (1530 m). Since Seidensticker et al. (1988) did not specify how this distance was used to calculate overall area, a square was centred over the dump with each side equal to the distance calculated and this was used for calculation of crude density. Its area was 234 ha.

Results

For locations determined by triangulation, distance between the observer and estimated transmitter location ranged from 8.3 m to 1837.9 m and averaged 330.5 m (SD=239.3 m). Uncertainties in Raccoon position for triangulated bearings (tan 20° × transreceiver distance) ranged from ±3.0 m to ±668.9 m with a mean of ±120.3 m and standard deviation (SD) of 87.1 m (n=1181). Overall locational uncertainty, including that associated with scanning and homing techniques as well as triangulation, was ±146.6 m (n=1110).

No statistical differences were detected between male and female ranges for values calculated using either the MCP method (P=0.78) or the grid cell method (P=0.26). Therefore, male and female data were pooled to compare summer and fall ranges. As well, only three yearlings were trapped at the dump in this study and home range data were available for two of those. Consequently, statistical comparisons between adult and yearling home range sizes were not performed. No differences could be detected between home ranges of Raccoons that regularly versus occasionally visited the dump. Average Minimum Convex Polygon (MCP) summer and fall home ranges for the collared raccoons were 78.4 ha (SD=46.2 ha) and 45.6 ha (SD=29.7 ha), respectively (Table 1). Average MCP summer/fall home range overlap was 31.2 ha (SD=17.2). Average grid cell summer and fall home ranges for the collared Raccoons were 143.3 ha (SD=40.0 ha) and 116.9 ha (SD=24.9 ha), respectively (Table 1). Average grid cell home range overlap between summer and fall was 95.8 ha (SD=27.5). Summer ranges of the Raccoons were significantly larger than fall ranges using both the MCP method (P=0.05) and the grid cell method (P=0.073).

The most widely ranging Raccoon (a male yearling) in the study was originally trapped at the dump on 27 June. It was later located by telemetry near a farmhouse 4 km northeast of the dump on 16 July. By 18 July, it was visually identified at the dump site again where it remained until 8 August. The only other yearling of the dump Raccoons wandered a maximum of 769 m from the dump during the summer. The average distance of the farthest fix from the dump during the summer for the yearling Raccoons was 2608 m (SD=1964, n=3) and for the adults (≥ 2 yr), 1239 m

TABLE 1. Summer (June to August) and fall (September to October) home ranges of 13 Raccoons which fed at a rural Ontario garbage dump and at a compost heap in 1995[1].

Method	Number of fixes (summer) mean (SD)[2]	Summer range (ha) mean (SD)	Number of fixes (fall) mean (SD)	Fall range (ha) mean (SD)	Area of overlap of ranges mean (SD)
MCP	52 (11.2)	78.4 (46.2)	34.1 (9.6)	45.6 (29.7)	31.2 (17.2)
Grid Cell	44 (6.7)	143.3 (40.0)	33 (9.2)	116.9 (24.9)	95.8 (27.5)

[1] n=13 raccoons {7 males – 6 adults and 1 yearling; 6 females – 5 adults (all lactating) and 1 yearling}
[2] SD=Standard Deviation

TABLE 2. Home range, movements and density of Raccoons in different areas of North America

Location	Habitat	Home Range (km²)	Movements (km)	Density (/km²)	Reference
Ontario	rural	0.5-4.0	4-45	4-11	Rosatte and MacInnes 1989 Rosatte 2000; Rosatte et al. 2001
North Dakota	rural	0.2-49	1-24	0.5-1	Fritzell 1978; Greenwood 1982
Minnesota	rural	7-12	>3	2-6	Schnell 1970; Mech et al. 1968
Wisconsin					Dorney 1954; Schneider et al. 1971
Toronto	urban	0.4	<1	7-85	Rosatte et al. 1991; Rosatte 2000
Ohio	urban	<0.2	0.4-0.5	45-100	Cauley 1970; Schinner 1969 Hoffmann and Gottschang 1977

(SD=547, n=10) (P=0.31). The Petersen estimate of the number of Raccoons using the dump was 19, with upper and lower 95% confidence limits of 35 and 12 respectively. Crude density was estimated at 1 Raccoon/12 ha.

