The Ecology of Red Foxes, *Vulpes vulpes,* in Metropolitan Toronto, Ontario: Disease Management Implications

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During 1989–1992, 33 Red Foxes (*Vulpes vulpes*) were fitted with radio-collars in metropolitan Toronto to study their behaviour which would provide data to assist with the design of a rabies control strategy for urban areas of Ontario. Annual home range size for adult foxes ($\bar{x}$ = 325 ha, SD = 207) was significantly larger than that of juvenile foxes ($\bar{x}$ = 165 ha, SD = 176), but we could not detect any seasonal differences in home range size for foxes. Mean (SD) nightly ranges were 38.3 ha (48.3) in spring, 97.4 ha (115.4) in summer, 26.8 ha (28.5) in fall, and 16.3 ha (13.6) in winter. Movements by foxes during the period from June to November averaged 3.5 km (2.89). Eleven of the foxes were known to have dispersed (≥ 3 km from their home range), but we could not detect a mean direction of dispersal. Thirty-six percent (4/11) of the foxes dispersed in December and 18% (2/11) dispersed in August, with the remainder dispersing between February and November. Average dispersal distance was 19.3 km (15.6), and a significant negative correlation was detected between initial home range size and dispersal distance of foxes. Mortality of radio-collared foxes was caused by collisions with automobiles, predation, and shooting. Foxes made extensive use of ravines and other greenbelt areas, such as parks and golf courses. Residential areas were also used by some foxes. Knowledge of the habitats frequented by foxes as well as their movement potential assisted researchers in determining where vaccine baits should be placed for the control of rabies in Red Foxes in metropolitan Toronto.

Key Words: Red Fox, *Vulpes vulpes,* home range, movements, metropolitan Toronto, Ontario.

Rabies was prevalent in Red Foxes (*Vulpes vulpes*) in rural habitats of Ontario (Voigt 1987) as well as in some urban complexes such as metropolitan Toronto, Ontario, during the 1960s through the 1980s (Rosatte et al. 1992). During the 1970s, Voigt (1987) used radio-telemetry to study the ecology of Red Foxes in southern Ontario. That ecological data assisted researchers in developing an aerial vaccine-baiting system for the control of rabies in rural habitats of the province (MacInnes et al. 2001). This control program, which used Twin Otter aircraft to distribute vaccine baits over large contiguous areas, was not feasible for urban landscapes with high human population levels and very fragmented fox habitat. A radio-telemetry study of urban fox ecology was initiated in metropolitan Toronto in 1989 to provide data to help design a rabies control strategy for urban foxes.

Study Area

The study area consisted of a 1000 km^2 urban complex known as metropolitan Toronto, Ontario, Canada, centred at 43°42'N, 79°26'W [see Rosatte et al. (1992) for a map of the study area]. At the time of the study, this urban complex consisted of the cities of North York, Etobicoke, Scarborough, Toronto, and York and the borough of East York. The study area also included the city of Mississauga. The human population at the time (circa 1989) was estimated at approximately 2.5 million (about 4200 people/km^2) and the landscape was composed of multiple land-use classes, including residential, industrial, commercial, and greenbelt areas [see Rosatte (1986) and Rosatte et al. (1992) for complete description and habitat maps]. The urban complex was intersected with a number of ravine systems associated with waterways, including the Credit River, the Humber River, Etobicoke Creek, the Don River, Highland Creek, and the Rouge River [see Rosatte et al. (1992) for a map of river systems].

Methods

During 1989–1990, a total of 33 Red Foxes were live-captured from 13 different areas in metropolitan Toronto using humane Novak foot snares and Tomahawk #108 double door cage traps (Tomahawk, Wisconsin). Traps were placed in habitats wherever fox sign (e.g., tracks, scat) was evident. The procedure following capture included chemical immobilization using a mixture of ketamine hydrochloride and acepromazine and vaccination with an intramuscular injection (1 mL) of Imrab inactivated rabies vaccine (Merial Inc., Athens, Georgia). The fox was fitted with a VHF radio-collar (148–152 MHz, Lotek, Newmarket, Ontario) and released at the point of capture. Animals were located on the ground as well as from Cessna aircraft with Lotek SRX 400 receivers and Yagi antennae during the period 1989 to 1992. Locations of foxes were calculated by the intersection of two or three compass bearings (triangulation) from the observer to the fox location and were plotted on topographical maps. Foxes were located during the day as well as at night.

