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What Free-Ranging Animals Do at the Zoo: A Study of the Behavior and Habitat Use of Opossums (*Didelphis virginiana*) on the Grounds of the St. Louis Zoo

Luke J. Harmon,[1]* Karen Bauman,[2] Matt McCloud,[2] John Parks,[1] Shannon Howell,[1] and Jonathan B. Losos[1]

[1]*Department of Biology, Washington University, St. Louis, Missouri*
[2]*St. Louis Zoo, St. Louis, Missouri*

Studies of urban wildlife are important because they can give us insight into both how animals adapt to novel environments and how some species survive and prosper in human-dominated landscapes. Urban zoological institutions provide an ideal setting for research on such species. We report on a study of the behavior and ecology of opossums (*Didelphis virginiana*) on the grounds of the St. Louis Zoological Park. We used radio tracking to investigate the movement patterns and den site use of opossums on the grounds of the zoo and compared the results to data available for opossums elsewhere. We find that urban opossums in the St. Louis zoo have smaller home ranges and move shorter distances than their rural counterparts. We suggest that increased food availability and decreased risk of predation might explain such differences, and we suspect that conditions are even more favorable to opossums in a zoological setting than in cities in general. Our findings illustrate that there is much to be learned from scientific study of the free-living animals found on zoological park grounds. Zoo Biol 24:197–213, 2005.

Key words: radio tracking; home range; minimum convex polygon; adaptive kernel; urban wildlife

Shannon Howell's present address is Division of Biostatistics, Washington University School of Medicine, St. Louis, MO 63110.

*Correspondence to: Luke Harmon, Campus Box 1137, Department of Biology, Washington University, St. Louis, MO 63130. E-mail: harmon@biology.wustl.edu

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INTRODUCTION

Human alteration of the environment has led to the extinction of thousands of species and the endangerment of many more [Brooks et al., 2002]. Nowhere are these alterations more apparent than in the cities in which we live, where native habitats, such as forests, rivers, and plains, have been transformed into mosaics of buildings and open areas, vegetation and concrete [Sanderson et al., 2002]. These changes have had catastrophic consequences for most species, but a small proportion are surviving, some even thriving, in these altered situations. Despite, or perhaps because of, their presence and visibility, relatively little research has been conducted on these species with which we share our urban surroundings. This dearth of research is unfortunate, because the success of our urban commensals is of inherent interest to many people. Moreover, studies of urban wildlife are important because they can give us insight into how animals adapt to novel environments. Modern urban areas are a relatively new habitat type on an evolutionary time scale, and species that are successful in such areas must be able to adjust to urban conditions, including unique competitors, dangers, sources of food, and other factors. Understanding how these adjustments take place could provide insight into the ecological and evolutionary processes that occur when species colonize and adapt to novel environments.

Zoological institutions provide an ideal setting for research on such species. Most zoos are landscaped with an abundance of vegetation and open areas; moreover, many zoos are located within metropolitan parks or other semi-natural areas. The result is that the grounds of many zoos are inhabited by a wide variety of free-ranging animals, including large populations of many of the species that thrive in urban settings, such as raccoons (*Procyon lotor*), opossums (*Didelphis virginiana*), and Canadian geese (*Branta canadensis*). Despite this abundance, very little research has been conducted on the free-living animals that live at the zoo.

This lack of research is undesirable in two respects. Most generally, the conjunction of healthy free-ranging animal populations living in the vicinity of the active research programs found at many zoological institutions provide an excellent setting to examine questions concerning the behavior, ecology, and natural history of urban wildlife; such research would provide many opportunities for educating the public, as well as providing public relations possibilities. In addition, the presence of free-living animals on zoo grounds is not always benign. Wild animals can serve as vectors for disease (most recently, West Nile Virus [Ludwig et al., 2002]) and can prey on captive populations. Informed management of such potential threats requires information on the life history and ecology of these urban wild animal populations.

To address some of these questions, we set out to study the behavior and ecology of opossums on the grounds of the St. Louis Zoological Park. The Virginia opossum (*Didelphis virginiana*) is ubiquitous in urban areas throughout most of the United States and its range seems to be expanding. Before European settlement, the opossum's northern limits were Kentucky, Indiana, and Ohio [Guildae, 1958]. The range of the opossum has expanded rapidly northward in the past 200 years, however, and *D. virginiana* can now be found as far north as southern Ontario, New York, Vermont, New Hampshire [Gardner, 1973], and southern Maine [Godin, 1977]. The opossum's range has also spread west to parts of Colorado, Wyoming, and California [Seidensticker et al., 1987], and introduced populations are now thriving in the Pacific Northwest as far north as Washington State [Scheffer, 1943]. Nonetheless, with the exception of one unpublished Master's thesis [Meier, 1983], all ecological research on this species has been conducted in rural areas (including one study at the National Zoological Park's Front Royal Conservation and Research Center [Seidensticker et al., 1987]). The St. Louis Zoo, whose 36 hectares of well-landscaped grounds lies within St. Louis's 555-hectare Forest Park, has a large population of opossums. Moreover, concerns had been raised about the presence of wild opossums in the zoo, in particular regarding their impact as potential predators on the nests of waterfowl maintained in outdoor enclosures. For these reasons, we initiated a study of urban opossums at the St. Louis Zoo.

Our specific goals were to investigate the movement patterns and den site use of opossums on the grounds of the zoo and compare them to data available for opossums elsewhere. Working in the zoo also allowed us to collect detailed information about actual hourly movement patterns of opossums through the course of entire nights, providing more detailed data than has been previously collected on this species.

MATERIALS AND METHODS

Between October 1999 and March 2001, we captured opossums on the grounds of the St. Louis Zoo using Tomahawk (Tomahawk Live Trap Co., Tomahawk, WI) and Havahart (Woodstream Corp., Lititz, PA) live traps. Traps were baited with sardines, cat food, and peanut butter and placed throughout the zoo near areas of known opossum activity. The morning after capture, opossums were sexed, weighed, their general health evaluated, and their age approximated by evaluating their size, sex, teeth, and general condition [Petrides, 1949]. Radio transmitters were only affixed to healthy adult animals. For these animals, we placed a 1.2 cm collar with an attached radio transmitter (Model 16M, Advanced Telemetry Systems, Isanti, MN) around the neck. Radio frequencies ranged from 150.024–150.124 MHz. Opossums were held until evening, then released near their original site of capture.

