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Spatial Ecology of Urban Raccoons in Northeastern Ohio: Implications for Oral Rabies Vaccination

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ABSTRACT In 1977, rabies was detected in a raccoon (*Procyon lotor*) in West Virginia, and since the mid-1980s raccoon variant rabies has spread throughout the eastern United States and moved west as far as the eastern edge of Cleveland, Ohio. The primary tool to combat this spread is the distribution of oral rabies vaccine (ORV) baits. A thorough knowledge of raccoon space use is critical in determining bait placement, particularly in urban areas. We monitored nine raccoons in urban areas of Cleveland, Ohio, calculated home range sizes, monitored raccoon movement with respect to potential movement barriers, and used resource selection functions (RSF) to determine habitat selection within home ranges. Fixed kernel annual home range estimates were 19.2 ha (SE = 6.7). Home range estimates were 21.5 ha (SE = 7.2) and 18.2 ha (SE = 7.4) for summer and fall, respectively. No seasonal differences in home range estimates were observed ($F_{1,15} = 0.16$, $P = 0.696$). One raccoon crossed an interstate highway and another was located across the Cuyahoga River, suggesting highways and rivers are not impermeable to raccoon movements. Resource selection data indicate that ORV baiting in urban environments should be concentrated in habitat patches and trees adjacent to human-made structures and industrial sites to take advantage of raccoon behavior.

KEY WORDS Ohio, oral rabies vaccination, *Procyon lotor*, rabies, raccoon, urban environment

In 1977, rabies was detected in a raccoon (*Procyon lotor*) in West Virginia and by 1983 over 1,500 rabid raccoons had been reported throughout the mid-Atlantic region (Smith et al. 1984, Jenkins and Winkler 1987). Since the mid-1980s, raccoon rabies has spread throughout the eastern U.S., north into southern Canada, west into northeast Ohio, easternmost Tennessee, and southwest Alabama (Wandeler and Salsberg 1999, Blanton et al. 2010). In 1997, the United States Department of Agriculture, Animal and Plant Health Inspection Service, Wildlife Services began cooperative oral rabies vaccination (ORV) programs which have expanded to all key eastern states to curtail the spread of raccoon rabies (National Rabies Management Program 2011).

In Ohio, the first case of raccoon rabies was documented in 1997 (Ohio Department of Health 2010), sparking aggressive distribution of ORV baits along the Ohio-Pennsylvania border to prevent further westward spread (Nelson 2005). In 2004, a rabid raccoon was found approximately 10 km west of the ORV boundary in Lake County, northeastern Ohio (Russell et al. 2005, Slate et al. 2008). This incident represented a breach in the barrier established by ORV bait distribution in Western Pennsylvania (Blanton et al. 2007). In response to this event, the ORV boundary was extended west toward the city of Cleveland, Ohio.

One challenge faced by large scale ORV distribution in urban landscapes such as Cleveland is deciding where to place baits. A more thorough understanding of raccoon space use in urban environments can be an important factor in determining where baiting should occur. Considerable research has been performed on raccoons in a variety of environments (Smith and Engeman 2002, Prange et al. 2003, 2004, Beasley et al. 2006, 2007), although few have examined space use at fine spatial scales (e.g., third-order selection) in an urban environment (Bozek et al. 2007). In urban areas, raccoons typically restrict their movements to patches of vegetated or forested habitat and tend to avoid commercial or industrial areas (Rosatte et al. 1991). Because northeastern Ohio represents a leading edge in the raccoon rabies epizootic, an examination of space use by raccoons in the urban landscapes that dominate portions of the state was warranted. Therefore, our objectives were to 1) estimate raccoon home range sizes in urban areas in northeastern Ohio, 2) evaluate the extent to which raccoons cross highways or other potential physical barriers, and 3) evaluate habitat selection by raccoons in urban areas within individual home ranges.

STUDY AREA

We conducted our study from May 2009 to March 2010 in urban areas of downtown Cleveland (Cuyahoga County), Ohio (Fig. 1). The city of Cleveland is located along the southern shore of Lake Erie, approximately 100 km west of the Pennsylvania border. Cleveland represented an urbanized landscape composed primarily of urban housing, commercial businesses, and industrial sites and had a population of approximately 400,000 residents (United States Census Bureau 2011).

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Figure 1. Representative urban study sites (with raccoon [*Procyon lotor*] locations), Cleveland, Ohio, USA, May 2009 to March 2010.