Discussion

Home ranges of Raccoons in North America are variable (Table 2) but tend to average around 100 to 300 ha (1-3 km²) (Kauffmann 1982), but may range from 18 to 2560 ha (0.18-25.6 km²) for adult males in North Dakota, or 5.1 to 372 ha (0.05-3.72 km²) for adult females (Stuewer 1943; Hoffmann and Gottschang 1977; Fritzell 1978). Urban Raccoons tend to have smaller home ranges than rural Raccoons (Rosatte et al. 1991) (Table 2). Range size may also vary with season, data collection methods and method of home range estimation (Harris et al. 1990). Distribution and abundance of food also affect home range size (Hoffmann and Gottschang 1977). Small home ranges are associated with high population densities and abundant food (Hoffmann and Gottschang 1977). Fall home ranges of Raccoons in this study were found to be significantly smaller than ranges during the summer. This was expected as, during the fall, in northern areas such as Ontario, Raccoon movement is thought to decrease to conserve energy in preparation for the winter denning period (Rosatte 2000). Large movements by Raccoons during the fall, when food sources are not as abundant, would likely result in a net energy loss thereby decreasing the condition of the animal

and decreasing the probability of surviving a harsh winter. Movements of Raccoons in this study were smaller than noted in other rural Ontario studies and in other North American jurisdictions (Rosatte 2000; Table 2). That may have been due to the concentrated food sources in the vicinity of the dump in this study. Raccoons have been known to change their movements and home ranges to include new concentrated sources of food; Seidensticker et al. (1988) discovered that within 27 days, 21 of 23 collared Raccoons living in the area had visited their artificial feeding station at least once. The feeding site in their rural study area was 0.5 ha in diameter and attracted Raccoons from a 127 ha area.

Home ranges of male Raccoons tend to be larger than those of females (Stuewer 1943; Fritzell 1978). The explanation as to why no difference was found in this study may have been because either there was no difference (due to abundant food sources at the dump), or the small sample size prevented the difference from being detected. Lack of a difference between home ranges of regular and occasional dump visitors in this study may have been the result of either a true lack of difference or the small sample size involved. It may also be that the definition for "occasional" was not adequate for comparative purposes.

The coarseness of the grid used for grid cell home range analysis in this study may have led to an overestimate of home range sizes based on the fixes obtained in this study (White and Garrott 1990) and would explain why the grid home range estimates were

larger than the MCP estimates. The advantage of the grid cell method over the MCP method is that the grid method takes into account the precision of the telemetry system (White and Garrott 1990). Raccoons in Hoffmann and Gottschang's (1977) study in suburban Ohio with a Raccoon density of 1/1.46 ha had average home ranges of 5.1 ha. Fritzell's (1978) study with a very low density of Raccoons in the spring and summer averaged 2560 ha. Home ranges of Raccoons in previous Ontario studies densities of 4 – 94/km², varied between 50 and 400 ha (Rosatte 2000; Broadfoot et al. 2001). Raccoons in our study fell between these two extremes, though their home ranges appeared to be smaller than average. However, home range estimates obtained from our study data are probably underestimates of actual home ranges because the study animals were monitored discontinuously over only two seasons. In a Niagara-St. Lawrence trap-recapture study, annual movements of Raccoons averaged 10 km and ranged up to 150 km. In a similar Barrie, Ontario, study, nightly movements of 4 km were common (Rosatte 1996*; 2000). Unless Raccoons are tracked continuously with an accurate system for a long period of time (e.g., 1 yr), their movements and home ranges will probably be underestimated.

Radio-telemetry indicated that one yearling male Raccoon occupied two distinct and widely separated areas during the summer of 1995. The fact that no points were located between these two ranges may have been because he traversed the distance between the two areas in the time between tracking nights. The distance between the two discrete areas was 4 km. Raccoons have been known to travel this distance in a single night (Rosatte 1996*). In addition, the main dispersal period for yearling males in some areas is May to June (Fritzell 1978) and this might have inclined this Raccoon to make such a movement if he were dispersing. A second explanation for the yearling male Raccoons' summer home range pattern is that it may have been aided by a vehicle. Raccoons have been known to ride on such vehicles as boats, transport trucks and rail cars (Rosatte et al. 2001).

One yearling female Raccoon did not travel as far from the dump as the yearling male noted above, indicating that it may have been a post-disperser, having immigrated to the dump area the previous fall. Two out of three of the yearlings in this study were found in excess of 2 km from their initial capture site within the same season of their capture; this indicates that the potential for rabies spread in an unvaccinated population using a common feeding site is probably exacerbated by dispersal of the yearlings from the site during the summer. This has been confirmed by Rosatte (unpublished data) in a Raccoon rabies epizootic area in eastern Ontario. As with the home ranges, mentioned above, these movements are probably minimum estimates of actual distances travelled by the dump Raccoons.