Home ranges using a kernel estimator were calculated using Ranges IV and V software. An estimate is provided for annual and seasonal ranges of foxes using the total number of fixes. A minimum of 25 fixes were required for annual home range analysis (using area-observation curves), and at least three months of tracking data were required for seasonal range calculations. Dispersal fixes were not included in home range calculations and were defined as a movement of ≥ 3 km from the home range; this distance was considered a significant movement, given the small home ranges reported for urban foxes in previous studies (Trewhella et al. 1988).

Home ranges were determined for the following seasons: spring (March–May), summer (June–August), fall (September–November), and winter (December–February). Foxes were tracked continuously during the evenings during each month to obtain an estimate of nightly range. The number of continuous tracking locations varied, from one location every 20 minutes to one location every 2 hours. Timing of dispersal of foxes was also determined in order to provide data on family unit separation.

This study occurred during a three-year period from July 1989 to July 1992. Adkins and Stott (1998) documented some of the movements of seven of these foxes over a three-month period during the summer/fall of 1990 as part of a graduate student program at Queen's University, Kingston, Ontario. Those data are included in our study.

Data were analyzed using Statistica 6.0 software. A repeated measures ANOVA was used to determine whether there were age (adults vs. juveniles) and sex (males vs. females) differences in home range. A Student's t-statistic was used to examine the data for sex and age differences in dispersal distances and nightly movements of foxes during spring and fall. Rayleigh's Test of Uniformity was applied to the movement data to determine whether the circular distribution of dispersal angles was uniform (Zar 1999).

Results

Annual/seasonal home ranges: A total of 3788 location fixes were acquired on 33 radio-collared foxes during 1989–1992. Four of the foxes were excluded from the analyses of annual home ranges because there were too few fixes (< 25 fixes because the transmitter malfunctioned, the animal died, or the signal could not be located). A juvenile male fox (T9017) that dispersed twice and did not settle down (resulting in an annual range > 182 km^2) was also excluded from the range analysis.

The mean number of location fixes for annual home range analysis for the 29 foxes was 129.3 (SD = 117.6). Annual home range size (using day and night fixes) for adult foxes ($\bar{x}$ = 325 ha, SD = 207; range 114–718 ha) was significantly larger than that of juvenile foxes ($\bar{x}$ = 165 ha, SD = 176; range 21–541 ha) (P = 0.02) (Table 1) during the study. However, no differences were found between annual home ranges of males and females (P = 0.89), adult males and adult females (P = 0.59), or juvenile males and juvenile females (P = 0.23) (Table 1). We could not detect any differences in seasonal home ranges of foxes (P > 0.05) (Table 1).

A juvenile male fox (T9017) was collared and released in Warden Woods Park, Scarborough, on 3 August 1990. It spent the fall and winter in a confined area, then dispersed (> 4 km from its home range) in March and April 1991. He then settled down in one area for the summer of 1990. Overall, the annual [18 285 ha (182.9 km^2)], spring [13 984 ha (140 km^2)], and summer [1677 ha (17 km^2)] ranges were exceptional; however, the fall range was more comparable to an urban fox [18.1 ha (0.18 km^2)].

Nightly ranges: Twenty-two foxes were monitored between 1 and 19 nights (4 to 8 hours/night) (1989 and 1990) when they were active (total of 54 nights for all foxes). Mean (SD) nightly ranges were 38.3 ha (48.3) in spring (n = 7 nights); 97.4 ha (115.4) in summer (n = 11 nights); 26.8 ha (28.5) in fall (n = 35 nights); and 16.3 ha (13.6) in winter (n = 4 nights). Summer ranges were significantly larger than fall ranges (P = 0.001).

