Human–Wildlife Interactions 6(2):311–326, Fall 2012

An investigation into the use of road drainage structures by wildlife in Maryland, USA

James L. Sparks Jr., University of Maryland Center for Environmental Science, Appalachian Laboratory, 301 Braddock Road, Frostburg, MD 21532, USA
J. Edward Gates, University of Maryland Center for Environmental Science, Appalachian Laboratory, 301 Braddock Road, Frostburg, MD 21532, USA *egates@umces.edu*

***Abstract*:** Culverts have been installed beneath roadways for drainage or to contain existing streams; however, most of them have not been installed to facilitate the passage of wildlife. Prior studies of existing drainage structures used by wildlife have been narrow in scope, targeting a restricted number of culverts, time periods, or locales. Use of culverts by wildlife has been postulated to promote connectivity of fragmented populations and their habitats and to reduce roadkills. We monitored 265 culverts located throughout Maryland, USA, with game cameras in all seasons and in every physiographic province. Our objectives were to identify those species using culverts and their relative occurrence and to determine how culvert and land-use and land-cover (LULC) characteristics affect use. We documented culvert use by 57 wildlife species. We analyzed species affiliation with culvert and LULC variables for 12 species that occurred in ≥30 culverts. Different factors affected culvert use by these species. White-tailed deer (*Odocoileus virginanus*), in particular, used culverts that were wider, taller, and longer than unused culverts, with higher use occurring in the Piedmont physiographic province of Maryland. Our results can be used to make informed decisions on retrofitting existing culverts or designing cost-effective underpasses that provide basic wildlife needs and promote wildlife passage across roadways.

***Key words*:** culvert, game camera, human–wildlife conflicts, Maryland, *Odocoileus virginanus*, road ecology, roadkill, underpass, vertebrate, white-tailed deer

Road drainage structures (hereafter, culverts) have been constructed principally beneath roadways to disperse runoff to waterways and to provide for intermittent and perennial streams (Maryland State Highway Administration [SHA] 2003). Research has also shown that many wildlife species often use such structures to cross roads, thereby mitigating many of the negative effects caused by roads by enhancing connectivity of fragmented populations and their habitats and reducing roadkills (Forman and Alexander 1998, Spellerberg 1998, Trombulak and Frissel 2000, Forman et al. 2003, Watson 2005). However, most studies of wildlife use of road culverts have been limited in scope, targeting a restricted number of culverts, time periods, or locales (Foster and Humphrey 1995, Rodriguez et al. 1996, Clevenger and Waltho 2000, Clevenger et al. 2001*a*, Ng et al. 2004, Aresco 2005, Ascensão and Mira 2007, Grilo et al. 2008).

There is a pressing need to evaluate the effectiveness of existing drainage culverts as wildlife passageways throughout different seasons and regions. To address this need in Maryland, we monitored wildlife use of 265 road culverts located throughout the state. Our objectives were to: (1) identify wildlife species that use existing culverts and their relative occurrence and (2) to determine the effect of culvert and land-use and land-cover (LULC) characteristics on use (Rodriguez et al. 1996, Spellerberg 1998, Smith 2003, Hardy et al. 2004, Ng et al. 2004, Arizona Game and Fish Department [AZGFD] 2006). We especially focused on white-tailed deer (*Odocoileus virginianus*), as this species is one of the largest mammals known to use culverts in Maryland and is of great concern to motorists and the SHA. We evaluated the effect of culvert features on use, seasonal and regional differences, and the relationship between culvert use by deer and deer roadkills.

Study area

Maryland is a mid-Atlantic state that spans 5 biotic regions (i.e., physiographic provinces) from the Appalachian Plateau (highest elevation = 1,024 m) to the Coastal Plain (lowest elevation = sea level, 0 m; Stewart and Robbins 1958; Paradiso 1969). Mixed mesophytic forest types are found at the highest elevations, with xeric oak (*Quercus* spp.)-hickory (*Carya* spp.) being the more common forest type in the Piedmont and oak-pine (*Pinus* spp.) in the Coastal Plain (Braun 1950). All sizable forests in Maryland are second-growth (Braun 1950). Average annual temperatures ranged from 9° C in the extreme western uplands to 15° C in the maritime southeast (<CityData.com> 2010). Average annual rainfall was around 109 cm and was fairly consistent across the entire state (<NationalAtlas.gov> 2010).

We classified the Appalachian Plateau, Ridge and Valley, and Blue Ridge provinces as 1 ecologically similar region that we called the Appalachian Mountains. We did this to maintain a more parsimonious sampling of the western uplands. The Appalachian Mountain region (4,672 km^2) is primarily wooded and rural, having a human population density of 66 people/km^2 (U.S. Census Bureau 2010) and road density of 1.7 km/km^2. The Piedmont Plateau Province (6,787 km^2) had urban and suburban elements, with a human population density of 297 people/km^2 (U.S. Census Bureau 2010) and road density of 3.0 km/km^2. The Western Shore (6,155 km^2) of the Coastal Plain province had an urban and suburban human population density of 284 people/km^2 (U.S. Census Bureau 2010) and road density of 3.2 km/km^2, whereas, the Eastern Shore (7,973 km^2) was primarily agricultural, with a much lower human population density of 47 people/km^2 (U.S. Census Bureau 2010) and road density of 1.3 km/km^2.

Methods

Culvert selection

Culverts were selected at random from the original drainage structure inventory database developed by SHA. We started with 11,162 structures that were pared down to 1,848 by selecting those that were: (1) >6.1 m in length; (2) >1.2 m in diameter; (3) located at a waterway, a relief for a waterway, or other depression; and (4) owned by SHA. Using a random number generator, we then selected 300 structures from this list. Because some structures either could not be found or were eliminated because of flooding or vandalism, our final count was 265 road culverts distributed throughout Maryland (Figure 1).

Monitoring culvert-use by wildlife species

We placed infrared motion detecting digital cameras (Moultrie Game Spy i40 digital game camera; Moultrie Feeders, Alabaster, Ala.) in 265 culverts throughout Maryland. During the process of locating culverts in the field with a GPS receiver, we included a handful of culverts that did not necessarily meet the selection criteria noted above. Our final sample had a minimum width and height of 0.61 m × 0.61 m and a maximum width and height of 4.57 m × 4.57 m. All culverts were located under paved roads. Camera effort per square kilometer (× 100 k) was nearly equal among the Appalachian Mountain (13.56), Piedmont (14.07), and Western Shore (13.48), while it was considerably less on the Eastern Shore (3.94). Each culvert site was surveyed for 14 nights at least twice per season, or 9 times, from August 28, 2008, to January 3, 2011. We logged 31,317 camera trap nights. Game cameras are the most effective technique among a variety of noninvasive methods for detecting the greatest number of species (Wolf et al. 2003, Gompper et al. 2006, Curtis et al. 2009, Ford et al. 2009).

Figure 1. Large double culvert.

We mounted cameras at the approximate midpoint of the culvert on a 12.7-cm steel angle bracket, 61 cm from the bed or water surface in the culvert. Exceptions were made when the drainage structure was too low to enter. In these situations, the camera was mounted on 1 end, either on a pressure-treated stake or upside down from a hanging angle bracket mount. In 4 cases, urban culverts had only 1 passable end with the other leading to multiple street-level, storm drains. The camera was then mounted in the culvert at the estimated mid-point of the road.

