Am. Midl. Nat. 156:128–134

Landscape Associations of Road-killed Virginia Opossums (Didelphis virginiana) in Central Massachusetts

L. LEANN KANDA[1]
Organismic and Evolutionary Biology, University of Massachusetts, Amherst 01003

TODD K. FULLER
Organismic and Evolutionary Biology, and Department of Natural Resources Conservation, University of Massachusetts, Amherst 01003

AND

PAUL R. SIEVERT
U.S. Geological Survey, Massachusetts Cooperative Fish and Wildlife Research Unit, Department of Natural Resources Conservation, University of Massachusetts, Amherst 01003

ABSTRACT.—Knowing the distribution of species at the landscape level can give insight into the proximate mechanisms determining the species' range on a regional scale. We used a survey of road-killed animals to investigate landscape features associated with the presence of Virginia opossums (*Didelphis virginiana*) in central Massachusetts. Volunteers noted road-killed opossums on their daily commutes through the Connecticut River Valley and surrounding towns in 2000 and 2002. We used a GIS to characterize both the locations of roadkills and random points according to elevation, land use, distance to open water, traffic speed and number of observers on the road and then used logistic regression to determine the association of roadkill sites with these variables. Dead opossums were found most often at low-elevation sites with less forest cover and more human development. Although the opossum usually is considered a habitat generalist found primarily in association with woodlands, opossums in central Massachusetts are not associated with woodlands and, instead, are most often found in and near urbanized areas.

INTRODUCTION

Species' distributions often are mapped at a coarse resolution that does not consider local patterns of occurrence on the landscape. However, the distribution on the local landscape is particularly important for understanding the proximate interplay of factors that ultimately set the limits of a species' range. The Virginia opossum (*Didelphis virginiana*) is broadly distributed throughout southern New England and Ontario (Gardner and Sunquist, 2003; Fig. 1). However, modeling of the demography and winter physiology of Virginia opossums suggests that their populations should not persist north of central Massachusetts (Kanda and Fuller, 2004; Kanda, 2005a).

Anecdotal and camera survey evidence suggest that opossums do not occur uniformly throughout central Massachusetts. Opossums are commonly sighted in the developed regions of the Connecticut River Valley, but residents of the area believe opossums to be scarce in the primarily forested Pelham Hills that border the valley to the east (Fig. 2A). In addition, wildlife researchers trapping mesocarnivores in the forest around the Quabbin Reservoir east of the Pelham Hills did not capture opossums at the site (W. Healy, pers.

[1] Corresponding author present address: Dept. of Biology, Siena College, 515 Loudon Rd., Loudonville, New York 12211; Telephone: (413)214-8528 (cell); e-mail: lkanda@siena.edu

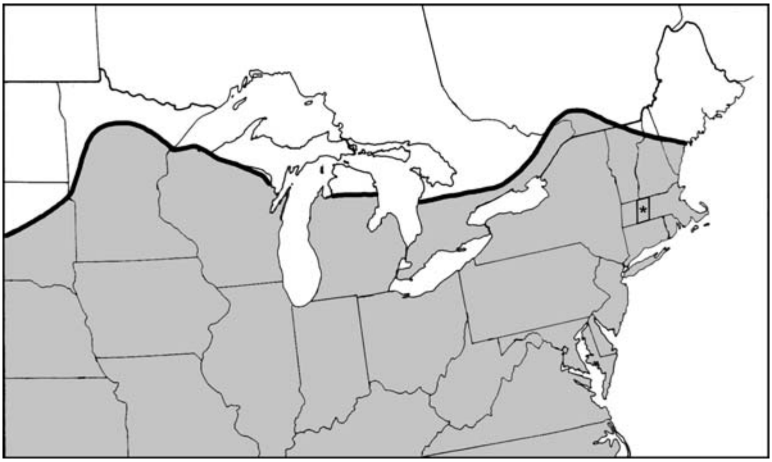

FIG. 1.—Distribution map for the Virginia opossum in northeastern North America, adapted from Gardner and Sunquist (2003), with the Connecticut River Valley of Massachusetts indicated by the star