Nightly movements: Nightly movements during June to November, 1989 and 1990, for 21 of the above noted foxes [an adult female (T8905) with kits was excluded from these calculations] averaged 3.5 km (SD = 2.89, range 0.3–11.1 km; n = 35 nights). No significant differences (P = 0.09) were detected between nightly movements in the summer ($\bar{x}$ = 4.7 km, SD = 3.1; range 0.9–11.1 km) vs. the fall ($\bar{x}$ = 2.9 km, SD = 2.7; range 0.3–9.9 km). Sample size was too small to compare nightly movements during winter and spring. One of the foxes, an adult female with kits (T8905), was monitored for 19 nights (1800 to 0600) between 21 March and 13 December 1990. Nightly movements ranged from 0.3 km to 5.4 km (Figure 1). However, mean nightly movement ($\bar{x}$ = 2.3 km, SD = 1.6; range 0.3–5.4 km) during the parturition/kit rearing months (March and April) was significantly greater than mean movements from September to December 1990 ($\bar{x}$ = 0.85 km, SD = 0.47; range 0.1–1.4 km) (P = 0.011) (Figure 1). When she was monitored for a week during late March 1990, T8905 used a different part of her range during each evening.

Dispersal: Data were collected on 32 foxes with sufficient information to determine that 25 of those either dispersed (≥ 3 km from their home range) or did not (it is possible that the other 7 that could not be located dispersed). Eleven of the 25 (44%) dispersed from the area in which they were radio-collared. Average dispersal (SD) distance for those was 19.3 km (15.6) (range 5–48 km) (Figure 2). There were no age or sex

TABLE 1. Mean (SD) annual and seasonal home ranges (ha) for Red Foxes in metropolitan Toronto during 1989 to 1992.[1]

	Adult female $n = 5$	Adult male $n = 5$	Juvenile female $n = 12$	Juvenile male $n = 6$	Adults $n = 10$	Juveniles $n = 18$	Females $n = 17$	Males $n = 11$
Annual	358.1 (243.9)	291.4 (183.5)	201.5 (192.2)	93.1 (118.4)	324.8[2] (206.5)	165.4 (175.5)	247.6 (213.8)	183.2 (176.6)
Spring	39.0 (20.8)	111.0 (142.7)	140.0 (182.9)	575.0 (773.0)	75.0 (101.9)	284.8 (435.8)	89.5 (132.1)	265.5 (434.7)
Summer	110.7 (149.6)	90.0 (80.8)	63.1 (84.2)	6.8 (8.9)	102.1 (121.2)	46.5 (74.8)	80.6 (111.1)	48.4 (69.7)
Fall	242.3 (222.6)	136.4 (88.3)	94.6 (81.1)	41.4 (29.0)	194.2 (175.9)	75.0 (70.7)	143.8 (154.8)	81.0 (75.4)
Winter	91.8 (43.2)	168.8 (158.9)	152.8 (142.0)	334.7 (371.3)	126.0 (109.8)	213.4 (235.3)	125.1 (108.8)	239.9 (257.8)

[1]SD = standard deviation; n = sample size; Spring = March–May; Summer = June–August; Fall = September–November; Winter = December–February. The total number of fixes for annual home range analysis was 3788, with the mean number of fixes/fox being 129.3 (SD = 117.6)
[2]Adult ranges > juvenile ranges ($P = 0.02$).

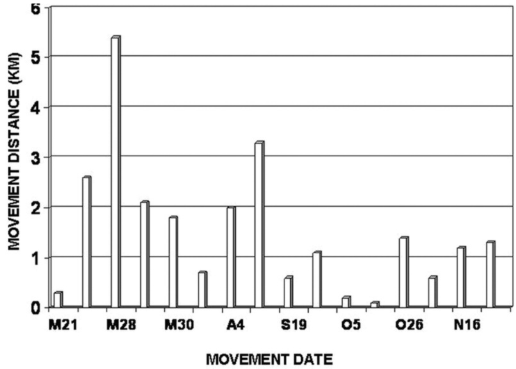

FIGURE 1. Nightly (1800 to 0600) movements (km) during March to December 1990 of an adult female Red Fox (that had a litter). M = March, A = April, S = September, O = October, N = November; monitoring nights included March 21, 22, 28, 29, and 30; April 3, 4, and 26; September 19; October 3, 5, 18, and 26; November 12 and 16; and December 13, 1990.