Cameras were set to 1-minute picture intervals to minimize taking pictures of the same animal. We counted each identifiable animal in a photograph as a single animal-use of a culvert, equivalent to a crossing. Our cameras

Table 1. Number of culverts sampled in Maryland by culvert shape and associated substrate.

	Substrate						
Shape	Silt	Sand	Gravel	Cobble	Steel	Concrete	Total
Arch	5	3	7	2	0	3	20
Box	17	14	20	8	0	42	101
Cylinder	23	18	13	10	35	45	144
Total	45	35	40	20	35	90	265

were triggered by moving heat signatures and, therefore, responded primarily to mammals and birds. We made direct observations of reptiles, amphibians, and other vertebrate fauna when we visited the sites to place and remove cameras.

Individual culverts were measured for openness (O = [width × height] ÷ Length [Yanes et al. 1995]). Openness is believed to be an important variable affecting the passage of large mammals through culverts (Yanes et al. 1995, Clevenger and Waltho 2000, Clevenger et al. 2001*a*). We measured the distance to woody vegetation cover on both ends of the culvert and the percentage visibility of the opening (i.e., lack of vegetation), on both ends. The depth of water at the camera posting site was measured during each visit. We used data provided by SHA concerning culvert dimensions and road characteristics.

Data analysis

We assumed that each culvert was independent of the others. This assumption was challenged at 27 sites that had double-cell culverts (Figure 1) and one that had triple cells. We retained the assumption, because we were analyzing species use of culvert type and related characteristics, not individual animal-use per individual culvert location. Our calculations were focused on frequency of use, not individual use. Many multiple-cell culverts also had differences in substrate type, and a few had different dimensions. We wanted to compare these differences rather than lose valuable data.

We used a multivariate method, Canonical Correspondence Analysis (CCA, CANOCO 4.5, Ithaca, N.Y.), to elucidate the relationships among species assemblages captured by camera traps and their environment. Twelve species that were found in ≥30 culverts and 12 structural and environmental variables were used in the analyses. Culvert structural variables are presented in all capital letters (see Figure 2 caption). Species counts were log-transformed before ordination. We used 499 permutations in a Monte Carlo permutation test.

We also used CCA to associate the 12 species with land-use and land-cover (LULC) data within a 1-km radius of each culvert site. The 1-km radius was determined to be the optimum size, including the maximum number of LULC types while retaining focus on the culvert site. ArcGIS 9.3 (ESRI ©1995–2010, Redlands, Calif.) was used to determine the proportion of LULC types within that radius. Land-use and land-cover categories were based on U.S. Geological Survey standards (Anderson et al. 1976). Eleven LULC variables were included in the analyses (see Figure 3 caption). Species counts were log transformed before ordination. We used 499 permutations in a Monte Carlo permutation test.

We analyzed the effect of culvert shape, substrate, and fence arrangement on white-tailed deer using a χ^2 goodness-of-fit test (Fowler and Cohen 1990, PASW Statistics v. 17.0.3 [SPSS, Chicago, Ill.]). Culverts occurred in 1 of 3 shapes and potentially 1 of 6 substrate types (Table 1). We described 7 categories of fencing arrangements (Table 2). We compared seasonal and regional differences in white-tailed deer capture rates among culvert cells by using 1-way ANOVA (Zar 1999; PASW Statistics v. 17.0.3 [SPSS, Chicago, Ill.]). We used ArcGIS 9.3 to further analyze culvert site use by white-tailed deer across the 4 physiographic regions. To counteract the problem of multiple comparisons, we used t-tests with a Bonferonni

Table 2. Descriptions of fence arrangements for each culvert cell encountered during this study in Maryland.

Type	Description	No. of culvert cells	Percentage of total
1	Sites with both sides having a fence ≥1.5 m tall, the fence being the same or lesser distance from the road as the culvert opening, thereby forming a wildlife guide or funnel.	10	4
2	Sites with 1 side having a fence ≥1.5 m tall, the fence being the same or lesser distance from the road as the culvert opening, thereby forming a wildlife guide or funnel.	19	7
3	Sites with both sides having a fence ≥1.5 m tall, both fences being at greater distances from the road to the culvert opening, thereby forming a potential barrier.	6	2
4	Sites with 1 side having a fence ≥1.5 m tall, the fence being at a greater distance from the road to the culvert opening, thereby forming a potential barrier.	21	8
5	Sites with 1 or both sides having a fence <1.5 m tall, or otherwise of a type not considered to hinder or direct wildlife toward the culvert opening.	12	4
6	Sites associated with street level storm drain fields at 1 opening.	5	2
7	Sites having no fences.	192	73
	Total	265	100

correction to compare the significance of structural and environmental variables at culverts that were used by white-tailed deer versus culverts that were not used by white-tailed deer.

We collected deer mortality data from the Large Animal Removal Reporting System (LARRS; Maryland State Highway Administration, Baltimore, Md.) and used it to plot a regression curve (PASW Statistics v. 17.0.3 [SPSS, Chicago, Ill.]) of deer roadkills near a culvert site versus photographic captures of deer at those culvert sites during the same 2.3-year monitoring period. Road-killed deer were counted within 0.40 km along the road, using the culvert site as a center point for a total 0.80 km length of road. We counted locations for this analysis as 236 culvert sites instead of the 265 individual culvert cells used in previous calculations. Multiple culvert cells at a site were counted as one. This gave us a more accurate count of deer-use per site, one that could be more readily compared to road-kill statistics for the same site.

Results

From August 28, 2008, to January 3, 2011, we recorded 32,783 identifiable images of wildlife. Forty species were recorded by camera traps (Table 3), and an additional 17 species were noted by direct visual observation (Table 4).

Effect of culvert characteristics on wildlife use

Summary of CCA. Culvert width was correlated most strongly with Axis 1 (R = 0.514), and culvert length was most strongly correlated with Axis 2 (R = -0.463). The Monte Carlo permutation test (499 permutations) was significant ($P = 0.002$) for the first canonical axis and for all canonical axes. Variance inflation factors (VIF) were between 1.06 and 2.95, indicating an acceptable or low multicollinearity among the environmental variables. The 4 axes explained 16% of the variance in the 12 major culvert-using species. The first and second axes explained 67% of the variation in the species–environment relationship.

Species–environment relationships. The selected species exhibited different responses to the structural and environmental variables found at culverts (Figure 2). The great blue heron was most closely associated with increasing average water depth and openness