Radio-collared opossums were relocated using a FM16 Fieldmaster Receiver with a 3-element folding Yagi antenna (Advanced Telemetry Systems). Opossums were located daily in their dens; we refer to such locations as "day dens." Direct visual confirmation of opossums during the day was rare; however, their den locations could be determined accurately by triangulation. Den locations were recorded with reference to a zoo map, and later incorporated into an ArcView GIS (ArcView 3.2a, ESRI Inc., 1992-2000, Redlands, CA) map of the zoo grounds. Ambiguous locations and locations outside the zoo and the immediate surrounding area were excluded from the analysis. Such locations were rare, however, as most opossums that we tracked rarely left the zoo grounds. A few opossums immediately moved off the grounds after being collared and stayed off for the majority of the time they were tracked. These opossums were excluded from the analysis. For the remainder of the opossums, excluded dens off the zoo grounds represented only 1.4% of all dens recorded.

We also tracked opossums over the course of entire nights throughout the year. Nighttime observations began in early evening, just before the normal time when the opossums first emerged from their dens. We located the opossums approximately hourly throughout the course of the night, until they entered a den and became inactive. In a small number of cases, opossums were still active and moving several hours after daylight, close to the time the zoo opens; in those cases, we stopped tracking the opossums before they returned to their dens. Night tracking was done either on foot or using a golf cart. Locations of opossums during night surveys were recorded and incorporated into an ArcView map of the zoo, again excluding ambiguous locations and those off the zoo grounds.

ArcView GIS was used to analyze spatial patterns of opossum movement. Daytime den sites were used to calculate the total number of unique dens used, with localities within 1 m of each other considered to be the same den site. We calculated the frequency with which an opossum used a particular den, and the total number of different dens used by each opossum. Using only data from consecutive days, we calculated the frequency with which opossums changed den sites from one day to the next, and when they did move, the average distance moved from one den site to the next. Because previous studies have found differences in behavior between male and female opossums [Shirer and Fitch, 1970; Gillette, 1980; Meier, 1983; Allen et al., 1985; Gipson and Kamler, 2001], we compared all of the above results between males and females using nonparametric Mann-Whitney *U*-tests. Also, climate data (minimum, average, and maximum temperatures, as well as daily precipitation) for St. Louis were obtained from the National Weather Service for the time of the study. We used linear regression to test for correlations between the distance moved by an opossum and these weather data for the day preceding and the day after the move.

For each opossum, day dens were used to calculate 100% minimum convex polygon (MCP) home range areas, as well as 90% and 20% kernel home range estimates, using the program CalHome [Kie et al., 1996]. The 100% MCP represents the maximum extent of the range of an opossum, but is sensitive to outliers and may include large areas never visited by the animal [Worton, 1995]. Kernel home ranges are generally more representative of areas commonly used by the opossum, with the 90% kernel representing the main area where the opossum can be found most of the time, and the 20% kernel representing the most heavily used "core area" of the home range [Worton, 1989]. Other percent coverages were calculated for both MCP and kernel home ranges, but results were highly correlated with the 100% MCP and 90% kernel, and thus are not presented here. We again compared all of the above results between males and females using nonparametric Mann-Whitney *U*-tests.

For the night tracking data, the number of data points per night was generally too small to obtain stable estimates of MCP or kernel estimates of nightly activity range size. Thus, to quantify nightly movement patterns, we calculated the distance an opossum moved between two observations, and totaled distances between these moves to find the minimum distance covered by an opossum in a night. We divided this value by the total amount of time between the first and last observations for that opossum on that night to obtain a minimum average speed of the opossum. When opossums' den sites were observed for days immediately preceding or after an observation night, these points were also included for distance calculations; however, because we did not know the exact time when the opossum left these dens in the evening or arrived back in the morning, these data points were not included in the minimum speed calculations. We compared these minimum average speeds and distances between males and females using Mann-Whitney *U*-tests, using averages for individual opossums to avoid pseudoreplication. We also used quadratic regression to test for changes in the minimum speed of an opossum's moves with the time of night that those moves took place. We investigated whether total distance moved and minimum average speeds varied by month over the course of the year with analysis of variance (ANOVA), using averages over multiple observations of the same animal in the same month to avoid pseudoreplication. No usable minimum average speed or distance observations were made in the month of August. Finally, we tested for a correlation between the total distance moved and average speeds for opossums with average daily temperature records. Opossums were not often tracked on rainy or snowy nights, so the relationship between nighttime movements and precipitation could not be analyzed.

Previous studies have calculated opossum home ranges based on lumping together both day den sites and night activity locations. For comparison with these studies, we added all night locations for each opossum to the den site locations, and calculated home ranges based on these total data sets using the minimum convex polygon and kernel methods described above.

RESULTS

We collared 17 opossums (10 females, 7 males). Opossums were followed for an average of 94 $\pm$ 27 (mean $\pm$ SE) days, with an average of 65 $\pm$ 19 daytime den locations per animal. Six of the opossums' tracking periods ended prematurely, with three slipping out of their collars and three disappearing into a large nearby park with their fate unknown (perhaps the battery died or the opossums moved so far away that their signal could not be detected). Of these six, five slipped out of their collars or disappeared after only two or fewer den observations; these five opossums were excluded from the remainder of the analyses. The sixth opossum was successfully tracked for 49 days before disappearing into the park; for this opossum, all observations up to the point of disappearance were used. The remaining 11 opossums died during the study, with five animals found dead of unknown causes, one run over by a car just outside of the zoo grounds, one run over by a light rail train on the other side of a large park, $\sim$2 km from the zoo, one killed during demolition of a building as part of a zoo construction project, and three killed by the zoo's lions. For these 11 opossums, the time between collaring and death averaged 140 days, and only one opossum survived for more than a year.