differences detected with respect to the dispersal distances traversed by foxes (juveniles and adults, 17.2 km and 21.8 km, respectively, $P = 0.648$) (males and females, 20.2 km and 18.2 km, respectively, $P = 0.847$). However, a significant negative correlation was detected between home range size and dispersal distance of foxes ($y = 866.4 - 23.91x$; $r = -0.70$; $P = 0.0348$) (Figure 3). Thirty-six percent (4/11) of the foxes dispersed in December and 18% (2/11) dispersed in August. Dispersal of foxes also occurred in February, March, June, July, September, and November. The dispersing foxes consisted of 4 juvenile males, 3 adult females, 2 juvenile females, and 2 adult males. The bearing angles of the dispersing foxes varied from 10 to 300 degrees, and we could not detect a mean direction of dispersal, i.e., the circular distribution was uniform ($z = 1.23$, $0.5 < P < 0.2$) (Figure 2).

Habitat utilization: Detailed habitat utilization analyses were not possible because fox locations were determined by triangulation; however, inferences on habitat use could be drawn where locations were in large tracts of habitat, such as ravines, woodlots, residential areas, and golf courses. Foxes generally remained within the greenbelt area (e.g., golf course, ravine system, forested park) where they had been captured until they dispersed. Dispersal occurred across many habitat types, including residential, commercial, industrial, and green areas. Foxes also crossed and/or travelled along major highways and city streets as well as railway lines and hydroelectric corridors to get to adjacent greenbelt areas. Half of the foxes (14 of 28 foxes for which we had sufficient data for home range analyses) used golf courses extensively but often traversed the ravine systems and visited residential areas. At least eight of the foxes used residential areas extensively, based on triangulation calculations. Generally, fox use of greenbelt areas was extensive, with other habitat classes (e.g., residential) being used opportunistically.

Mortality: Eleven of the 33 radio-collared foxes were confirmed to have died during the study period. Nine foxes were listed as missing, collars were removed from 5, and 8 foxes still had functioning collars at the end of the study. Of the 11 known mortalities, the cause of death was known for 6 of those: 3 were killed by collisions with vehicles, 2 were killed by predators (Coyote, *Canis latrans*, and/or dog), and one was shot.

Parturition/Litters: During this study, fox kits were observed on 19 March 1990 at the Toronto Golf Course running and playing about the entrance of the maternity den. The kits appeared to be about three weeks of age, so breeding probably occurred during mid-January and parturition likely occurred in late February or early March. Another vixen, radio-collared as a juvenile in 1990, had six kits as a yearling. She was observed on 4 April 1991 with the kits, which appeared to be about six to eight weeks of age, so parturition must have occurred during late February and breeding in early to mid-January.

Five of the foxes were known to have litters during the study period (as evidenced by observations at the den site when the kits were one to two months of age). The number of kits observed at the den sites were 2, 2, 4, 5, and 6 (this does not confirm litter size). Of the five foxes with litters, three were juveniles when they were radio-collared. Two of those had litters when they were two years old and one when it was a yearling.

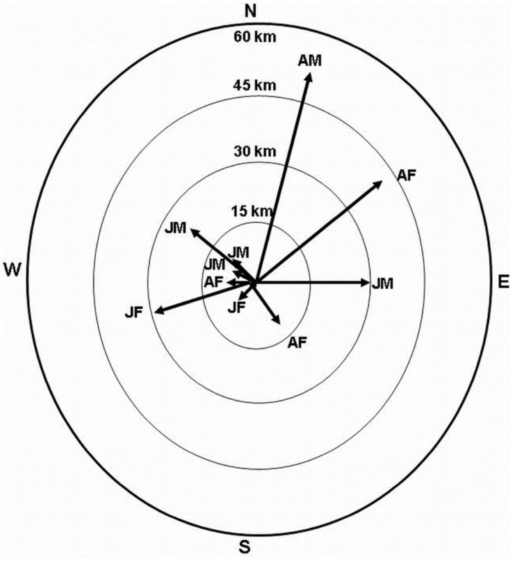

FIGURE 2. Dispersal direction and distance of Red Foxes in metropolitan Toronto, Ontario, during 1989–1992. AM = adult male; AF = adult female; JM = juvenile male; JF = juvenile female.