METHODS

Capture and Handling

From May to July 2009, we live captured raccoons in cage traps (Tomahawk Live Trap Co., Tomahawk, WI, USA) at six urban locations and chemically immobilized them with a 5:1 mixture of ketamine:xylazine (Kreeger 2002). Capture locations ranged from approximately 1.5–12.0 km apart and no more than two raccoons were collared at a given location. We fitted raccoons with remote-download global positioning system (GPS) collars (Model 7000SLU, Lotek Wireless, Inc., Ontario, Canada). Each GPS collar was programmed to take a single nightly location at 2300 hours. A single location was selected to conserve battery life and obtain locations throughout a full twelve months to document potential seasonal home range differences. A nightly location was chosen because raccoons are nocturnal, feed during night time hours, and typically spend daylight hours at den sites (Gehrt 2003). We remotely downloaded locations every six weeks using a three-element UHF antenna from June 2009 to March 2010. Our capture and handling of raccoons was performed in accordance with the National Wildlife Research Center's Animal Care and Use Committee (protocol QA 1375).

Home Range Estimates

We used only collars that recorded >30 locations for annual and seasonal home range estimates (Seaman et al. 1999). Seasonal home ranges were calculated for summer (Jun–Aug) and fall (Sep–Nov). We calculated 50% fixed kernel core areas and 95% fixed kernel home ranges in ArcView v 3.3 (Environmental Systems Research Institute, Redlands, CA, USA; Seaman et al. 1999) using the Animal Movement extension (Hooge and Eichenlaub 2000) and least-squares cross-validation (Silverman 1986). We imported shapefiles into ArcMap v9.3 (Environmental Systems Research Institute). We compared seasonal home range estimates using the MIXED procedure in SAS (SAS Institute 2010) with statistical significance given at $P < 0.05$.

Habitat Classification

To assign habitat information to raccoon locations we overlaid a 20 × 20 m grid on top of the raccoon locations and habitat data from orthographic satellite images (United States Department of Agriculture NRCS National Cartography and Geospatial Center 2010). We selected a 20 × 20 m grid because it provided comparable resolution to available land-cover datasets for developed landscapes. We assigned individual raccoon locations to one of four categories:

1) Habitat patch: cells of vegetated habitat not containing structures
2) Residential trees: grid cell with a structure(s), but <50% of the cell was occupied by the structure(s) and ≥50% of the cell occupied by trees
3) Structure: grid cell with ≥50% of the cell occupied by housing units, warehouses, barns, etc.

4) Transitional: sites associated with quarries, railroad tracks, roads, recreational fields, parking lots, waterway/water edge (e.g., locations within 10 m of a river, pond or other body of water)

We used the 100% minimum convex polygon (MCP) to estimate the available habitat for each raccoon. The 100% MCP was chosen because it includes the total area used by each animal and is not limited to the area used during normal movements (White and Garrott 1990). Thus, MCP represents a reasonable estimate of the available habitat. We generated the same number of random locations within the MCP as the number of locations recorded for each animal. We classified cells occupied by recorded locations as "used" and those containing randomly generated points as "available."

We estimated accuracy of the GPS collars by setting each GPS collar to record multiple locations and calculate the mean location. We then calculated the Euclidean distance between the mean GPS collar location to the location of each collar as recorded by a handheld GPS. Also, we reported the mean dilution of precision for each GPS collar.

Resource Selection

We estimated a population-level resource selection function (RSF) using a mixed-effects logistic regression model with habitat type, sex and age as covariates. Our primary interest was the influence of habitat type, but we included sex and age to account for potential additional sources of variation. For RSF analysis, we used the lmer function (family = binomial) from the lme4 package in Program R (R Core Team 2012). We examined a correlation matrix for all covariates before modeling to screen for collinearity. Using logistic regression with use–availability data presents some problems because predicted values are not scaled between 0 and 1 and generally do not reflect true probabilities of resource selection (Manly et al. 2002, Keating and Cherry 2004), but logistic regression can provide an informative and unbiased method for ranking habitat use and for comparing relative probability of use (Keating and Cherry 2004, Johnson et al. 2006). We used individual raccoon as a random-intercept effect in our mixed-effects logistic regression analysis to address issues associated with autocorrelation and uneven sample sizes between individuals (Gillies et al. 2006). We ranked models using Akaike's Information Criterion for model selection (Burnham and Anderson 2002).

RESULTS

We obtained 1,501 locations ($\bar{x}$ = 167, range 98–249) from nine GPS-collared raccoons (four males, five females; two were yearlings, seven were adults) captured at six sites. Mean GPS fix rate success was 83%. Battery life was shorter than expected and ranged from four to nine months. Mean location error was estimated at 7.5 m (SE = 0.9). Mean dilution of precision was 4.7 m (SE = 0.1).