Day Time Den Sites

For the 12 opossums with three or more daytime den locations, we created ArcView coverages of all dens used by a given opossum superimposed on a map of the St. Louis Zoo (Fig. 1). We observed each of these opossums at a den site an average of 98.1 times; although females were observed almost twice as many times, on average, as males, this difference was not significant (male average = 63.4, female average = 112.1, Mann-Whitney $U = 24.0$, $P = 0.29$). Opossums denned in a variety of locations, including natural cavities in the ground and in trees, inside buildings, in a shed full of hay, and inside faux rock boulders made out of gunnite. Figure 1 illustrates that dens were found all over the zoo grounds, but were clustered in the bear pits (center of north side of zoo) and the ungulate yards (east end of zoo). We attribute this clustering both to the availability of food in these areas, as well as the

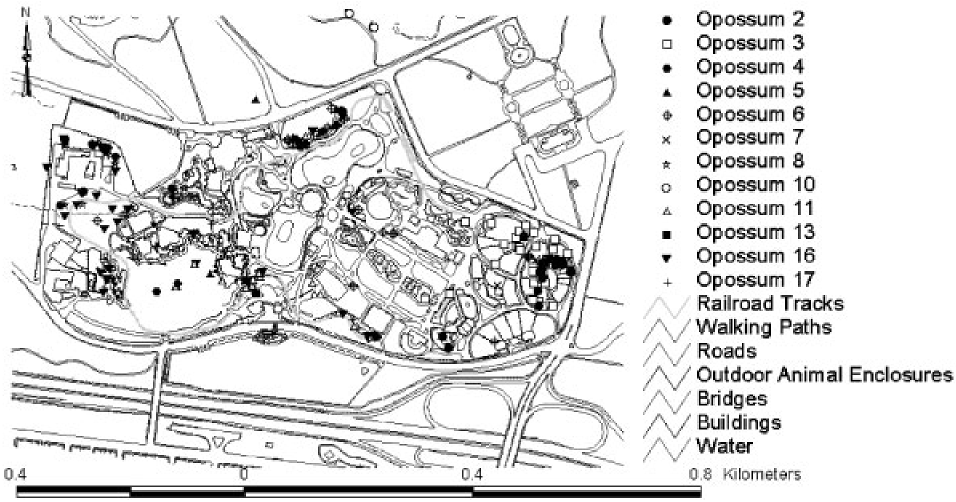

Fig. 1. Map of St. Louis zoo showing all den locations from the study. Filled symbols, male opossums; open symbols, females.

fact that both areas are built in a naturalistic style using gunnite, which presents a rock facade but is hollow inside, with many available den sites.

For each of these opossums, we counted the total number of unique dens and calculated the proportion of time the opossum spent in the three most-used dens (Table 1). Opossums averaged 16.3 unique dens per individual. Individuals tended to spend a large proportion of their time in a single, "favorite" den. On average, opossums spent 40% of their nights in this favorite den, although this proportion varied greatly among individuals (range = 13–67%). A significant positive correlation existed between total number of unique dens and the number of observations ($r^2 = 0.82$, $P < 0.001$). Sexes differed in the average number of dens per observation, with males adding a unique den site more often than females (males = 0.35 new dens/observation, females = 0.17 new dens/observation, Mann-Whitney $U = 4.0$, $P = 0.028$). Males also seemed to use their favorite den less frequently, but this difference was not significant (males = 32%, females = 45%, Mann-Whitney $U = 24.0$, $P = 0.29$). Observations made on consecutive days were used to determine the actual proportion of times an opossum changed dens (Table 2). On average, opossums were almost as likely to change dens from one day to the next as they were to stay in the same den (average percentage of den changes = 45.3%); males switched more frequently, but the difference was not statistically significant (male average = 53.0%, females average = 39.8%, Mann-Whitney $U = 11.0$, $P = 0.26$).

When changing den sites, opossums moved an average of 145.2 m (Table 2); males (mean = 180.5 m) moved farther than females (mean = 120.0 m), but this difference was not statistically significant (Mann-Whitney $U = 12.0$, $P = 0.37$, Table 2). Animals that changed dens more frequently also tended to move further between den sites (frequency of den site shifts [square root-arcsine-transformed] vs. average minimum distance, $r = 0.62$, $P = 0.032$). No significant

TABLE 1. Proportion of time spent by opossums in particular den sites

Opossum	Sex	Number of den observations	Total number of unique dens	Percentage use of most-used dens			
				First	Second	Third	Rest
2	M	67	18	23.9	19.4	16.4	40.3
3	F	262	47	13.4	11.1	8.4	67.2
4	M	83	17	20.5	15.7	15.7	48.2
5	M	9	6	44.4	11.1	11.1	33.3
6	F	93	21	39.8	14.0	10.8	35.5
7	F	37	7	62.2	16.2	10.8	10.8
8	F	45	11	55.6	13.3	8.9	22.2
10	F	22	3	52.2	34.8	8.7	4.3
11	F	219	24	24.2	15.1	12.8	47.9
13	M	7	3	57.1	28.6	14.3	0.0
16	M	151	29	15.2	13.9	13.2	57.6
17	F	107	9	67.3	15.0	6.5	11.2
Average		91.8	16.3	39.6	17.3	11.5	31.6

TABLE 2. Percentage of time opossums changed dens, counting only consecutive days with observations, and average distance moved during those den changes

Opossum	Sex	% of days moved	Average distance moved (m)
2	M	52.1	139.8
3	F	54.2	60.9
4	M	43.3	230.9
5	M	85.7	346.1
6	F	71.4	242.6
7	F	16.7	103.3
8	F	47.5	67.0
10	F	33.3	140.8
11	F	27.7	160.6
13	M	40.0	15.1
16	M	43.8	170.8
17	F	27.6	64.6

linear relationship existed between distance moved and temperature or precipitation for the day after the move (linear regression, following day low temperature: $r = 0.022$, $P = 0.52$; average temperature: $r = 0.016$, $P = 0.64$; high temperature: $r = 0.010$, $P = 0.76$; precipitation: $r = -0.008$, $P = 0.82$); regression on weather data for the day preceding the move showed a similar lack of significant patterns (results not presented). A precipitation effect, however, does seem to exist. Opossums move little on very rainy days, and show a wide range of movement distances on dry days (Fig. 2).