Discussion

Red Fox social structure is based on a family unit. In Ontario, the family generally consists of an adult male and vixen and the kits; however, sometimes several related females may belong to the family unit (Voigt 1987). According to Voigt (1987), mating by Red Foxes in Ontario occurs during late January or early February. With an average gestation period of 51–53 days, foxes usually give birth in early March in rural areas of the province (Voigt 1987). In our Toronto study, we observed kits outside the maternity den during March and April, so breeding must have occurred in early to mid-January and parturition during late February to early March.

Litter sizes in rural Ontario were as high as 8.0, as reported by Voigt and Macdonald (1984), based on placenta scar counts. The greatest number of kits we observed in Toronto was six; however, prenatal mortality may have accounted for the difference between litter sizes in urban and rural foxes in Ontario. In rural Ontario, it is estimated that 80–90% of yearling vixens and 95% of older vixens produce litters (Voigt and Macdonald 1984). We also observed litters in yearling and two-year-old vixens in Toronto but did not have data on the proportion having litters. It is acknowledged that any differences in the percentage of foxes breeding, age at breeding, and litter sizes between foxes in urban and rural areas of Ontario is most likely related to food abundance, the density of foxes, and mortality rates (Voigt 1987).

Most mortality of foxes in rural Ontario habitats is the result of collisions with vehicles, trapping, shooting, and diseases such as rabies (Voigt 1987). Twenty-five percent of juvenile fox mortality during one telemetry study in rural Ontario was the result of road kills, with 60% from hunting and trapping (Voigt 1987). Similarly, in our study in urban Toronto, mortality was due to collisions with vehicles and predation, but shooting also accounted for one mortality. As our foxes were vaccinated against rabies, we could not evaluate mortality due to that disease; however, historically, it has been significant in Toronto, as noted in Rosatte et al. (2007).

Red Foxes exist in Ontario by consuming a variety of prey, including species of lagomorphs, birds, mice, and voles. In rural Ontario, as much as 50% of the diet of foxes may be Meadow Voles (*Microtus pennsylvanicus*) (Voigt 1987). Although we did not obtain any quantitative food habit data in our study in Toronto, we did observe foxes preying on small rodents, Woodchucks (*Marmota monax*), and domestic cats, as well as scavenging on garbage. In addition, remains of a variety of animals were found around the kit-rearing dens, including various bird species, rabbits (Leporidae), Raccoons (*Procyon lotor*), and squirrels (*Sciurus* sp.). An omnivorous foraging strategy obviously contributes to the success of foxes living in urban environments such as metropolitan Toronto.

Home range and movement by Red Foxes is habitat dependent. In urban areas of Great Britain, where fox use of residential areas was extensive, ranges as small as 10 ha were noted (Harris 1977; Voigt and Macdonald 1984). In one Toronto study, Adkins and Stott (1998) reported mean ranges of 52 ha for Red Foxes. However, that study involved tracking foxes for only a few months. We found that when foxes in Toronto were tracked for at least a year, home ranges were significantly larger than those reported by Adkins and Stott (1998). However, our seasonal ranges (fall) for some foxes were comparable to those of Adkins and Stott (1988).

In rural habitats of southern Ontario, home range of foxes averaged 900 ha and ranged between 500 and 2000 ha (Voigt and Tinline 1980). In our study in Toronto, adult and juvenile annual ranges averaged 325 ha and 165 ha, respectively, with nightly movements averaging 3.5 km during June to November. These figures are smaller than ranges for rural Ontario foxes but larger than the ranges reported for urban foxes in Great Britain (Voigt and Macdonald 1984). This may be related to the fact that foxes in Great Britain make extensive use of residential areas and there is little green space (Harris 1977; Harris and Rayner 1986), whereas urban foxes in Ontario live in urban environments but make use of greenbelts and ravine areas as well as golf courses which accommodate greater movement by foxes. In addition, foxes in Toronto move from one "green" patch to another by traversing residential and commercial areas. They use railway lines, ravine systems, and hydroelectric corridors for movement in metropolitan Toronto.

We also detected a negative correlation between fox home range size and dispersal distance. This is in contrast to other studies (Trewhella et al. 1988) where the larger the home range, the greater the dispersal distance. We have no explanation for this difference but the size and shape of ravine systems may have accommodated significant dispersals by Toronto foxes even though they had small home ranges. However, the ravine systems of Toronto are oriented in a north/south direction. One would expect that if ravine systems were used for dispersal, there would be a northward bias in dispersal, but we could not detect any directional bias in dispersal by Toronto foxes.