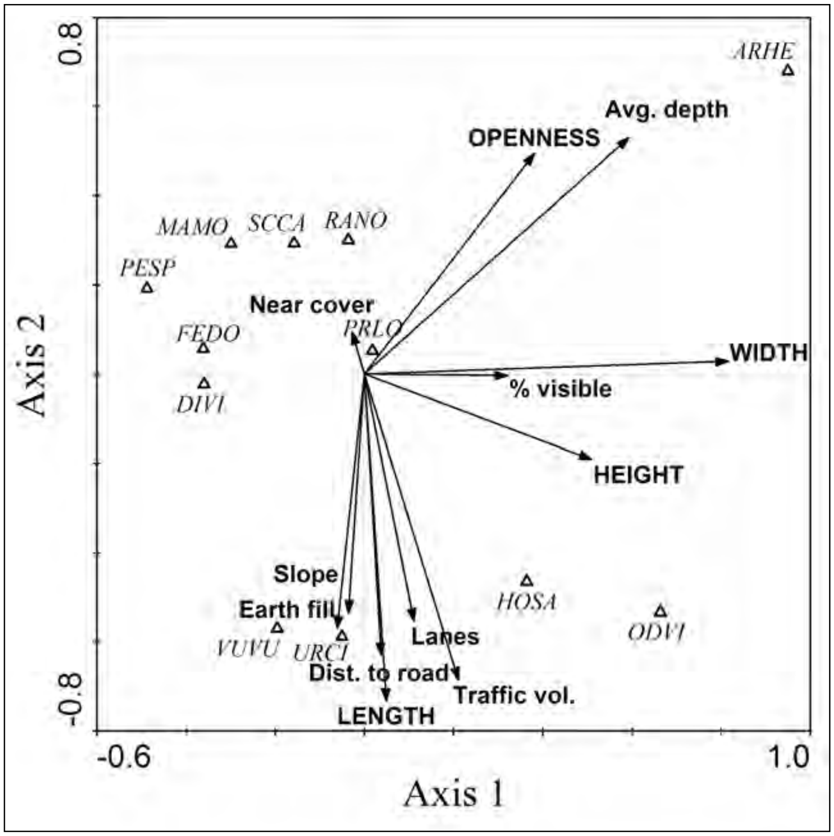

Figure 2. Canonical Correspondence Analysis (CCA) biplot showing the relationship among 12 vertebrate species occurring in ≥30 culverts (Δ) and 12 environmental and structural variables (arrows) at 265 road drainage structure cells in Maryland. The species are: PRLO = *Procyon lotor* (northern raccoon), DIVI = *Didelphis virginianus* (Virginia opossum), FEDO = *Felis domesticus* (domestic cat), MAMO = *Marmota monax* (woodchuck), ARHE = *Ardea herodias* (great blue heron), VUVU = *Vulpes vulpes* (red fox), HOSA = *Homo sapiens* (human), ODVI = *Odocoileus virginianus* (white-tailed deer), SCCA = *Sciurus carolinensis* (eastern gray squirrel), RANO = *Rattus norvegicus* (Norway rat), URCI = *Urocyon cinereoargenteus* (common gray fox), and PESP = *Peromyscus* spp. (white-footed or deer mouse). The environmental and structural variables are: Avg. depth = average depth of water, WIDTH = width of culvert, HEIGHT = height of culvert, LENGTH = length of culvert, OPENNESS = culvert openness ratio ([width × height]/length), Traffic vol. = average daily traffic volume, Lanes = number of traffic lanes, Dist. to road = distance from the culvert opening to the road's edge, Earth fill = the height of earth fill measured from the top of the culvert to the bottom of the paved surface, Slope = degrees of slope from the culvert opening to the edge of the paved surface, % visible = mean percent visibility of the culvert opening, and Near cover = proximity of nearest woody vegetation. Culvert dimensions are stated in all capital letters.

at culverts. Woodchucks, eastern gray squirrels (*Scurius carolinensis*), Norway rats (*Rattus norvegicus*), and white-footed or deer mice (*Peromyscus* spp.) were found in culverts with decreasing culvert length, width, and height and moderate openness and water depth. Virginia opossums (*Didelphis virginianus*) and domestic cats (*Felis domesticus*) were associated with culverts having decreasing length, height, width, and water depth. Northern raccoons (*Procyon lotor*) that were placed near the center of the 2 axes were not strongly associated with any particular variable. Raccoons were found in all types of culverts. The 2 largest species, humans and deer, were associated with wide, high, and long culverts; heavy traffic volume; and increasing number of lanes, slope, and earth fill. Both gray and red foxes (*Vulpes vulpes*) used similar culverts characterized as longer, farther from the road, with greater traffic volume and number of lanes, and having steeper slopes, more earth fill above the culvert, less water, and being less open.

Effect of land use and land cover on wildlife use at culverts

Summary of CCA. Cultivated crops were correlated most strongly with Axis 1 (R = -0.406)

Table 3. Forty species that used culverts and were detected by camera traps in Maryland during this study.

Scientific name	Common name	Culvert cells used	Number captured	Captures/ night × 100
Procyon lotor	Northern raccoon	246	24,800	79.19
Didelphis virginiana	Virginia opossum	129	1,076	3.44
Felis domesticus	Domestic cat	103	2,169	6.93
Marmota monax	Woodchuck	97	822	2.62
Ardea herodias	Great blue heron	77	545	1.74
Vulpes vulpes	Red fox	66	928	2.96
Homo sapiens	Human	66	399	1.27
Odocoileus virginianus	White-tailed deer	63	1,903	6.08
Sciurus carolinensis	Eastern gray squirrel	53	531	1.70
Rattus norvegicus	Norway rat	52	326	1.04
Urocyon cinereoargenteus	Common gray fox	47	294	0.94
Peromyscus spp.	White-footed or deer mouse	33	296	0.95
Anas platyrhynchos	Mallard	28	635	2.03
Tamias striatus	Eastern chipmunk	28	105	0.34
Castor canadensis	Beaver	21	133	0.42
Canis familiaris	Domestic dog	19	81	0.26
Mustela vison	American mink	18	39	0.12
Sylvilagus floridanus	Eastern cottontail	18	39	0.12
Lutra canadensis	Northern river otter	18	51	0.16
Aix sponsa	Wood duck	13	50	0.16
Corvus brachyrhynchos	American crow	11	96	0.31
Branta canadensis	Canada goose	10	198	0.63
Mephitis mephitis	Striped skunk	8	24	0.08
Ondatra zibethicus	Muskrat	7	22	0.07
Turdus migratorius	American robin	6	7	0.02
Hirundo rustica	Barn swallow	5	726	2.32
Sayornis phoebe	Eastern phoebe	3	34	0.11
Dumetella carolinensis	Gray catbird	3	5	0.02
Quiscalus quiscula	Common grackle	2	20	0.06
Mustela frenata	Long-tailed weasel	2	5	0.02
Butorides virescens	Green heron	2	2	0.01
Bos taurus	Domestic cattle	1	547	1.75
Melospiza melodia	Song sparrow	1	5	0.02
Columba livia	Rock pigeon	1	2	0.01
Sturnus vulgaris	European starling	1	1	0.00
Thryothorus ludovicianus	Carolina wren	1	1	0.00
Aythya valisineria	Canvasback	1	1	0.00
Nerodia sipedon	Northern watersnake	1	1	0.00
Chelydra serpentina	Snapping turtle	1	1	0.00
Zapus hudsonius	Meadow jumping mouse	1	1	0.00