Home ranges based on den locations for each opossum are presented in Table 3 and Figure 3. Two opossums had fewer than 20 observations, making it impossible to accurately estimate their home ranges; these individuals (both males) were excluded from the home-range analyses. The 100% MCP was positively correlated with both 90% and 20% kernel home ranges (90%: $r = 0.89$, $P < 0.001$; 20%: $r = 0.6$, $P = 0.07$; Table 3). The 90% kernel was not related to the 20% kernel home range,

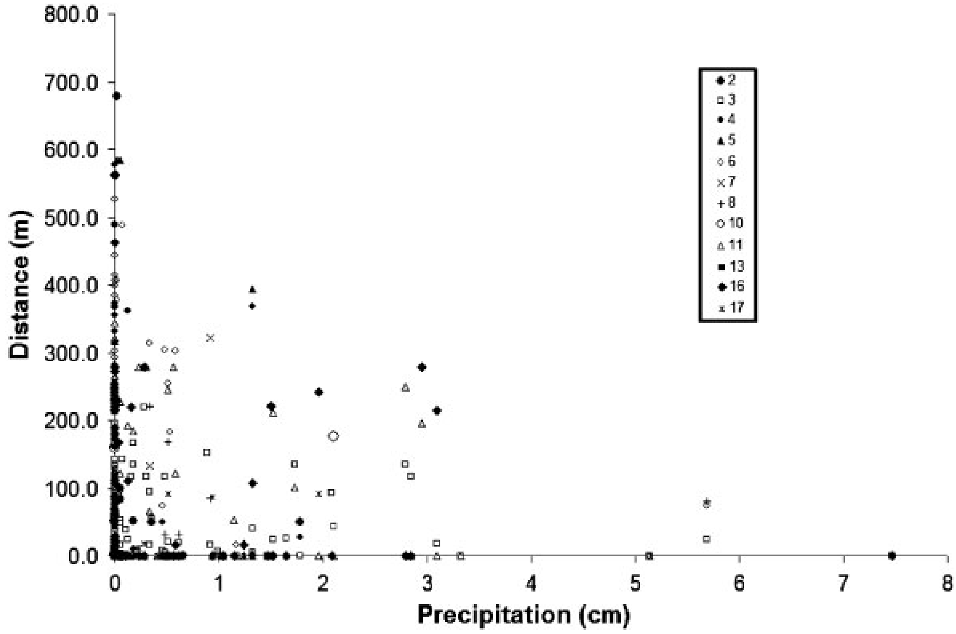

Fig. 2. Relationship between distances moved between consecutive dens by opossums and precipitation. Filled symbols, male opossums; open symbols, females.

TABLE 3. Home range estimates for opossums using various metrics

Opossum ID	Sex	n	100% MCP area (ha)	90% kernel area (ha)	20% kernel area (ha)
2	M	67	9.56	2.23	0.05741
3	F	262	2.89	1.49	0.04191
4	M	83	15.32	4.47	0.12254
6	F	93	17.61	7.82	0.00670
7	F	37	1.67	2.12	0.01205
8	F	45	1.58	0.62	0.00141
10	F	22	0.41	0.26	0.00095
11	F	219	9.15	6.16	0.00150
16	M	151	15.21	8.60	0.16732
17	F	107	2.12	0.58	0.00318

which represents the size of the heavily used core of the home range (Table 3). None of the above measures of home range size were significantly correlated with sample size. Of the three estimates, the 20% kernel was most variable among individuals (coefficient of variation: 90% kernel = 0.91; 20% kernel = 1.42; 100% MCP = 0.88). The sexes did not differ in overall home range size (Table 3, Fig. 3; Mann-Whitney tests: 90% kernel: $U = 4.0$, $P = 0.14$, 100% MCP: $U = 3.0$, $P = 0.087$), but males had larger core activity areas (20% kernel: $U = 0.0$, $P < 0.001$); in fact, the smallest core activity area from a male opossum was larger than the largest of any female.