comm.). A camera survey in conservation areas around the Connecticut River Valley found that opossums were associated with forest edge (generally within 300 m of a residence) rather than forest interior, and were not found above 120 m in elevation (M. Voight and T. Fuller, pers. obs.). Opossums also were found to be restricted to forest edges in a camera survey in the White Mountains of Vermont (Moruzzi *et al.*, 2002; T. Moruzzi, pers. comm.). Based on these observations, we decided to identify landscape factors influencing the distribution of opossums in and near the Connecticut River Valley of central Massachusetts. To accomplish this goal, we indexed opossum abundance by identifying dead opossums on road transects throughout the valley and measured landscape variables associated with these sites.

Surveys of roadkills are a common tool for assessing the relative population size of medium-sized mammals. Counts often are used to index abundance (*e.g.,* Eberhardt and Simmons, 1987; Rolley and Lehman, 1992; Gehrt, 2002) and its changes over time (*e.g.,* Case, 1978; Hicks, 1993; Gehrt *et al.*, 2002). They also can be used to evaluate the landscape features associated with species' presence. A survey of mammal road carcasses in the Central Valley of California included the Virginia opossum, and indicated that opossum roadkills were equally likely in association with rural and urban development (Caro *et al.*, 2000). In that study, Caro *et al.* (2000) used defined sections of road to evaluate a single predictor variable's effect on mammal abundance. Herein, we describe habitat use-availability analysis of multiple variables at roadkill sites compared with random sites along our transects (*cf.,* Compton *et al.*, 2002; Baldwin *et al.*, 2004; Henner *et al.*, 2004).

METHODS

OBSERVATIONS

We recruited volunteers to participate in a roadkill survey, asking them to look for opossum roadkills on their regular daily commute between April and November 2000 and again between April and November of 2002. Thirty-eight people participated over the 2 y, with 11 participating both years. As most volunteers were based at the University of Massachusetts at Amherst, the majority of routes converged on downtown Amherst (Fig. 2A).

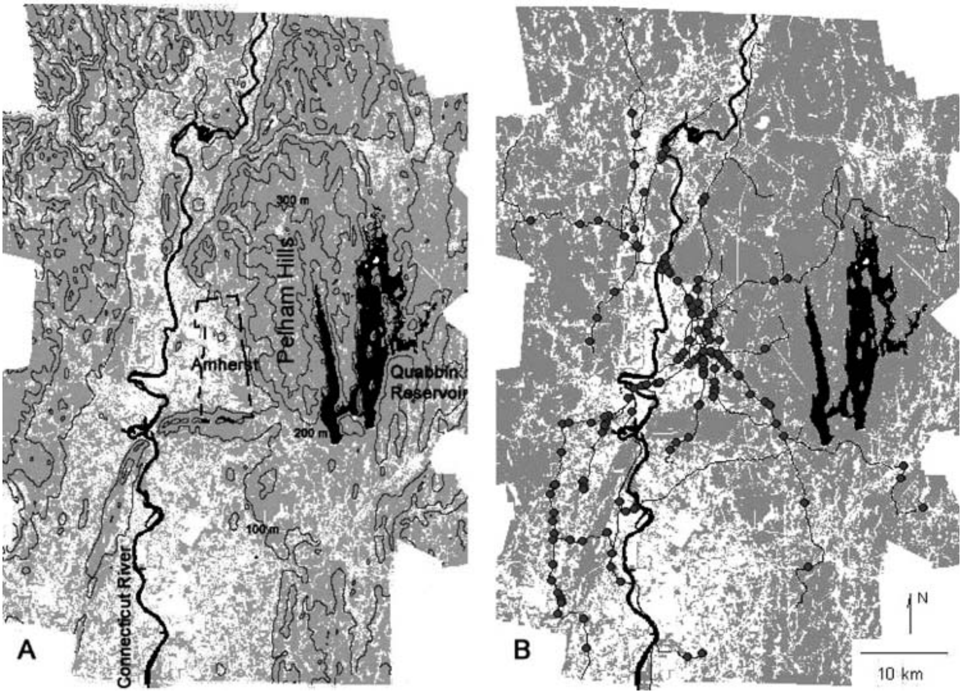

FIG. 2.—A) Topography (elevation in 100-m contours), forest cover (in gray) and place names and B) roads (fine black lines) surveyed for road-killed opossums (circles), in the Connecticut River Valley study area in west-central Massachusetts