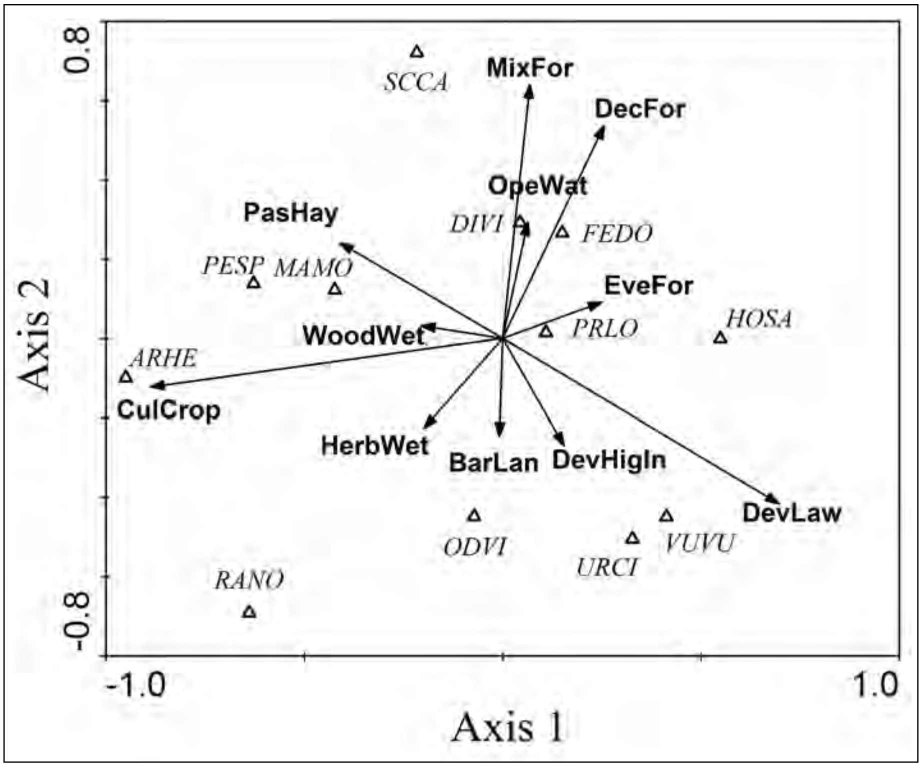

Figure 3. Canonical Correspondence Analysis (CCA) biplot showing the relationship among 12 vertebrate species occurring in ≥30 culverts (Δ) and 13 Land Use and Land Cover (LULC) variables (arrows) found within 1 km of each culvert at 236 road drainage structure sites in Maryland. The LULC variables are: OpeWat = Open water, DevLaw = Developed open space/lawns, DevHighIn = Developed high intensity or urban, BarLan = Barren land without vegetation cover, DecFor = Deciduous forest, EveFor = Evergreen forest, MixFor = Mixed evergreen and deciduous forest, PasHay = Pasture and hay, CulCrop = Cultivated crops, WoodWet = Woody wetlands, and HerbWet = Herbaceous wetlands. See Figure 2 caption for species codes.

and mixed forests were most strongly correlated with Axis 2 (R = 0.255). The Monte Carlo permutation test (499 permutations) was significant (P = 0.002) for the first canonical axis and for all canonical axes. Variance inflation factors (VIF) were between 1.35 and 3.34, indicating a low multicollinearity among the selected LULC variables. Two variables, Developed Low Intensity and Developed Medium Intensity, were removed owing to issues of multicollinearity with the variable Developed High Intensity. The 4 axes explained 8% of the variance in the 12 major culvert-using species. The first and second axes explained 52% of the variation in the species-environment relationship.

Species-environment relationships. The selected species showed different responses to the LULC variables in the vicinity of culverts (Figure 3). Northern raccoons, Virginia opossums, and domestic cats did not show a strong affiliation for any particular cover type. Eastern gray squirrels did associate with a greater proportion of mixed and deciduous forests. White-footed mice (*Peromyscus leucopus*) or deer mice (*Peromyscus maniculatus*) and woodchucks generally used culvert sites predominated by pasture, hay fields, and woody wetlands. Use of culverts by great blue herons was strongly associated with cultivated crops. Norway rats were loosely affiliated with a greater extent of herbaceous wetlands. Deer appeared to use culverts most frequently at sites surrounded by barren lands lacking vegetation. Red and common gray foxes used culverts more often in areas of highly developed land and lawns. Humans used culverts most frequently in areas with developed lawns.

Effect of culvert characteristics on use by white-tailed deer

White-tailed deer (n = 63 culverts) were

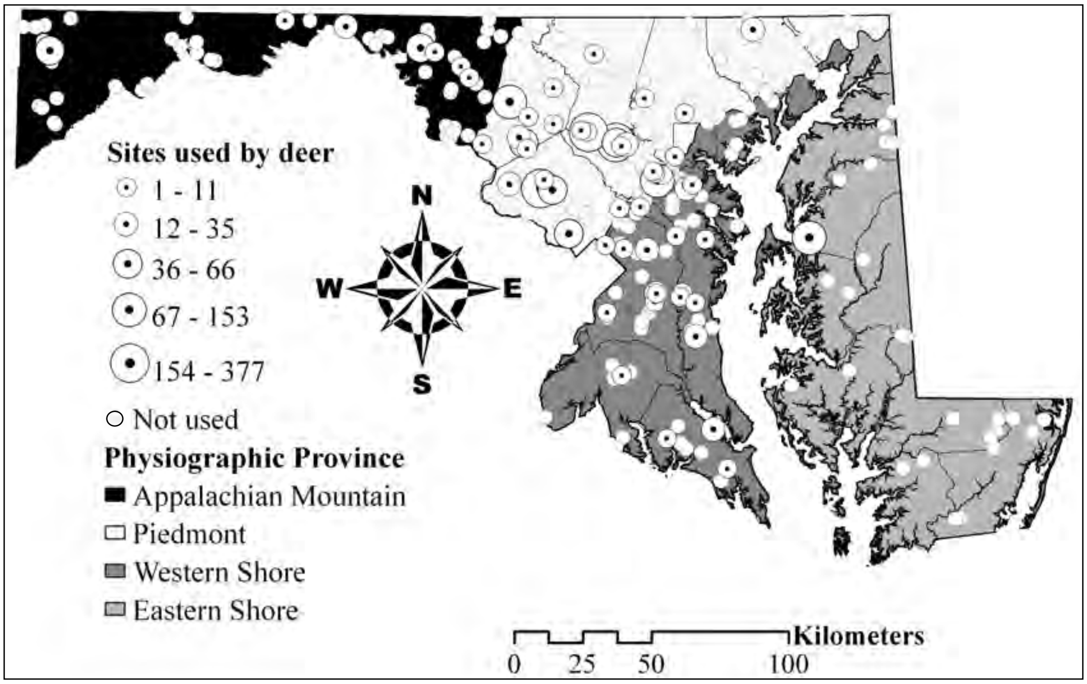

Figure 4. Physiographic regions and location of culvert sites used by white-tailed deer (n = 59) and those not used by white-tailed deer (n = 177) in Maryland from August 28, 2008, to January 3, 2011.

somewhat associated with a particular culvert shape (χ^2_2 = 5.59, P = 0.06), i.e., the box culvert. They were not associated with a particular substrate type (χ^2_5 = 7.46, P = 0.188). Culverts with no fence on either side of the highway were used the least by deer (χ^2_5 = 26.49, P < 0.001). Culverts used by white-tailed deer generally had shallower water; were wider, taller, and longer; and had more traffic lanes than those receiving no use. Openness ratio was not a significant factor (Table 5).