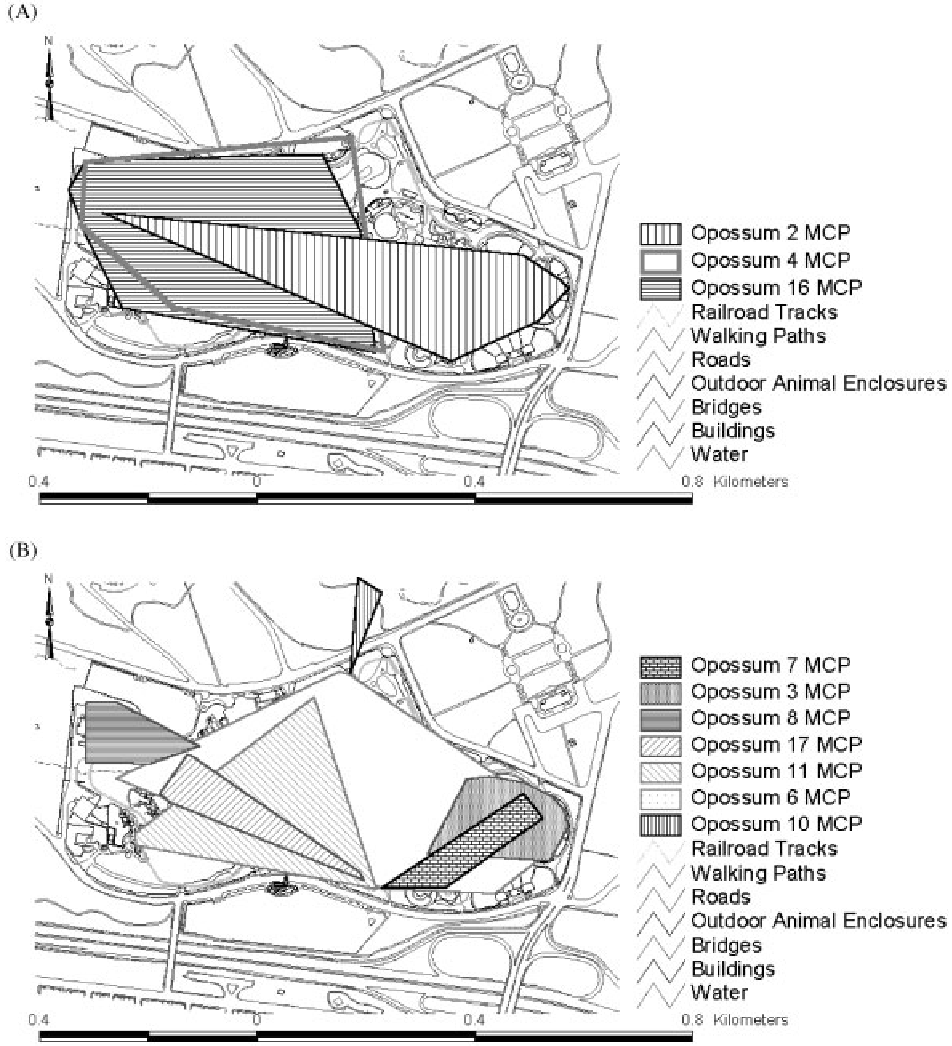

Fig. 3. One hundred percent minimum convex polygon home ranges for all opossums with sufficient points based on day den site data. (A) Male opossums. (B) Female opossums.

Night Time Activity Ranges

We followed 12 opossums (5 males, 7 females) over the course of entire nights for a total of 126 opossum-nights. Individual opossums were tracked for varying numbers of nights (mean = 10.5, range = 1–30). A total of 651 hourly data points were recorded, for an average of 5.2 data points per night (range = 1–12). Opossum den locations for the days immediately preceding and after the observation night were also included in calculations for total distance when available (previous day = 89/126, next day = 86/126), bringing the total number of observation points to 826.

From these night observations, the average minimum speed of individual opossums was 82.8 m/hr (range = 18.9–194.5 m/hr). No difference in the average minimum speed was detected between males and females (males: $n = 5$, mean = 93.3 m/hr, females: $n = 7$, mean = 75.3 m/hr, Mann-Whitney $U = 13.0$, $P = 0.53$). On average, the minimum total distance moved by an opossum in a given night was 478 m; this also did not differ significantly between males and females (males: mean = 387 m, females: mean = 542 m, $U = 17.0$, $P = 0.935$). Average minimum speed depended on the hour the measurement was taken, with the data showing a trend of decreasing activity at dusk and dawn (Fig. 4; quadratic regression $r^2 = 0.071$, $P = 0.016$).

Minimum speed varied among months ($n = 50$, $F_{10,39} = 2.40$, $P = 0.025$), with a peak in opossum activity in the late fall, followed by greatly lowered movements in the winter. Differences also occurred in the times at which opossums were moving, with shorter activity times shifted earlier in the evening during the winter months. Both of these patterns together resulted in significant differences between months for the average minimum total distance moved by an opossum in a night (Fig. 5, $n = 49$, $F_{11,37} = 2.285$, $P = 0.03$), with a peak in the springtime, and overall lowered distances in the winter. There was a weak trend for opossums to move farther and faster on warmer nights (Fig. 6, average temperature vs. minimum total distance $n = 32$, $r = 0.30$, $P = 0.092$; average temperature vs. average speed $n = 32$, $r = 0.34$, $P = 0.061$; data from multiple opossums on the same night averaged to avoid pseudoreplication); similar correlations were found with daily low and high temperatures.

For comparison with other studies, we also calculated home range sizes for opossums that included all day and night data points for each individual. We used the same methods as described above, but included the 651 additional night points in the calculations. Again, two opossums had <20 locations and were excluded. The

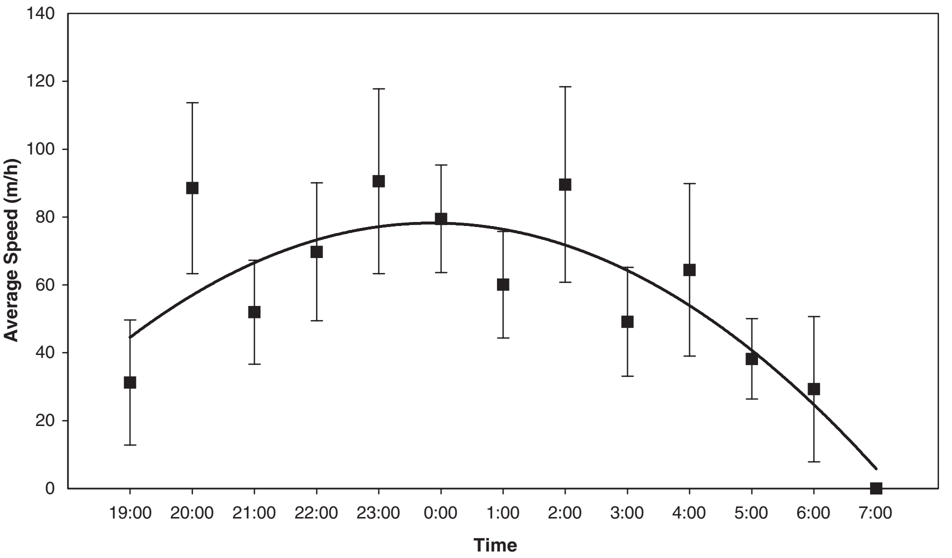

Fig. 4. Differences in average minimum speed of opossum movements ending in each hour through the night, with standard errors, and quadratic best fit line.