Routes spread throughout the Connecticut River Valley and the adjoining hills to the west and east, covering 517.5 km of road in 2000 and 347.5 km of road in 2002 in an area 52×78 km (Fig. 2B). Volunteers had both maps and observation record forms for identifying where and when they observed a dead opossum. For simplicity, the volunteers recorded all opossums they saw, on or off their regular commute. Some off-commute roadkills were useful in verifying roadkills on other observer's commutes. The present analysis focuses only on roadkills that were observed by a volunteer on their own commute transect.

GEOGRAPHIC INFORMATION

Each volunteer route was identified and labeled in a road datalayer from the Office of Geographic and Environmental Information (MassGIS), Commonwealth of Massachusetts Executive Office of Environmental Affairs, using ArcView 3.3. From these roads, a datalayer for each year was developed which consisted of line transects representing roads driven on daily commutes. Each section of road was labeled with the number of observers driving the road that year. Roadkills were placed in a point datalayer for each year. A roadkill was entered in the database only once, even if observed multiple times by different observers. The accuracy of one subset of roadkill locations was verified through comparison of independent observations from multiple observers. The accuracy of a second subset of roadkills was verified through observation of the roadkills by one of the authors (LLK or TKF). Volunteers used landmarks and/or odometer readings to pinpoint roadkill locations; authors verified a subset of points with landmarks or GPS readings. All volunteer roadkill observations examined by the authors were verified as opossums and the carcasses were within 50 m of the reported location. Observations of live animals on the road were not included. We did measure the number of days each observer used their route during the observation period, however preliminary analyses indicated that the number of observing days per observer did not have an effect on likelihood of noticing a roadkill. We therefore assumed equal observing effort among observers. The differing number of observers on each stretch of road was accounted for in the creation of random points used as the baseline for comparison.

RANDOM POINTS

We assumed a simple linear relationship between number of observers on a stretch of road and the likelihood that, if a dead opossum was there, it would be seen. To create a spatially random sample conditional on the number of observers driving a specific stretch of road, we first generated a large population of points in a uniform spatial distribution, then did a weighted selection of points falling on monitored stretches of road. We began by delimiting in GIS a simple polygon that encompassed the entire study area, and generated in this polygon 10,000 random points from a uniform spatial distribution (Hooge *et al.*, 1999). From these 10,000 points, we selected those that were within 50 m of a road transect (a pool of roughly 800 points). Each road point was moved to be centered on the road (within 2 m of the line transect) at the point closest to its original position (we originally chose to accept points within a 50-m association because computer processing time limited the total number of points that could be generated). Each road point was assigned multiple ID numbers, one ID for each observer who drove past that point. The ID numbers were then submitted to a random sequence generator (Haahr, 1998). Points were selected according to the random sequence until the appropriate sample size was reached. The more ID numbers assigned to a point, the more likely it was to be selected (*i.e.,* a point associated with two observers would be twice as likely to be in the sample as a point associated with one observer). This process generated a selection of random points on the transects describing a scenario in which the underlying distribution of dead opossums on the road is spatially uniform, but the chances of a dead opossum being observed (added to the sample) increases with the number of volunteers that drove by it.

Because of a change in volunteers between the two years of the study, the roads covered each year were slightly different. The generation of random points along the transect was therefore done twice, once with each year's transects (beginning with the generation of the 10,000-point pool), and the sample drawn from each year was equal in size to the number of roadkills seen that year to ensure proper proportional representation of the transects.