Effect of season and physiographic province on culvert use by white-tailed deer

White-tailed deer frequency of culvert use differed among seasons ($F_{3,196}$ = 3.40, P = 0.02). Deer used culverts the least during spring ($\bar{x}$ = 0.40 ± 0.06 SE, n = 54) and the most during summer ($\bar{x}$ = 0.94 ± 0.17 SE, n = 57); use in spring and summer were not significantly different from use in fall ($\bar{x}$ = 0.68 ± 0.12 SE, n = 65) or winter ($\bar{x}$ = 0.48 ± 0.09 SE, n = 24). Mean frequency of culvert use by white-tailed deer differed also among regions ($F_{3,261}$ = 5.99, P < 0.001). White-tailed deer use of culverts was greatest in the Piedmont region ($\bar{x}$ = 0.15 ± 0.04 SE, n=82), particularly in Howard, Montgomery, and Frederick counties (Figure 4). There was no difference among the Appalachian Mountain ($\bar{x}$ = 0.01 ± 0.06 SE, n = 61), Western Shore ($\bar{x}$ = 0.01 ± 0.00 SE, n = 88), or Eastern Shore ($\bar{x}$ = 0.01 ± 0.02 SE, n = 34). White-tailed deer used only 1 culvert site on the Eastern Shore.

White-tailed deer roadkill and use of culvert sites

One hundred forty-three of the 236 combined culvert sites were associated with road-killed deer, and deer were detected by cameras at 59 of these culvert sites. There was a positive quadratic relationship between road-killed white-tailed deer and use of culvert sites (r^2 = 0.24; Figure 5). When we compared deer roadkills at culvert sites where they had been detected by cameras (n = 59) to roadkills at randomly selected sites along the highway (n = 64), we found that culvert sites used by deer had a greater number of road-killed deer than did the randomly selected sites (t_{121} = 2.52, P = 0.01).

Discussion

Our study identified a large number of wildlife species using existing culverts to cross beneath roadways. We detected 57 species, and many passed through each of the 265 culverts that we monitored in Maryland. This number of species and number of culverts sampled are the largest reported in the literature (Foster and Humphrey 1995, Yanes et al. 1995, Clevenger and Waltho 2000, Ng et al. 2004, Clevenger et al. 2001*a*, Brudin 2004, Gordon and Anderson 2004, Donaldson 2006, Rogers et al. 2010).

Effect of culvert characteristics on wildlife use

Species responded differentially to the variation in environmental and structural characteristics of culverts, demonstrating that some designs and locations are better than others for certain species (Carbaugh et al. 1975, Clevenger and Waltho 2005, Grilo et al. 2008).

Table 4. Thirty-two terrestrial vertebrate species that we observed in culverts.

Scientific name	Common name	Culvert cells used	Number observed
Lithobates clamitans[1]	Green frog	38	138
Sayornis phoebe	Eastern phoebe	12	23
Hirundo rustica	Barn swallow	11	116
Odocoileus virginianus	White-tailed deer	9	13
Lithobates sphenocephalus[1]	Southern leopard frog	9	129
Anas platyrhynchos	Mallard	7	41
Ardea herodias	Great blue heron	7	7
Lithobates palustris[1]	Pickerel frog	7	10
Nerodia sipedon	Northern watersnake	6	6
Plestiodon fasciatus[1]	Common five-lined skink	5	8
Chelydra serpentina	Snapping turtle	5	5
Homo sapiens	Human	3	5
Vulpes vulpes	Red fox	3	3
Pantherophis alleghaniensis[1]	Black rat snake	3	3
Lithobates pipiens[1]	Northern leopard frog	3	5
Plethodon cinereus[1]	Eastern red-backed salamander	3	3
Felis domesticus	Domestic cat	2	2
Marmota monax	Woodchuck	2	2
Thamnophis sirtalis[1]	Common gartersnake	2	2
Sylvilagus floridanus	Eastern cottontail	2	2
Lithobates catesbeianus[1]	Bullfrog	2	2
Pseudacris crucifer[1]	Spring peeper	2	2
Microtus pennslvanicus[1]	Meadow vole	1	1
Peromyscus spp.	White-footed or deer mouse	1	1
Sciurus carolinensis	Eastern gray squirrel	1	2
Branta canadensis	Canada goose	1	1
Trachemys scripta elegans[1]	Red-eared slider	1	1
Chrysemys picta[1]	Painted turtle	1	1
Desmognathus fuscus[1]	Northern dusky salamander	1	100
Eurycea bislineata[1]	Northern two-lined salaman-der	1	1
Anaxyrus americanus[1]	American toad	1	1
Lithobates sylvaticus[1]	Wood frog	1	1

[1]Seventeen species, primarily amphibians and reptiles, were never recorded by the infrared, motion-detecting cameras.

Table 5. Comparison of structural and environmental variables at culverts with and without white-tailed deer use. Culvert dimensions are stated in all capital letters. Based on Bonferroni correction, only $P \leq 0.004$ was considered significant.

	Culverts with white-tailed deer					Culverts without white-tailed deer					*t*-value	*P*-value
	Maximum	Mean	± SE	Minimum	*n*	Maximum	Mean	± SE	Minimum	n		
Average water depth (cm)	46.25	6.16	0.90	0.00	63	82.50	10.80	1.02	0.00	199	-3.404	0.001
Visibility of entrance (%)	100.00	88.77	2.28	17.50	63	100.00	88.80	1.21	15.00	202	-0.013	0.990
Near cover (m)	200.00	7.03	3.24	0.00	63	500.00	10.32	2.91	0.00	200	-0.588	0.557
Distance to road (m)	90.00	11.98	1.85	0.00	63	65.00	7.67	0.78	0.00	202	2.475	0.014
Slope (˚)	47.50	20.63	1.54	0.00	63	50.00	16.50	1.03	0.00	202	2.234	0.027
WIDTH (m)	5.18	2.99	0.13	1.42	63	5.79	2.26	0.06	0.71	202	5.510	<0.001
HEIGHT (m)	4.57	2.24	0.08	0.99	63	5.18	1.77	0.04	0.61	202	5.213	<0.001
LENGTH (m)	256.64	61.52	5.57	9.14	63	197.51	40.65	2.51	7.32	201	3.822	<0.001
OPENNESS ([w × h]/l)	1.68	0.21	0.04	0.01	63	1.16	0.16	0.01	0.00	201	1.159	0.250
Earth fill (m)	10.67	3.20	0.35	0.00	63	18.03	2.82	0.26	0.00	196	0.764	0.446
Number of lanes	12.00	4.10	0.31	1.00	63	10.00	3.04	0.12	1.00	201	3.161	0.002
Traffic volume (vehicles/day)	230,300.00	41,351.38	57,98.14	575.00	63	191,575.00	23,599.12	2,312.18	325.00	194	2.844	0.006

Great blue herons, large wading birds that feed in shallow waters (Butler 1997), are capable of flight; so, we surmised that they did not need culverts to cross roads. However, their occurrence in culverts with relatively deep water is likely related to their foraging behavior as they feed on small fish, amphibians, and a variety of aquatic invertebrates (Naumann 2002). Great blue herons also were reported drinking or foraging in culverts in Pennsylvania (Brudin 2004) and using culverts in Virginia (Donaldson 2006). They also used wider and taller culverts, probably to accommodate their 2-m wingspan. Woodchucks, eastern gray squirrels, Norway rats, and white footed or deer mice used culverts with similar characteristics (i.e., shorter in length, narrower in width, and less tall). Except for eastern gray squirrels, which are primarily arboreal (Koprowski 1994), such culverts, being smaller and more burrow-like, were probably used for transit by these fossorial and semi-fossorial species (Kwiecinski 1998, Nowak and Paradiso 1983, Lackey et al. 1985). Other wildlife have been documented using culverts apparently for transit, foraging, and drinking (Brudin 2004, Donaldson 2006). Virginia opossums and domestic cats also utilized culverts that were generally smaller and had less water. Northern raccoons, which are highly adaptable omnivores inhabiting diverse habitats (Lotze and Anderson 1979), occurred in nearly all culverts. Humans and white-tailed deer typically used culverts with similar structural variables, e.g., taller, wider, and longer culverts at sites with elevated vehicular traffic volume. The ecologically similar and sympatric red and gray foxes (Fritzell and Haroldson 1982, Larivière and Pasitschniak-Arts 1996) used culverts where the entrance was farther from the road bed, the associated road had greater traffic volume, the culvert had less water, and the embankment had steeper slopes.