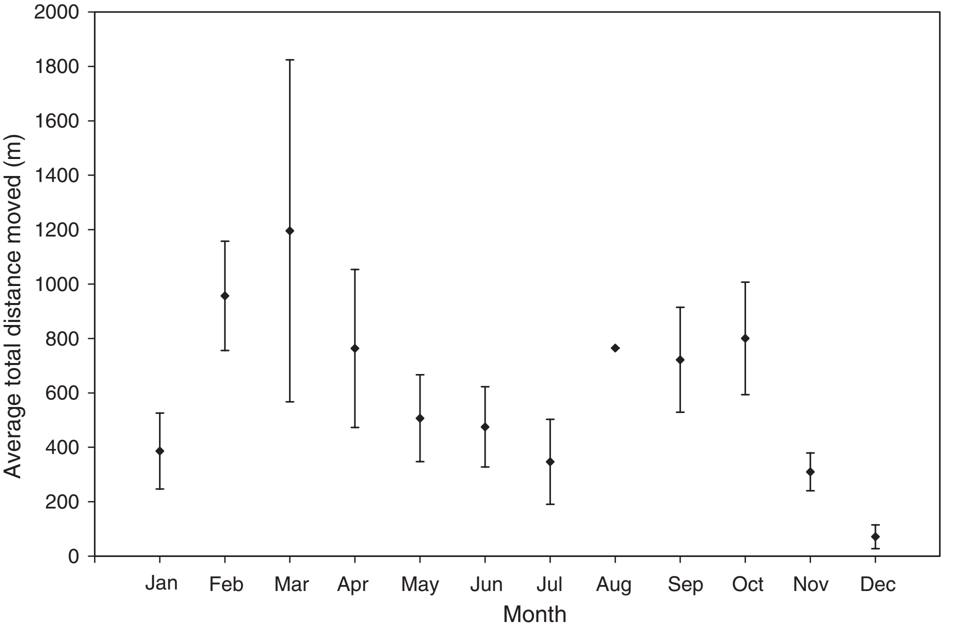

Fig. 5. Average total distance moved by opossums during one night's observation by month, with standard errors.

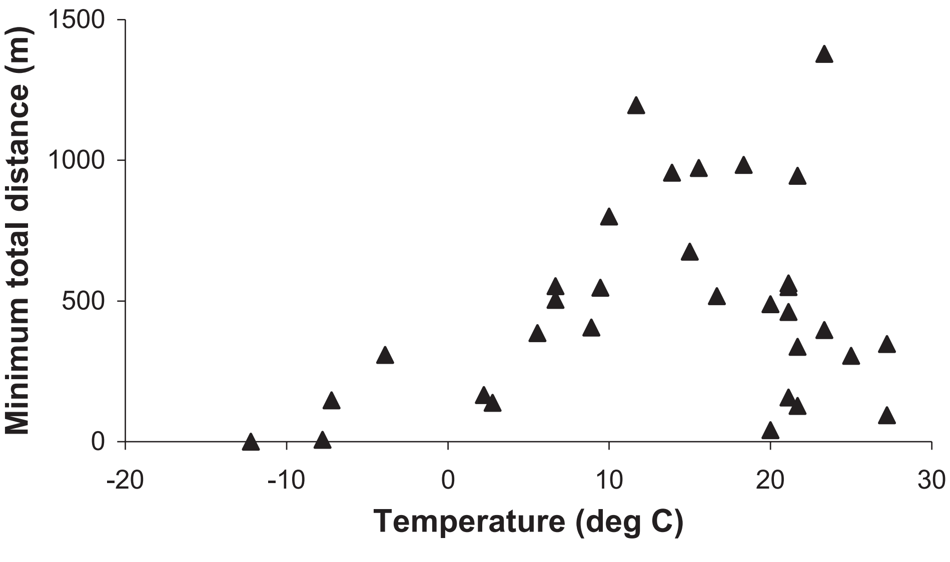

Fig. 6. Relationship between nightly minimum total distance for opossums and average temperature for the preceding day.

percentage of the total locations taken at night varied greatly among individual opossums (average = 39%, range = 14–73%). These home range estimates were strongly correlated with estimates based only on day locations (100% MCP: $r = 0.94$, 90% kernel: $r = 0.90$, 20% kernel: $r = 0.62$). When including night locations, home range estimates were larger in almost all cases; the one exception was a slightly smaller core range (20% kernel) for one female opossum (results not presented). Furthermore, results of analyses on these home ranges were qualitatively identical to those based on den locations presented above.

DISCUSSION

Opossums are abundant on the grounds of the St. Louis Zoo, as they are in many urban areas. Despite this abundance, almost all previous studies of the behavioral ecology of opossums have been conducted in rural settings. The urban environment differs in many important respects compared to that experienced by rural populations. In particular, predators may be more scarce and food may be more abundant. As a result, urban populations may differ greatly from their rural counterparts, exhibiting higher population densities, smaller home ranges, and smaller movements [Meier, 1983; Doncaster and Macdonald, 1997]. We observed that the behavior and habitat use of urban opossums in this study were similar in many respects to those of more rural opossums found in other studies. Nonetheless, we also found some substantial differences that are explicable as a result of differences between urban and rural environments.

Mortality

Opossums in this study showed a relatively high mortality rate. Of the opossums whose tracking periods did not end prematurely due to collar loss or failure, only 1 of 11 survived more than a year, with average survival of 6 months for all 11 opossums. Similarly high rates of mortality have also been reported in rural opossums. For example, Gipson and Kamler [2001] estimate annual survival rates between 17–25% for opossums in northeastern Kansas, whereas Gillette [1980] reports that no adult opossums collared in the first year of his study in rural Wisconsin survived to reproduce in the next year. Although our small sample size prevents direct comparison between our mortality rates and those from rural opossums, it seems likely that these opossums experience high mortality similar to their rural counterparts.