POINT ATTRIBUTES

To identify the land-use association for roadkill and random points, we used the Land Use datalayer from MassGIS. We simplified the land-use categories into agriculture, forest (which includes nonforest wetland), open, commercial, residential and other (including water and highway). Studies of opossum home ranges have indicated that the opossums' ranges are fluid, with nightly movements anywhere between 6 and 1800 m, though most studies found movements confined to less than 600 m (Gardner and Sunquist, 2003). Between these findings and our own study of local opossum movements (Kanda, 2005b), we concluded that a 200-m radius area around the roadkill location would be an appropriate scale for measuring the land-use associations of the opossum. We built buffers of 200 m around each point in the GIS database and then intersected these buffers with the land-use database. For every point, we then recorded the percentage of each type of land-use within the 200-m association. The percentage was arcsine transformed to meet the assumption of a normal distribution (*cf.,* Baldwin *et al.*, 2004).

TABLE 1.—Parameter estimates and odds ratios from step-wise logistic regression of roadkill locations compared with observer-weighted random points along the transects

Parameter	Estimate	SE	Wald χ^2	P	Odds ratio	Odds ratio 95% confidence intervals	
						Wald	Bootstrap
Intercept	3.317	1.153	8.280	0.004			
Elevation	−0.607	0.277	4.782	0.029	0.545	0.317–0.939	0.292–0.945
Forest at 200 m	−1.105	0.370	8.937	0.003	0.331	0.160–0.683	0.151–0.702

Elevation and distance to water are other major topographical features that may influence opossum distribution in this region (Gardner and Sunquist, 2003). Elevation and hydrographic datalayers (MassGIS) are line databases; therefore, we used "spatial join" to identify the nearest elevation contour and to find the distance to the closest water for each point. These attributes were added to the database of land-use associations. The speed limit also was noted for each point by recording posted speed limits throughout the study area. Each of these attributes was log transformed to generate normally-distributed parameters for analysis. Although traffic volume is likely an important predictor variable, it was not available for most locations so was not included in the analysis.

LOGISTIC REGRESSION

We used logistic regression to model the probability of a point being a roadkill in a data set of roadkills and random points. The transformed parameters for elevation, distance to water, speed limit and each of the six land-use percentages were included as potential explanatory variables. We selected the final model through step-wise regression, which was then validated by performing 1000 bootstrap replications. In each bootstrap, the identity of each point as roadkill or random was randomly assigned. The likelihood that the model based upon the real points could occur by chance was determined by comparing the actual model to the distribution of 1000 bootstrap models.

RESULTS

Observers located 93 dead opossums on their commutes in 2000 and an additional 64 opossums in 2002. A matching 93 random points were generated from the transects in 2000 and 64 were generated for the 2002 transects. The final model from step-wise regression of the full data set included elevation and forest cover as significant predictors of roadkill locations (Table 1). The probability of a point being a roadkill decreased with both increasing elevation and increasing forest cover in the immediate landscape. The bootstrap replication of the logistic regression model resulted in corrected odds-ratio confidence intervals for the effect of elevation and forest cover. Both confidence intervals remained below 1, indicating that the negative effect of elevation and of forest cover on the probability of a point being a roadkill is greater in the true data than expected from random assignment of points.

DISCUSSION

Throughout most of their range, opossums seem to have a particularly strong association with deciduous forest (Gardner and Sunquist, 2003). However, in the Connecticut River Valley region of Massachusetts, they were less likely to be found in forested areas than in other land-use types. In our analysis, we assumed that an opossum is most likely to be hit on a road in the habitat where it spends most of its time. It is possible that dispersing opossums may be hit on the road in habitats they would not settle; however, we believe it is more likely that the habitat association of kills on the road reflected the habitat association of the opossums. Radio-tracking of opossums in the area showed that individuals with established home ranges showed no hesitation to cross roads, and road mortality was a major cause of mortality for the local population regardless of sex or age (Kanda, 2005b).

Because our analyses were based on a use-availability design, interpretation of the logistic regression must be limited in scope (Keating and Cherry, 2004). However, we were only interested in broad patterns of association, an acceptable use of the technique.

