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Seasonal and regional animal use of drainage structures to cross under roadways

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Abstract: Road drainage structures, hereafter designated culverts, are often used by wildlife and other animals to cross under roadways. However, crossings may vary by species, culvert design, different environmental factors, and land-use and land-cover (LULC) at culvert sites. We monitored 265 culverts located throughout Maryland, USA, with motion-detecting game cameras to assess seasonal and regional effects on culvert crossing rates by wildlife and other animal species considered common to the areas. Northern raccoon (*Procyon lotor*) and Virginia opossum (*Didelphis virginiana*) exhibited lower crossing rates in culverts during winter than at other times of the year. We did not detect any difference in seasonal crossings for other species, but several species exhibited similar patterns of lower crossings/culvert/day during winter. We detected more crossings/culvert/day in the Piedmont ecoregion of Maryland for several species associated with farmland and suburbia (e.g., raccoon and red fox [*Vulpes vulpes*]). In contrast, opossum and free-ranging domestic cat (*Felis catus*) crossing rates were greater in the Appalachian Mountain ecoregion. The crossing rates for the only bird species we recorded on camera traps, the great blue heron (*Ardea herodias*), tended to increase from west to east, with its highest crossing rate on the Eastern Shore (lower coastal plain) of Maryland, where these birds are known to be abundant in tidal marshes. Besides a myriad of LULC and structural variables known to affect wildlife and other animal crossing rates, seasonal and regional differences in animal use must also be taken into consideration for culvert design and placement or retrofitting existing culverts to enhance crossings by particular animal species.

Key words: animals, culvert, game camera, human–wildlife conflicts, Maryland, regional distributions, road ecology, seasonal movements, underpass, wildlife crossings

In 2014, there were 6.7 million km of public roads and 14 million km of lanes in the United States (U.S. Department of Transportation [USDOT] 2016). Along with associated edge effects, they influence the ecology of 15–20% of the land area (Forman and Alexander 1998). Habitat fragmentation by roads is perhaps the most pervasive form of direct anthropogenic terrestrial habitat destruction (Spellerberg 1998, Forman et al. 2003). Roads result in habitat loss, degradation of gene flow, and direct mortality of wildlife by vehicle collisions (Forman and Alexander 1998, Spellerberg 1998, Trombulak and Frissel 2000, Forman et al. 2003, Watson 2005).

Vehicle traffic on roads has a direct effect on mortality and behavior of sensitive wildlife species by altering movement patterns, home range, reproductive success, escape response, and physiological state (Trombulak and Frissel 2000). As the demand for mitigation of effects caused by road development increases, managers seek new understanding and methods to restore fragmented wildlife populations (Trombulak and Frissel 2000, Forman et al. 2003).

Road drainage structures, hereafter designated culverts, are principally constructed for the purpose of alleviating erosion by channeling intermittent and perennial streams under roadways (Maryland Department of Transportation [MDDOT] 2003). Existing culverts are also used by wildlife and other animals for passage under roads, thereby mitigating some of the detrimental effects of roads by enabling animal movements, increasing habitat connectivity, and potentially reducing animal–vehicle collisions (Clevenger and Waltho 2000, Ng et al. 2004, Aresco 2005, Grilo et al. 2008, Sparks and Gates 2012). Rising concerns about habitat fragmentation and loss and isolation of wildlife populations caused by roadways have led to the increased scrutiny of existing culverts as habitat linkages (Clevenger