Although caution should be exercised in using data from healthy animals to predict the behavior of rabid ones, telemetry studies on two other species indicated that movements of rabid animals are not very different from the movements of healthy ones (Storm and Verts 1966; Artois and Aubert 1985). Storm and Verts (1966) determined that the movements of a radio-tracked rabid Striped Skunk (*Mephitis mephitis*) in its last weeks of life were not statistically different from the movements of non-rabid skunks. Also, a radio-telemetry study by Artois and Aubert (1985) on three wild foxes inoculated with rabies indicated that these animals occupied a comparable home range before and during the phase at which the virus would have been shed. Rosatte (unpublished) found that during a trap-vaccinate-release study in eastern Ontario, movements of rabid Raccoons were not different from movements of non-rabid Raccoons. If the same rules hold true for Raccoons as they do for skunks or foxes, then rabid Raccoons are likely to encounter the same conspecifics as they would while they were healthy. This indicates that data obtained from this study have direct relevance to potential movements of Raccoons in the study population should they become infected with rabies. That is, dispersing yearling Raccoons using the common feeding site would probably be the main vectors spreading the disease into areas beyond the population.

Contact rates for Red Foxes (*Vulpes vulpes*) used in rabies simulation models are estimates of potential contact rates drawn from analysis of home range overlap obtained from radio telemetry data (Blancou et al. 1991). The low precision of the telemetry system used in this study prevented analysis of home range overlap, spatial relationships and potential contact rates. It was not possible to tell, with the coarseness of the grid used for grid cell home range analysis, the potential for Raccoons with overlapping ranges to contact each other. Two Raccoons could be within the same 23-ha grid cell area at the same time and yet be unaware of each other.

Data from this study indicated extensive overlap of home ranges within the population. Territoriality does not normally occur in Raccoons (Kauffmann 1982; Seidensticker et al. 1988) and has only been found for adult males in the spring and summer in North Dakota, at the northern edge of the Raccoons' range and is thought to be due to competition for access to females (Fritzell 1978). Studies from more southern latitudes failed to demonstrate territoriality in Raccoons (Stuewer 1943; Johnson 1970).

Although caution should be used in comparing densities between studies, especially if different methodologies, seasons, and habitats are involved, population densities for Raccoons are usually around one Raccoon per 8-10 ha (Kauffmann 1982) but may range from one Raccoon per 100 ha in North Dakota and northern Ontario (Fritzell 1978; Rosatte 1996*) to one

Raccoon per 0.4 ha in more favourable habitat (Twichell and Dill 1949). In southern Ontario, Raccoon density averaged over 200 plots sampled was one Raccoon/9-33 ha (Rosatte, unpublished) though densities of up to one Raccoon/1.8 ha have been recorded in forested park areas of Scarborough, Ontario (Rosatte et al. 1991). Density for our study area falls within the high end of the average range for Raccoon density in southern Ontario. It should also be noted that in our study, trapping for population estimates occurred at the end of summer when the local population expanded because the young-of-the-year were entering the population.

Causes of mortality for Raccoons include starvation, heavy parasitism, poison, dogs, automobiles, hunting, trapping, canine distemper, and of course, rabies (Mech et al. 1968; Rosatte and MacInnes 1989; Riley et al. 1998; Rosatte et al. 1991; Rosatte 2000); however, the hunting season in this area was from 15 October to 31 December (OMNR 1996*), after Raccoon density was estimated in this study. Thus, trapping and hunting mortalities for the fall had yet to occur. Also, a considerable number of the dump Raccoons were trapped early in the study and vaccinated against rabies and distemper; therefore, the major source of mortality in this population at the time of the study was probably due to collisions with automobiles. Apart from roadway mortality, the death rate of juveniles in this population was probably very low until winter food shortages set in. For this reason, the density estimated for our population probably represents a peak annual value.

Management Implications

Raccoon home range and movement data were used to estimate areas that need to be treated to control Raccoon rabies in Ontario (Rosatte et al. 2001). Intimate knowledge of Raccoon behavior provides benchmarks to consider when determining the width of the population reduction and vaccination zones in order to prevent the spread of Raccoon rabies (Raccoon Rabies Task Force 1992*). These data are also being used to develop a Raccoon rabies model for Ontario which will be capable of predicting the movement of Raccoon rabies over time in the absence or presence of rabies control strategies.

Acknowledgments

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