Effect of land use or land cover at culverts on wildlife use

Land use and land cover can affect the occurrence of different wildlife species, and appeared to influence culvert use by certain species. Humans and red and gray foxes were associated with developed lawns. Red and gray foxes were known to inhabit urban areas (Larivière and Pasitschniak-Arts 1996, Riley 2006, Gosselink et al. 2007). Virginia opossums and domestic cats used culverts near deciduous forests and open water. Virginia opossums were associated with waterways and riparian forests (Llewellyn and Dale 1964, McManus 1974). White-tailed deer use of culverts was loosely associated with barren land without vegetation. White-tailed deer were more likely to be found in forested riparian zones in less forested areas (Smith 1991). Perhaps this resulted in deer using culverts more frequently in the Piedmont. The lands from the Piedmont to the Coastal Plain have the least forest cover and the greatest fragmentation of the remaining forests (McElfish and Wilkinson 2000).

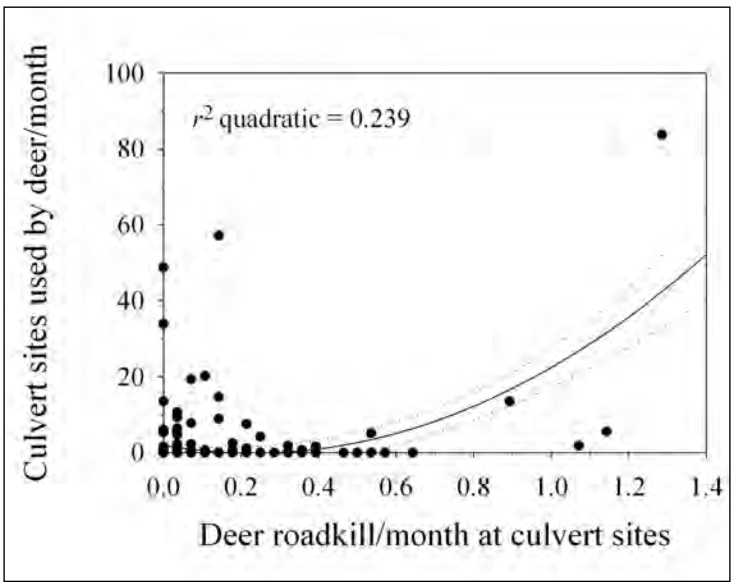

Figure 5. The relationship between the use of culvert sites by white-tailed deer documented by camera traps and white-tailed deer roadkill as documented by the Maryland State Highway Administration Large Animal Removal Reporting System (LARRS) during the course of this survey. The slope (culvert-use by white-tailed deer $\hat{Y} = 1.984 - 17.870x + 38.337x^2$ [where x = deer road-kill rate]) was considered significant ($F_{2, 233} = 36.603$, $P \leq 0.001$). There was a positive relationship between roadkills and use of culverts by white-tailed deer, but it was weakly correlated ($r^2 = 0.239$).

Effect of culvert characteristics on use by white-tailed deer

Most large mammals are thought to use culvert underpasses with openings that are larger than needed for drainage. Research in Colorado suggested that 4.3 m was a minimum width and height dimension for mule deer (*Odocoileus hemionus*; Reed et al. 1975). Minimum culvert dimensions for mule deer in Wyoming were found to be 6.1 m wide × 2.4 m tall (Gordon and Anderson 2004). A survey of 9 box culverts used by white-tailed deer in Pennsylvania had average dimensions of 4.6 m wide × 2.5 m tall (Brudin 2004). We found that white-tailed deer can use smaller culverts than have been documented in previous studies. Average width and height of the 63 culverts used by white-tailed deer in our study were 3.0 m × 2.2 m. Ungulates are known to use culverts of smaller dimensions in urban and suburban settings (Bisonette and Cramer 2008). Further, use of small drainage structures may be learned by offspring accompanying a parent. We documented 72 occasions of a doe leading young deer through culverts. Deer often travel in matriarchal family groups (Smith 1991). Such behavior may familiarize offspring with alternative road crossings offered by culverts.

Openness ratios have been used to determine whether or not a certain size of culvert passing under a road or a certain width is suitable for particular wildlife species. As culvert length increases, the cross-sectional area of the culvert opening would need to increase to accommodate different-sized animals. For white-tailed deer, the suggested openness ratio has ranged from 0.6:1.0 (Ontario Ministry of Transportation [OMOT] 2006). However, mule deer and elk have been documented using narrow crossing structures with long dimensions and low openness ratios in Banff National Park, Canada (Clevenger and Waltho 2005). Openness ratios did not seem to be as important as width and height for the passage of white-tailed deer in our study. Our results suggest that white-tailed deer will use longer culverts with lower openness ratios, provided that the openings are wide enough and tall enough to allow unrestricted passage.

An unobstructed view of the far side of a culvert can also be an important factor influencing animal use of a culvert (Foster and Humphrey 1995, Arizona Game and Fish Department 2006). We found that 50 culverts (79%) used by white-tailed deer had an 80% or better unobstructed view of the far side. It is recommended that culvert entrances be kept clear of vegetation when planning for deer use of culverts (Arizona Game and Fish Department 2006).

Effect of season and physiographic province on culvert-use by white-tailed deer

Use of culverts by white-tailed deer varied with season and physiographic province. Deer used culverts mostly in the summer and fall and least in the winter and spring. Deer may be more restricted in their foraging during winter (Beier and McCullough 1990). White-tailed deer used culverts most frequently in the Piedmont region, perhaps because their densities are higher in these landscapes of second-growth forest fragments, croplands, and suburbs (Smith 1991). Forested riparian pathways in more modified landscapes, such as the Piedmont, may also serve as travel corridors, guiding more deer toward stream culverts than would have occurred in well-forested regions, such as the Appalachian Mountains (Smith 1991, Naiman and Décamps 1997, Whittaker and Lindzey 2004).

White-tailed deer roadkill and use of culvert sites

There was a higher number of road-killed deer at culverts used by deer than at random sites without culverts. This relationship could be due to higher local deer population densities in the vicinity of drainages noted in the previous section. Road-killed deer were most frequently associated with highway bridges in Iowa (Hubbard et al. 2000). Permanent protection and restoration of riparian forests for the benefit of wildlife and reduction of sediments and nutrients entering streams are encouraged by the U.S. Department of Agriculture under the Conservation Reserve Program (2012). Our data further showed that many culverts used by deer also had relatively low (≤0.25 kills/month) roadkills. Our interpretation of the results is confounded by the fact that: (1) many culvert sites with low roadkills had no culvert use by deer, and (2) a handful of culverts used by deer had extremely high roadkills; 1 culvert in particular had both the highest use and highest deer mortality observed during the study. More research is needed to tease apart the relationship between culvert use and roadkills, including accurate estimates of local deer population densities.