We found negative association of opossum roadkills with the one land-use type that was not dominated by human influence, the forest. Although Gardner and Sunquist (2003) suggested that opossum numbers were low in residential areas, opossums do coexist with humans in urbanized landscapes (Crooks, 2002; Caro *et al.*, 2000). Opossums have been generally considered to use woodlands as their primary habitat (*e.g.*, Hunsaker, 1977), but in central Massachusetts opossums were rarely killed on stretches of road surrounded by forest. It is possible that opossums did live in forested areas and these animals were warier than their urban counterparts in approaching the road; however, this explanation seems unlikely for this disturbance-insensitive species (Crooks, 2002).

Elevation also was a significant predictor, with opossum roadkills more likely at low elevation. Elevation and forest cover were correlated, but only at an r of 0.53. We interpreted this to mean that opossums were absent from high-elevation areas, which also were predominantly forest, but the opossums also were less likely in forested areas at lower elevations.

We were surprised to find that distance to the nearest open water did not emerge as a significant predictor variable. Opossum association with open water sources has long been documented (Lay, 1942; Reynolds, 1945; Sandidge, 1953; Llewellyn and Dale, 1964). It is possible that in human-dominated landscapes, natural open water sources (such as streams) are not as necessary to the opossum because other water sources are available such as irrigation ditches or even urban bird baths.

The reduced likelihood of locating opossum roadkills in central Massachusetts areas with a high percentage of forest was odd considering the opossum's habitat associations in most of its range, but it was consistent with both local anecdotal observations and camera surveys. In central Massachusetts, we found opossum abundance, as indexed by roadkills, to be negatively associated with forest cover. In this area, non-forested land was human-dominated agricultural and urbanized landscape. The urban-rural interface at the northern edge of the opossum's range may serve as the local distributional limit. This patchy distribution of opossums across the landscape suggests that urbanization enhances opossum population persistence in the northeastern U.S., and that opossums may not be able to survive this far north without anthropogenic resources. The presence of human-dominated landscape may explain the continued expansion of the Virginia opossum's range northward into climatic regimes generally considered too harsh for their survival under natural forest conditions.

Acknowledgments.—We are indebted to the roadkill observers: T. Algeo, B. Braun, R. Brooks, T. Castro-Santos, B. Compton, R. DeGraaf, S. DeStefano, R. Dizard, K. Druzisky, K. Fite, L. Fortin, D. Foster, C. Griffin, P. Godfrey, R. Harrington, A. P. Jaques, E. Jakob, C. Jenkes, B. Kane, S. Kleinfeldt, M. LaPrade, T. Maier, M. Matteo, D. Mazzarese, P. O'Neil, J. Organ, E. Henyey Parker, A. Patnode, T. Pelletier, M. Perusse, A. Porter, J. Richburg, A. Richmond, K. Rolih, P. Schroeder, E. Walker, A. Walton and their families. We also thank A. Porter and B. Compton for advice on statistical analysis and E.M. Jakob and J. Podos for comments on the manuscript. This work was supported by the Cooperative State Research, Education and Extension Service, U.S. Department of Agriculture, Massachusetts Agricultural Experiment Station, under Project No. MAS0071. This is Massachusetts Agricultural Experiment Station Publication No. 3362.

LITERATURE CITED

BALDWIN, R. A., A. E. HOUSTON, M. L. KENNEDY AND P. S. LIU. 2004. An assessment of microhabitat variables and capture success of striped skunks (*Mephitis mephitis*). *J. Mammal.,* **85**:1068–1076.

CARO, T. M., J. A. SHARGEL AND C. J. STONER. 2000. Frequency of medium-sized mammal road kills in an agricultural landscape in California. *Am. Midl. Nat.,* **144**:362–369.

CASE, R. M. 1978. Interstate highway road-killed animals: a data source for biologists. *Wildl. Soc. Bull.,* **6**:8–13.