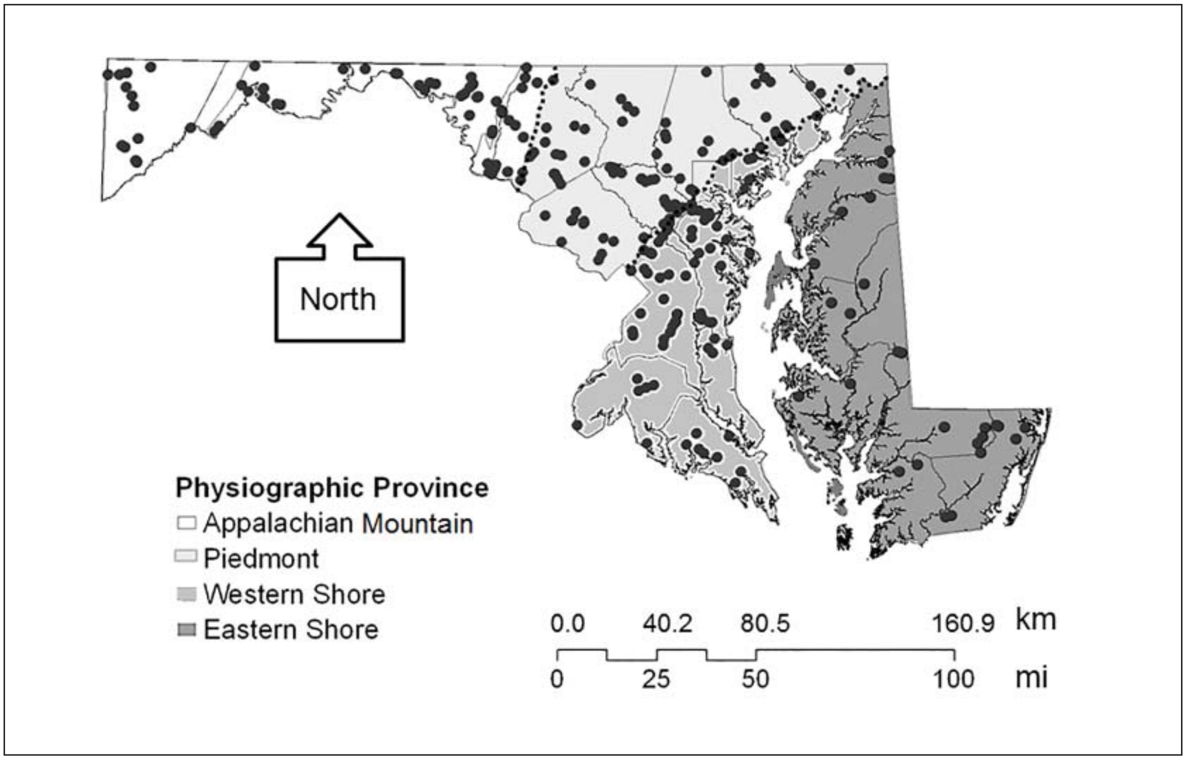

Figure 1. Locations of 265 surveyed culverts within 4 physiographic provinces or ecoregions in Maryland, USA from August 28, 2008 to January 3, 2011. Dotted lines separate the Piedmont from the Appalachian Mountain to the west and from the Western Shore to the east.

and Waltho 2000, Clevenger et al. 2001, Forman et al. 2003, Ascensão and Mira 2007, Sparks and Gates 2012). Existing culverts are known to be used by numerous animal species in a variety of ecosystems around the world (Clevenger and Waltho 2000, Aresco 2005, Meaney et al. 2007, Grilo et al. 2008, Hagood 2009).

In 2014, the State of Maryland had 49,853 km of public roads and 110,106 km of lanes (MDDOT 2014). In Maryland, 57 species of mammals, birds, reptiles, and amphibians have been documented using culverts (Sparks and Gates 2012). Species-specific differences in capture rates were related to differences in culvert design, the local and regional environment, as well as land-use and land-cover (LULC; Sparks and Gates 2012). Here, we expand on our previous research (Sparks and Gates 2012), taking into consideration the effects of season and ecoregion on crossing rates by common Maryland animal species.

Study area

Maryland is a mid-Atlantic state that spans several physiographic provinces or ecoregions, from the Appalachian Plateau (highest elevation 1,024 m) in the west to the Coastal Plain (lowest elevation, sea level 0 m) to the east (Stewart and Robbins 1958; Paradiso 1969; <ftp://newftp.epa.gov/EPADataCommons/ORD/Ecoregions/us/Eco_Level_III_US.pdf>, accessed July 25, 2016). Average annual temperatures range from 9°C in the western uplands to 15°C in the maritime southeast (CityData.com 2010). Average annual precipitation is about 124 cm in the southeast, but only 91 cm near the City of Cumberland, east of the Appalachian Plateau. Mixed mesophytic forest types are found at the highest elevations, with xeric oak (*Quercus* sp.)-hickory (*Carya* sp.) being more common in the Piedmont ecoregion and oak-pine (*Pinus* sp.) in the Coastal Plain (Braun 1950). All sizable forests in the state of Maryland are secondary re-growth (Braun 1950).