Management implications

We demonstrated that existing culverts can provide basic needs and that underpasses across roads are used by a high diversity of wildlife species. Species-specific differences in use of culverts were related to differences in structure and the local and regional environment. Results from our study can be used as a guide to the design and placement of future wildlife underpasses, as well as retrofitting existing structures. For example, placement of properly sized culverts along riparian corridors and road-kill hot spots with appropriately sized guide fencing should encourage their use by white-tailed deer and aid in reducing deer–vehicle collisions (Ward 1982, Gates 1993, Clevenger et al. 2001*b*). Alternatively, allometrically scaled wildlife underpasses can be constructed at distances reflecting the home range size and encompassing suitable habitat of the target species, thereby providing basic wildlife needs and improving wildlife movements across paved roads (Bisonette and Cramer 2008).

Acknowledgments

We thank K. Parsh, C. Yeaney, J. Utz, J. Saville, L. Smith, and M. Brady for their invaluable help in the field and in the office. J. B. Churchill and S. M. Guinn provided assistance with all GIS-related aspects of this project. S. Hertz and N. W. Bucke were our primary technical and research liaisons with the Maryland State Highway Administration. The original concept for this project came from W. L. Branch, who provided comments and suggestions on the initial proposal and was helpful throughout the field work. Comments by W. J. Landesman and 2 anonymous reviewers greatly improved the manuscript. This project was made possible with funding from the Maryland State Highway Administration. This is UMCES Appalachian Laboratory Scientific Contribution No. 4683.

Literature cited

Anderson, J. R., E. E. Hardy, J. T. Roach, and R. E. Witmer. 1976. A land-use and land-cover classification system for use with remote sensor data. Geological Survey Professional Paper 964. U.S. Geological Survey, Washington, D.C., USA.

Aresco, M. J. 2005. Mitigation measures to reduce highway mortality of turtles and other herpetofauna at a north Florida lake. Journal of Wildlife Management 69:549–560.

Arizona Game and Fish Department. 2006. Guidelines for culvert construction to accommodate fish and wildlife movement and passage. Arizona Game and Fish Department, Habitat Branch, Phoenix, Arizona, USA, <http://www.azgfd.gov/hgis/pdfs/CulvertGuidelinesforWildlifeCrossings.pdf>. Accessed July 18, 2012.

Ascensão, F., and A. Mira. 2007. Factors affecting culvert use by vertebrates along two stretches of road in southern Portugal. Ecological Research 22:57–66.

Beier, P., and D. R. McCullough. 1990. Factors influencing white-tailed deer activity patterns and habitat use. Wildlife Monographs 109:3–51.

Bissonette, J. A., and P. C. Cramer. 2008. Evaluation of the use and effectiveness of wildlife crossings. National Cooperative Highway Research Program Report 615. Transportation Research Board, Washington, D.C., USA.

Braun, E. L. 1950. Deciduous forests of eastern North America. Blackiston Company, Philadelphia, Pennsylvania, USA.

Brudin, C. O. 2004. Wildlife use of existing culverts and bridges in north central Pennsylvania. Pages 344–352 *in* C. L. Irwin, P. Garrett, and K. P. McDermott, editors. Proceedings of the 2003 international conference on ecology and transportation. Center for Transportation and the Environment, North Carolina State University, Raleigh, North Carolina, USA.

Butler, R. 1997. The great blue heron: a natural history and ecology of a seashore sentinel. University of British Columbia Press, Vancouver, British Columbia, Canada.

Carbaugh, B., J. P. Vaughan, E. D. Bellis, and H. B. Graves. 1975. Distribution and activity of white-tailed deer along an interstate highway. Journal of Wildlife Management 39:570–581.

CityData.com. 2010. Maryland climate, <http://www.city-data.com/states/Maryland-Climate.html>. Accessed June 25, 2012.

Clevenger, A. P., and N. Waltho. 2000. Factors influencing the effectiveness of wildlife underpasses in Banff National Park, Alberta, Canada. Conservation Biology 14:47–56.

Clevenger, A. P., and N. Waltho. 2005. Performance indices to identify attributes of highway crossing structures facilitating movement of large mammals. Biological Conservation 121:453–464.

Clevenger, A. P., B. Chruszcz, and K. Gunson. 2001*a*. Drainage culverts as habitat linkages and factors affecting passage by mammals. Journal of Applied Ecology 38:1340–1349.

Clevenger, A. P., B. Chruszcz, and K. Gunson. 2001*b*. Highway mitigation fencing reduces wildlife–vehicle collisions. Wildlife Society Bulletin 29:646–653.

Curtis, P. D., B. Boldgiv, P. M. Mattison, and J. R. Boulanger. 2009. Estimating deer abundance with infrared-triggered cameras. Human–Wildlife Conflicts 3:116–128.

Donaldson, B. M. 2006. Use of highway underpasses by large mammals and other wildlife in Virginia and factors influencing their effectiveness. Pages 433–441 *in* C. L. Irwin, P. Garrett, and K. P. McDermott, editors. Proceedings of the 2005 international conference on ecology and transportation. Center for Transportation and the Environment, North Carolina State University, Raleigh, North Carolina, USA.

Ford, A. T., A. P. Clevenger, and A. Bennett. 2009. Comparison of methods of monitoring crossing structures on highways. Journal of Wildlife Management 73:1213–1222.

Forman, R. T. T., and L. E. Alexander. 1998. Roads and their major ecological effects. Annual Review of Ecology and Systematics 29:207–232.

Forman, R. T. T., D. Sperling, J. A. Bissonette, A. P. Clevenger, C. D. Cutshall, V. H. Dale, L. Fahrig, R. France, C. R. Goldman, K. Heanue, J. A. Jones, F. J. Swanson, T. Turentine, and C. Winter. 2003. Road ecology: science and solutions. Island Press, Washington, D.C., USA.

Foster, M. L., and S. R. Humphrey. 1995. Use of highway underpasses by Florida panthers and other wildlife. Wildlife Society Bulletin 23:95–100.

Fowler, J., and L. Cohen. 1990. Practical statistics for field biology. Wiley, New York, New York, USA.

Fritzell, E. K., and K. J. Haroldson. 1982. *Urocyon cinereoargenteus*. Mammalian Species 189:1–8

Gates, W. R. 1993. Mammalian use of over-sized stream culverts under Interstate 97, Anne Arundel County, Maryland. Thesis, Frostburg State University, Frostburg, Maryland, USA.

Gompper, M. E., R. W. Kays, J. C. Ray, S. D. LaPoint, D. A. Bogan, and J. R. Cryan. 2006. A comparison of non-invasive techniques to survey carnivore communities in northeastern North America. Wildlife Society Bulletin 34:1142–1151.

Gordon, K. M., and S. H. Anderson. 2004. Mule deer use of underpasses in western and southeastern Wyoming. Pages 309–318 *in* C. L. Irwin, P. Garrett, and K. P. McDermott, editors. Proceedings of the 2003 international conference on ecology and transportation. Center for Transportation and the Environment, North Carolina State University, Raleigh, North Carolina, USA.

Gosselink, T. E., T. R. van Deelen, R. E. Warner, and P. C. Mankin. 2007. Survival and cause specific mortality of red foxes in agricultural and urban areas of Illinois. Journal of Wildlife Management 71:1862–1873.