Mean fixed kernel home range estimates were 19.2 ha (SE = 6.7, range 0.8–63.1) and 2.8 ha (SE = 1.1, range 0.1–7.0) for 95% and 50% core areas, respectively (Table 1). Sufficient locations were obtained to calculate nine summer home ranges and eight fall home ranges. Mean summer fixed kernel home ranges were 21.5 ha (SE = 7.2, range 64.5–0.8) and 3.5 ha (SE = 2.0, range 10.1–0.1) for 95% and 50% core areas, respectively. Mean fall fixed kernel home ranges were 18.2 ha (SE = 7.4, range 64.7–0.5) and 2.8 ha (SE = 1.3, range 10.8–0.04) for 95% and 50% core areas, respectively. We were unable to detect seasonal difference between summer and fall 95% ($F_{1,15}$ = 0.16, P = 0.696) or 50% ($F_{1,15}$ = 0.19, P = 0.668) fixed kernel home range estimates. Mean Euclidean distance between consecutive nightly locations was 190.8 m (range 0.5–1,369).

Table 1. Number of locations and fixed-kernel estimates of 95% and 50% home ranges for urban raccoons in Cleveland, Ohio, USA, May 2009 to March 2010.

			Fixed kernel home range size (ha)	
Gender	Age	Number of Locations	95% home range	50% core area
Male	Yearling	141	63.1	0.2
Male	Yearling	228	22.8	1.5
Female	Adult	98	2.8	0.2
Male	Yearling	173	28.6	7.0
Male	Yearling	171	5.0	0.8
Female	Yearling	180	0.8	0.1
Female	Yearling	140	16.3	1.4
Male	Adult	121	29.9	5.9
Female	Yearling	249	3.5	0.5

Resource Selection

Habitat type had the most support with some influence from both sex and age (Table 2). There was some influence of sex (ΔAIC <2), but due to small sample sizes we did not further evaluate the influence of sex on our model selection. Due to the skewed sample size of age classes (2 adults, 7 yearlings) and ΔAIC >2, the influence of age on our model selection was likely an artifact of the skew. Parameter estimates indicated a greater selection for habitat patches than residential trees, structures, or transitional zones (Table 3).

Movement

We recorded two raccoons crossing potential movement barriers in downtown Cleveland. In one case the raccoon crossed a two-lane highway into a recreational field. In this case, a nearby pedestrian freeway overpass was the likely method of crossing (Fig. 2). In the second occurrence, a raccoon crossed the Cuyahoga River, with several locations coming from within the river itself (Fig. 3).

DISCUSSION

Nocturnal locations of raccoons in urban areas of northeastern Ohio were primarily in discrete patches of available forested habitat, residential trees, and occasionally structures which are similar to those reported by Hoffmann and Gottschang (1977) and Rosatte et al. (1991). Home range sizes were variable, but within the ranges reported by Gehrt (2003) and Rosatte et al. (2010). Results from RSFs indicated that urban raccoons appeared to use habitat patches in urban areas during nocturnal hours. Although we detected limited use of residential trees and structures, urban raccoons occupied habitat patches adjacent to dwellings and structures on a regular basis.

As with most ecological studies, limitations exist that must be taken into consideration. Our study was limited by the relatively small number of raccoons studied and the inability to collect multiple diurnal and nocturnal locations. Raccoons were fitted with newly designed GPS collars which had undergone limited field application in urban environments. We chose to record only a single nightly location rather than multiple locations based on battery life expectancy. The expected battery life for one nightly location every 24 hrs was approximately 9–12 months with more frequent locations decreasing battery life. We erred on the side of using single nightly locations over a longer time frame to detect potential seasonal home range differences rather than more frequent locations for a shorter duration. In doing so, we recognize that we lost the ability to make a more detailed evaluation of nightly raccoon movements within seasons.

Implications for Oral Rabies Vaccination

While we did not estimate the density of raccoons in urban areas, previous research indicates that densities are higher in urbanized settings with specific habitat characteristics like the presence of open and small forest areas than in many other environments (Rosatte et al. 1991). Higher densities can result in increased prevalence of diseases such as rabies among raccoons and potential transmission to humans (Rosatte et al, 1991). Our study provides a more complete understanding of resource use by raccoons in urban Cleveland.

Table 2. Top 4 models identified by Akaike's Information Criterion (AIC), ΔAIC, and AIC weights (w_i) from the mixed-effect logistic regression analysis for raccoon resource selection in Cleveland, Ohio, May 2009 to March 2010.

Model Parameters	df	AIC	ΔAIC	w_i
Habitat Type	5	3517.8	0.0	0.539
Habitat Type + Sex	6	3519.7	1.9	0.209
Habitat Type + Age	7	3520.0	2.2	0.180
Habitat Type + Sex + Age	8	2521.8	4.0	0.073

Table 3. Parameter estimates for the models with the most support of raccoon resource selection in urban Cleveland, Ohio, USA, May 2009 to March 2010. Habitat patch was used as the reference category.