COMPTON, B. W., J. M. RHYMER AND M. MCCOLLOUGH. 2002. Habitat selection by wood turtles (*Clemmys insculpta*): an application of paired logistic regression. *Ecology,* **83**:833–843.

CROOKS, K. R. 2002. Relative sensitivities of mammalian carnivores to habitat fragmentation. *Cons. Biol.,* **16**:488–502.

EBERHARDT, L. L. AND M. A. SIMMONS. 1987. Calibrating population indices by double-sampling. *J. Wildl. Manage.,* **51**:665–675.

GARDNER, A. L. AND M. E. SUNQUIST. 2003. Opossum, p. 3–29. *In:* G. A. Feldhamer, B. C. Thompson and J. A. Chapman (eds.). Wild mammals of North America: biology, management, and conservation, 2nd ed. Johns Hopkins University Press, Baltimore.

GEHRT, S. D. 2002. Evaluation of spotlight and road-kill surveys as indicators of local raccoon abundance. *Wildl. Soc. Bull.,* **30**:449–456.

———, G. F. HUBERT, JR. AND J. A. ELLIS. 2002. Long-term population trends of raccoons in Illinois. *Wildl. Soc. Bull.,* **30**:457–463.

HAAHR, M. 1998. www.Random.org. Distributed Systems Group, Dept. of Computer Sciences, University of Dublin, Trinity College, Dublin.

HENNER, C. M., M. J. CHAMBERLAIN, B. D. LEOPOLD AND L. W. BURGER, JR. 2004. A multi-resolution assessment of raccoon den selection. *J. Wildl. Manage.,* **68**:179–187.

HICKS, A. C. 1993. Using road-kills as an index to moose population change. *Alces,* **29**:243–247.

HOOGE, P. N., W. EICHENLAUB AND E. SOLOMON. 1999. The animal movement program version 2.0. Alaska Biological Science Center, U.S. Geological Survey, Anchorage, Alaska.

HUNSAKER, D., II, 1977. Ecology of New World marsupials, p. 95–126. *In*: D. Hunsaker II (ed.). The biology of marsupials. Academic Press, New York.

KANDA, L. L. 2005a. Winter energetics of Virginia opossums (*Didelphis virginiana*) and implications for the species' northern distributional limit. *Ecography,* **28**:731–744.

———. 2005b. Factors influencing survival and reproduction in Virginia opossums (*Didelphis virginiana*) at their northern distributional limit. Ph.D. Dissertation, University of Massachusetts, Amherst, Massachusetts. 172 p.

——— AND T. K. FULLER. 2004. Demographic responses of Virginia opossums to limitation at their northern boundary. *Can. J. Zool.,* **82**:1126–1134.

KEATING, K. A. AND S. CHERRY. 2004. Use and interpretation of logistic regression in habitat-selection studies. *J. Wildl. Manage.,* **68**:774–789.

LAY, D. W. 1942. Ecology of the opossum in eastern Texas. *J. Mammal.,* **23**:147–159.

LLEWELLYN, L. M. AND F. H. DALE. 1964. Notes on the ecology of the opossum in Maryland. *J. Mammal.,* **45**:113–122.

MORUZZI, T. L., T. K. FULLER, R. M. DEGRAAF, R. T. BROOKS AND W. LI. 2002. Assessing remotely triggered cameras for surveying carnivore distribution. *Wildl. Soc. Bull.,* **30**:380–386.

REYNOLDS, H. C. 1945. Some aspects of the life history and ecology of the opossum in central Missouri. *J. Mammal.,* **26**:361–379.

ROLLEY, R. E. AND L. E. LEHMAN. 1992. Relationships among raccoon road-kill surveys, harvests, and traffic. *Wildl. Soc. Bull.,* **20**:313–318.

SANDIDGE, L. L. 1953. Food and dens of the opossum (*Didelphis virginiana*) in northeastern Kansas. *Trans. Kansas Acad. Sci.,* **56**:97–106.

SUBMITTED 2 MAY 2005 ACCEPTED 8 FEBRUARY 2006