Grilo, C., J. A. Bisonette, and M. Santos-Reis. 2008. Response of carnivores to existing highway culverts and underpasses: implications for road planning and mitigation. Biodiversity and Conservation 17:1685–1699.

Hardy, A., A. P. Clevenger, M. Huijser, and N. Graham. 2004. An overview of methods and approaches for evaluating the effectiveness of wildlife crossing structures: emphasizing the science in applied science. Pages 319–330 *in* C. L. Irwin, P. Garrett, and K. P. McDermott, editors. Proceedings of the 2003 international conference on ecology and transportation. Center for Transportation and the Environment, North Carolina State University, Raleigh, North Carolina, USA.

Hubbard, M. W., B. J. Danielson, and R. A. Schmitz. 2000. Factors influencing the location of deer–vehicle accidents in Iowa. Journal of Wildlife Management 64:707–713.

Koprowski, J. L. 1994. *Sciurus carolinensis*. Mammalian Species 480:1–9.

Kwiecinski, G. G. 1998. *Marmota monax*. Mammalian Species 591:1–8.

Lackey, J. A., D. G. Huckaby, and B. G. Ormiston. 1985. *Peromyscus leucopus*. Mammalian Species 247:1–10

Larivière, S., and M. Pasitschniak-Arts. 1996. *Vulpes vulpes*. Mammalian Species 537:1–11.

Llewellyn, L. M., and F. H. Dale. 1964. Notes on the ecology of the opossum in Maryland. Journal of Mammalogy 45:113–122.

Lotze, J. -H., and S. Anderson. 1979. *Procyon lotor*. Mammalian Species 119:1–8.

Maryland State Highway Administration. 2003. Guide for completing structure inventory and appraisal input forms. Maryland State Highway Administration, Office of Bridge Development, Baltimore, Maryland, USA.

McElfish, J. M., Jr., and J. B. Wilkinson. 2000. Forests for the bay. Environmental Law Institute, Washington, D.C., USA.

McManus, J. J. 1974. *Didelphis virginiana*. Mammalian Species 40:1–6

Naiman, R. J., and H. Décamps. 1997. The ecology of interfaces: riparian zones. Annual Review of Ecology and Systematics 28:621–658.

NationalAtlas.gov. 2010. Annual precipitation in the State of Maryland. U.S. Department of the Interior and U.S. Geological Survey, Washington, D.C., USA. <www.nationalatlas.gov/printable/images/pdf/precip/pageprecip_md3.pdf>. Accessed July 18, 2012.

Naumann, R. 2002. *Ardea herodias*, Animal Diversity Web. <http://animaldiversity.ummz.umich.edu/site/accounts/information/Ardea_herodias.html>. Accessed July 18, 2012.

Nowak, R., and J. Paradiso. 1983. Walker's mammals of the world. Johns Hopkins University Press, Baltimore, Maryland, USA.

Ng, S., J. W. Dole, R. M. Sauvajot, S. P. D. Riley, and T. J. Valone. 2004. Use of highway undercrossings by wildlife in southern California. Biological Conservation 115:499–507.

Ontario Ministry of Transportation. 2006. Environmental guide for wildlife in the Oak Ridges Moraine. Provincial and Environmental Planning Office, Ministry of Transportation, Ontario, Canada.

Paradiso, J. L. 1969. Mammals of Maryland. North American Fauna, Number 66. U.S. Bureau of Sport Fisheries and Wildlife, Washington, D.C., USA.

Reed, D. F., T. N. Woodard, and T. M. Pojar. 1975. Behavioral response of mule deer to a highway underpass. Journal of Wildlife Management 39:361–367.

Riley, S. P. D. 2006. Spatial ecology of bobcats and gray foxes in urban and rural zones of a national park. Journal of Wildlife Management 70:1425–1435.

Rodriguez, R., G. Crema, and M. Delibes. 1996. Use of non-wildlife passages across a high-speed railway by terrestrial vertebrates. Journal of Applied Ecology 33:1527–1540.

Rogers, L., D. Stimson, K. Holden, D. Kay, D. Kaye, R. McAdow, B. Metcalfe, B. Windmiller, and N. Charney. 2010. Wildlife tunnels under a busy suburban Boston roadway. Pages 102–115 *in* P. J. Wagner, D. Nelson, and E. Murray, editors. Proceedings of the 2009 international conference on ecology and transportation. Center for Transportation and the Environment, North Carolina State University, Raleigh, North Carolina, USA.

Smith, D. J. 2003. Monitoring wildlife use and determining standards for culvert design. Final report, contract BC354–34. Florida Department of Transportation, Tallahassee, Florida, USA.

Smith, W. P. 1991. *Odocoileus virginianus*. Mammalian Species 388:1–13.

Spellerberg, I. F. 1998. Ecological effects of roads and traffic: a literature review. Global Biology and Biogeography Letters 7:317–333.

Stewart, R. E., and C. S. Robbins. 1958. Birds of Maryland and the District of Columbia. North American Fauna, Number 62. U.S. Bureau of Sport Fisheries and Wildlife, Washington, D.C., USA.

Trombulak, S. C., and C. A. Frissel. 2000. Review of ecological effects of roads on terrestrial and aquatic communities. Conservation Biology 14:18–30

U.S. Census Bureau. 2010. State and county quick facts: Maryland. U.S. Census Bureau, Washington, D.C., USA, <http://quickfacts.census.gov/qfd/states/24000.html>. Accessed June 25, 2012.

U.S. Department of Agriculture. 2012. Conservation Reserve Program, <http://www.md.nrcs.usda.gov/programs/crp_crep/crp_crep.html>. Accessed July 18, 2012.

Ward, A. L. 1982. Mule deer behavior in relation to fencing and underpasses on Interstate 80 in Wyoming. Transportation Research Record 859:8–13.

Watson, M. L. 2005. Habitat fragmentation and the effects of roads on wildlife and habitats: background and literature review. New Mexico Department of Game and Fish, Santa Fe, New Mexico, USA.

Whittaker, D. G., and F. G. Lindzey. 2004. Habitat use patterns of sympatric deer species on Rocky Mountain Arsenal, Colorado. Wildlife Society Bulletin 32:1114–1123.

Wolf, K. N., F. Elvinger, and J. L. Pilcicki. 2003. Infrared triggered photography and tracking plates to monitor oral rabies vaccine bait contact by raccoons in culverts. Wildlife Society Bulletin 31:387–391.

Yanes, M., J. M. Velasco, and F. Suarez. 1995. Permeability of roads and railways to vertebrates: the importance of culverts. Biological Conservation 71:217–222.

Zar, J. H. 1999. Biostatistical analysis. Prentice Hall, Upper Saddle River, New Jersey, USA.

JAMES L. SPARKS JR. is a freelance field biologist. He holds a B.A. degree from Antioch College and an M.S. degree from Virginia Commonwealth University. He has worked on diverse projects, including the current work on drainage structure use by wildlife, habitat use by predators in a variety of habitats, and conservation genetics of the northern flying squirrel in Virginia.

J. EDWARD GATES is a professor at the Appalachian Laboratory, University of Maryland Center for Environmental Science. He holds a B.S. degree from Old Dominion College, an M.A. degree from Bowling Green State University, and a Ph.D. degree from Michigan State University. His research interests comprise habitat fragmentation and alteration, connectivity (corridors), edge effects, and boundary dynamics; habitat suitability for vertebrate species; species inventory and monitoring for natural resource management; and natural resources and the human enterprise.