Covariate	Estimates	SE	z value	*P*-value
Intercept	1.105	0.127	8.705	<0.001
Residential tree	–0.907	0.136	–6.625	<0.001
Structure	–1.535	0.134	–11.433	<0.001
Transitional	–2.688	0.117	–22.968	<0.001

Figure 2. Raccoon (*Procyon lotor*) location across an interstate highway, showing pedestrian crossing bridge, Cleveland, Ohio, USA, May 2009 to March 2010.

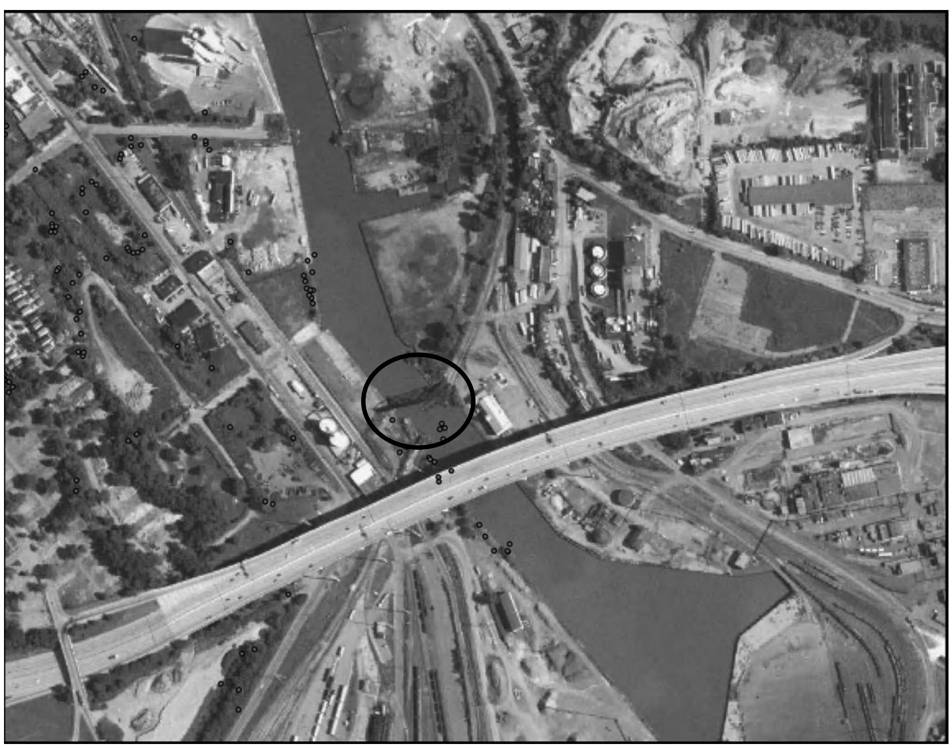

Figure 3. Urban site depicting raccoon (*Procyon lotor*) locations from the Cuyahoga River and nearby drawbridge (circled; bridge is raised in this image, with shadow visible in the river), Cleveland, Ohio, USA, May 2009 to March 2010.

This information allows bait applicators to select areas more likely to be used by raccoons for ORV bait distribution and potentially reduce the spread of raccoon variant rabies. From 1997–2000 the overall cost of ORV baiting in Ohio ranged from $101– $260/km^2 (Foroutan et al. 2002). Concentrating efforts in areas most likely to be inhabited by raccoons could increase the cost-effectiveness of the program. Cleveland is on the northwestern edge of the ORV boundary and effective and targeted vaccine deployment is an important component in reducing the westward spread of raccoon variant rabies across Ohio. Cleveland is surrounded by a network of parks that may provide easy movement corridors for raccoons and a logical area for ORV bait distribution. However, raccoons are found in the urbanized areas of Cleveland, making ORV bait distribution more challenging. Our research represents the first evaluation of resource use by raccoons in downtown, urban Cleveland. And while we provide some recommendations for ORV bait application, some caution must be exercised in interpreting our results due to relatively small sample sizes.

MANAGEMENT IMPLICATIONS

Our data indicate that in urban areas it may be prudent to focus ORV bait distribution in habitat patches near residences and industrial sites, including residential trees and vegetation along major highways. Baiting near potential crossing points (e.g., bridges and overpasses) may help maximize bait access by urban raccoons which could be accomplished either through hand baiting or establishment of short term bait stations. In regions where ORV baiting is conducted by aircraft, restricting baiting to forested habitat may be appropriate although this study did not attempt to evaluate rural habitats. Small areas not easily baited may be candidates for trap-vaccinate-release programs.

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