Daytime Den Sites

We found a positive correlation between the number of observations made per opossum and the number of unique dens. This result, which was also found for opossums in rural Kansas [Fitch and Shirer, 1970], suggests that opossums seem to continually use new dens throughout their lives (or at least throughout the time span covered by these tracking studies).

St. Louis Zoo opossums were found in a different den than the one used the previous day 45% of the time, a rate comparable to that found in other studies (Kansas = 42%, [Fitch and Shirer, 1970]; New York = 38%, [Hossler et al., 1994]). Their use of a "favorite" den an average of 40% of the time is also comparable to other rural studies (Kansas = 40%, [Fitch and Shirer, 1970], 25%, [Pippitt, 1976]). When opossums in the St. Louis zoo switched dens, however, they moved shorter distances than rural opossums from Kansas and Georgia (Fig. 7) [Fitch and Shirer, 1970; Allen et al., 1985]. This may be due to the increased availability of den sites, because many man-made structures on the zoo grounds contain suitable den

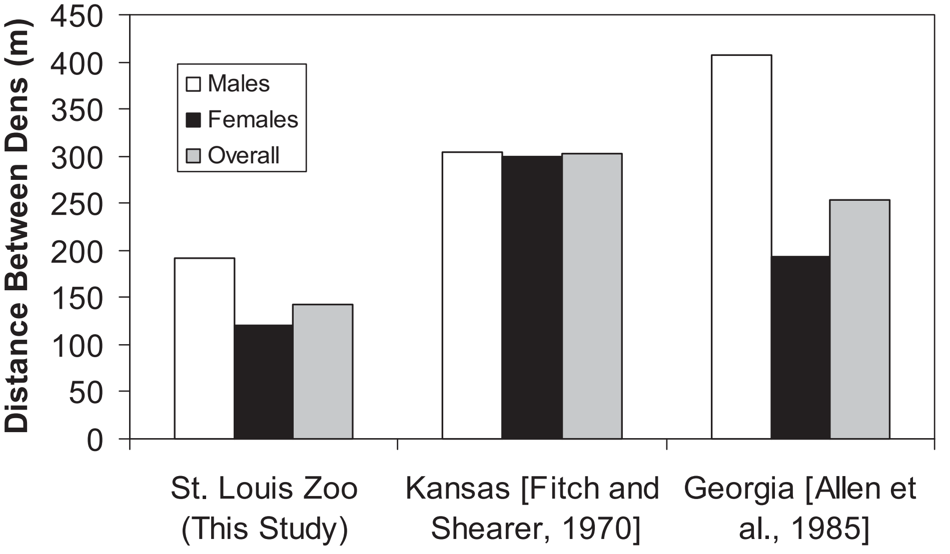

Fig. 7. Distances moved between consecutive dens, comparison between this study and two previous studies of rural opossums.

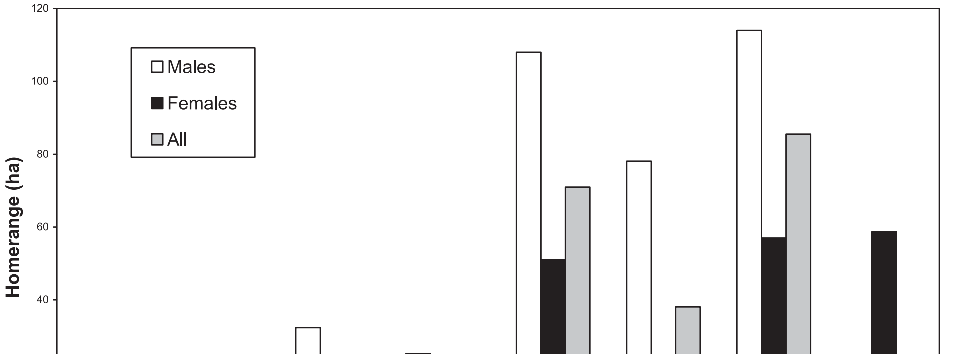

Fig. 8. Home ranges of opossums, based on day den use, compared between studies (all home ranges estimated using 100% of the minimum convex polygon, except Gillette [1995], which used 95% of the MCP estimate, and Allen et al. [1985], which used the modified minimum area method [Harvey and Barbour, 1965], which is always <100% MCP and can thus be considered a minimum). *Analyses including both den and foraging sites; all others include only den sites.

locations. From these data, it seems that opossums are moving from den to den at the same frequency as rural opossums, but those movements are over much shorter distances. These differences are reflected in home ranges, which are much smaller in this study than in all rural studies for which data are available (Fig. 8) [Shirer and

Fitch, 1970; Gillette, 1980; Meier, 1983; Allen et al., 1985; Sunquist et al., 1987; Gipson and Kamler, 2001]. The only other study with comparable opossum home range estimates is another urban opossum study from Corvallis, Oregon (Fig. 8) [Meier, 1983]. Our data are also consistent with the common observation that male opossums move farther and have larger home ranges than females (Figs. 7,8). Our results for these comparisons were not statistically significant, but this is likely due to small sample size.

Night Time Activity Range

St. Louis Zoo opossums moved shorter total distances per night than opossums in other studies (Fig. 9) [Allen et al., 1985; Seidensticker et al., 1987]). In particular, they moved much less than opossums tracked at the National Zoological Park's Front Royal Conservation and Research Center, Smithsonian Institution, a zoo-like setting located in a rural area near Fort Royal, Virginia [Seidensticker et al., 1987].