Foxes are fairly sedentary during the breeding and parturition periods in the late winter and spring. Family life normally focuses on the kit-rearing den until kits are old enough to venture away from the den on their own during the summer. As kits become independent, movements increase. Foxes in our study were fairly active during the evenings, with movements averaging 3.5 km (SD 2.9). Adkins and Stott (1998) also reported that foxes were active during the evenings in Toronto, with mean movements of 3.4 to 8.6 km. Most male kits and some female kits disperse from the parental range before they are one year of age (Voigt 1987).

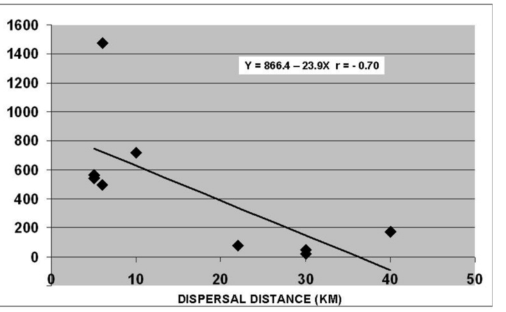

FIGURE 3. Negative correlation between dispersal distance and home range size of Red Foxes in metropolitan Toronto, Ontario.

Peak dispersal by foxes in rural southern Ontario habitats occurred during October and November but ranged from August to March (Voigt 1987). In our urban Toronto study, peak dispersal was in December but occurred in other months as well. This was expected as juvenile foxes leave their natal range.

Most male fox dispersals in rural Ontario were about 30 km but one fox traversed 122 km (Voigt 1987). Female dispersal was about 8 km and ranged from 1 to 50 km (Voigt 1987). During a rabies control program in Scarborough, Ontario (a suburb of metro Toronto), an adult female Red Fox was captured, ear-tagged, and released in 1994. That fox was captured 170 km to the east in 1996 (Rosatte 2002). In our Toronto study, dispersal averaged 19 km but we could detect no age or sex differences with respect to dispersal.

This is significantly greater than the dispersal distances reported by Harris and Trewhella (1988) for Bristol (mean in the 1 to 3 km range for juvenile foxes) as well as those reported by Robinson and Marks (2001) for foxes in Melbourne, Australia (3.5 km and 2.0 km for male and female foxes, respectively). This was no doubt due to habitat differences between Bristol and Toronto, in that foxes use high-density housing areas in Bristol (i.e., there is little green space available) while foxes in Toronto make extensive use of ravine systems and greenbelt areas, which may be long and narrow, making effective movement corridors.

Data acquired from this study were used to design an oral rabies vaccination tactic for metropolitan Toronto. Knowledge of the areas frequented by foxes as well as their potential movement assisted researchers in determining where vaccine baits should be placed, both by ground distribution and from fixed-wing aircraft and helicopters, and how widely spaced the baits should be. Between 1989 and 1991, about 55% to 80% of the foxes sampled had contacted rabies vaccine baits that had been distributed along the ravine systems of metropolitan Toronto (Rosatte et al. 1992, 2007). In fact, the program was so successful that rabies was eliminated from foxes in metropolitan Toronto in 1996 (Rosatte et al. 2007).

During the late 1980s and early 1990s, Red Foxes were doing extremely well in metropolitan Toronto. At that time, it is estimated that there were in excess of 1000 foxes in that urban complex (about 1 fox/km^2) (Rosatte unpublished data; Rosatte et al. 1991). Their success appeared to be a function of high reproductive potential, including large litter size and breeding by yearling vixens, and omnivorous food habits, as well as their dispersal potential and ability to survive in the presence of predators such as dogs and Coyotes as well as automobiles. The data from this study were used to design a rabies control tactic for metropolitan Toronto that proved to be very effective. However, as rabies has been controlled in Toronto, it remains to be seen whether other diseases and parasites, such as distemper, parvovirus, and mange, will play a greater role in limiting fox populations in that urban complex. However, one thing is certain—due to the dispersal capability of Toronto foxes (up to 48 km), they are capable of spreading infectious diseases and parasites significant distances, including from urban to rural habitats.

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