Average minimum speeds for opossums in this study varied with time of the night. This is concordant with results from rural opossums; Allen et al. [1985] found that opossums in Kansas were most active between 20:00–24:00, which is similar to the peak activity times found for these opossums (Fig. 4). Movement patterns also varied through the course of the year, with significantly lowered movements in the winter (Fig. 5). This is also similar to data for rural opossums. Gillette [1980] showed that opossums in Wisconsin showed greatly reduced movements during the winter. Yearly patterns found in this study, with greatly decreased activity over the winter months, are similar to those found in urban opossums in Corvallis, Oregon [Meier,

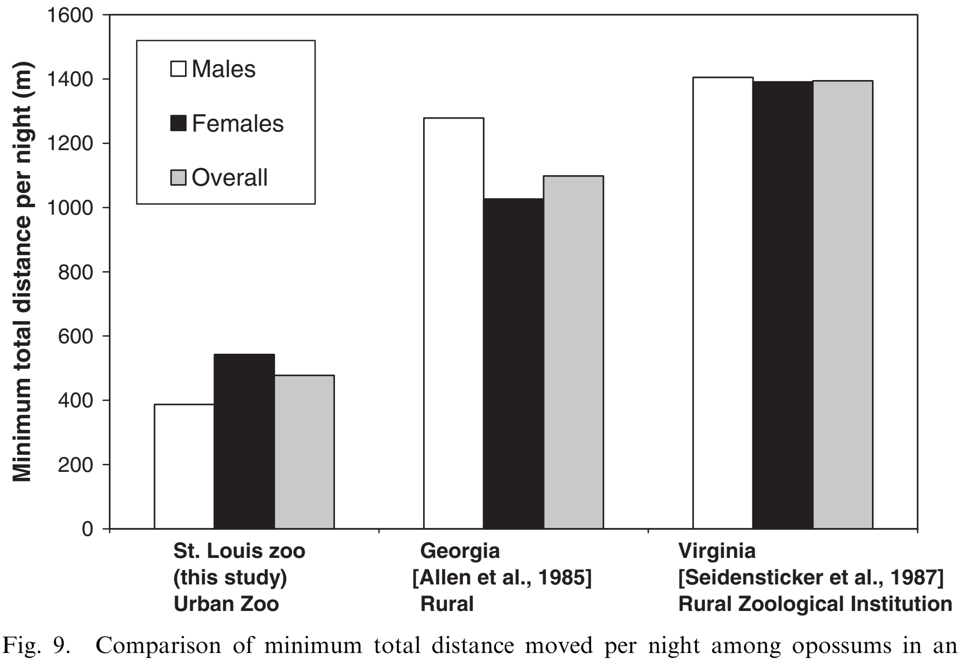

Fig. 9. Comparison of minimum total distance moved per night among opossums in an urban zoo, rural land, and a rural zoological institution.

1983]. The St. Louis opossums, however, moved farther distances earlier in the year compared to those in Oregon, starting these increased moves in late February and March in St. Louis as opposed to April in Oregon. This is likely due to the warmer temperatures in St. Louis during the early spring, because opossum behavior is strongly influenced by changes in temperature (Fig. 6), a relationship also observed for Kansas opossums [Fitch and Shirer, 1970].

St. Louis Zoo opossums are much more sedentary than rural opossums, both in terms of how much they move in a given night and how far they move from one den site to the next. We attribute this lessened movement to the greater availability of food on the grounds of the zoo, a suggestion that is in line with a previous observation by Allen et al. [1985], who found that one opossum in an area of abundant food had an unusually small home range. The one other study on urban opossums [Meier, 1983], conducted in Corvallis, Oregon, also found smaller home range sizes than reported in the literature for rural opossums. We suggest that food may generally be more plentiful in urban settings, but even compared to urban settings in general, zoo grounds are a particularly rich food source.

Although we did not quantitatively measure food availability, two lines of evidence support our contention. First, we directly observed opossums foraging. Although some feeding was in more ‘‘natural’’ settings, such as eating fruits fallen to the ground underneath a tree, other food locations included the repeated observation of opossums sitting in and feeding out of the food pans in the ungulate stock yards, as well as the finding of opossums in trash dumpsters. Second, opossums were often seen within animal enclosures (hence the untimely demise of several to lions; zoo staff also reported regularly finding partially eaten opossums in the cheetah yards; S. Bircher, personal communication). Indeed, some animals in the hoofed stock yards apparently rarely, if ever, left these yards.

Our results suggest that opossums are adept at exploiting resources available in urban settings. Opossums have become plentiful in cities throughout North America. We suspect that conditions are even more favorable to opossums in a zoological setting than in cities in general. Such settings contain the necessary features for opossum survival, i.e., abundant food sources and available den locations, in a higher concentration than is available in rural environments. Opossums are able to exploit these features and live in relatively high densities without drastic changes to their behavior patterns. Further work in St. Louis may allow a direct comparison between zoo opossums and city opossums to directly test this hypothesis. More generally, our findings illustrate that there is much to be learned from scientific study of the free-living animals found on zoological park grounds.

This study provided both management information and educational opportunities for the St. Louis Zoo. Our data suggests that opossum on zoo grounds spend very little time in and around lakes used for the zoo’s waterfowl breeding program and are unlikely to be the cause of waterfowl predation. Therefore, predation control methods in these areas were no longer directed at opossums. Furthermore, this study provided a unique way to educate the zoo visitors about native wildlife at the zoo as well as on-going zoo research projects. Informal educational opportunities occurred when the researcher was out on the zoo grounds tracking individual daily den locations. Although these casual interactions differ from the typical classroom setting, we believe they had two main advantages: first, many of the visitors were adults or families, who do not often attend formal classes; and second, they provided the visitors an opportunity to see science in action, particularly valuable because the majority of zoo research occurs "behind the scenes". Some visitors were interested enough to try their hand at radio tracking by putting on the ear phones and trying to follow the signal. Additionally, the project was featured on a local TV show. Researchers explained the project to the audience and then demonstrated the tracking of the daily den locations using a radio collared stuffed opossum hidden in a bush.

CONCLUSIONS

This study offers the following conclusions: (1) opossums in the St. Louis zoo switch dens at a similar frequency but move shorter distances than rural opossums; (2) similar to results from one other study [Meier, 1985], these urban opossums have much smaller home ranges than in all rural studies for which data are available; (3) opossum movements vary with time of night, with peak activity between 20:00 and 24:00; (4) opossum activity varies through the course of the year, with greatly reduced activity in winter; and (5) smaller urban opossum home ranges in the zoo may be a consequence of increased food availability.

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