Maryland can be subdivided into several ecoregions, ranging from the western mountains to the eastern coastal plain. For our geographic analysis, the mountainous Appalachian Plateau, Ridge and Valley, and Blue Ridge ecoregions were combined into 1 ecologically similar ecoregion, which we named the Appalachian Mountain ecoregion. We did

Table 1. Ten common animal species that used >30 culverts and were detected by camera traps in culverts over 31,317 trap days in 228–265 actively surveilled drainage structure cells during all 9 Maryland camera placement cycles from August 28, 2008 to January 3, 2011.

Common name	Scientific name	Alpha code	Culvert cells used	No. crossings	Crossings/ culvert/day $\times 10^{-2}$
Northern raccoon	*Procyon lotor*	PRLO	246	24,800	79.19
Virginia opossum	*Didelphis virginiana*	DIVI	129	1,076	3.44
Domestic cat[a]	*Felis catus*	FEDO	103	2,169	6.93
Woodchuck	*Marmota monax*	MAMO	97	822	2.62
Great blue heron	*Ardea herodias*	ARHE	77	545	1.74
Red fox	*Vulpes vulpes*	VUVU	66	928	2.96
Eastern gray squirrel	*Sciurus carolinensis*	SCCA	53	531	1.70
Norway rat	*Rattus norvegicus*	RANO	52	326	1.04
Common gray fox	*Urocyon cinereoargenteus*	URCI	47	294	0.94
White-footed mice	*Peromyscus* spp.	PESP	33	296	0.95

[a] Because we could not determine if domestic cats recorded on camera traps were pets or feral cats, we referred to them as free-ranging domestic cats.

this to maintain a more parsimonious sampling of the western uplands. This ecoregion plus the Piedmont and Upper and Lower Coastal Plain resulted in 4 ecoregions. The Appalachian Mountain ecoregion is primarily rural with a population density of 66/km^2 (USCB 2010). The Piedmont ecoregion is delineated by Catoctin Mountain to the west and the fall line to the east and includes urban and suburban elements with a population density of 297/km^2 (USCB 2010). The Coastal Plain consists of the Upper Coastal Plain or Western Shore and Lower Coastal Plain or Eastern Shore of the Chesapeake Bay. The Western Shore includes the City of Baltimore and surrounding suburbs and has an urban/suburban population density of 284/km^2 (USCB 2010). The southern part of the Western Shore, considered low density, has experienced much suburban development as Washington, D.C. suburbs have expanded southward. The Eastern Shore is primarily agricultural land with a much lower population density of 47/km^2 (USCB 2010).

For our study, we randomly selected 265 culverts within the State of Maryland (longitude: 75° 4′ W to 79° 33′ W, latitude: 37° 53′ N to 39° 43′ N; Figure 1). Our sample culverts had a mean width and height of 2.44 m (SE = 0.06 m) by 1.90 m (SE = 0.04 m), respectively and a mean length of 46.36 m (SE = 2.36 m). All culverts were located under paved roads and contained a waterway, a relief for a waterway, or other depression. Culvert types were arch (7.5%), box (38.1%), and cylinder (54.3%). Six different substrates were found in culverts, including silt (17.0%), sand (13.2%), gravel (15.1%), cobble (7.5%), steel (13.2%), and concrete (34.0%). These substrates were distributed among the 3 culvert types, with the exception that steel substrate was not found in arch or box culverts (Sparks and Gates 2012; Table 1).

Methods

Culvert use

We documented animal use of culverts with passive infra-red motion-detecting digital cameras (Moultrie® Game Spy i40 digital game camera; Moultrie Feeders, Alabaster, Alabama, USA; Sparks and Gates 2012). Our cameras were triggered by moving heat signatures and therefore responded primarily to mammals and birds. We mounted cameras at the approximate midpoint of the culvert on a 12.7-cm steel angle bracket, 61 cm from the floor or water surface in the culvert. Exceptions were made when the drainage structure was too low to enter. In these instances, 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 instead of another passable culvert opening. The camera was then mounted in the culvert at a point estimated to be the midpoint of the road above. Cameras were set to 1-min intervals to minimize taking pictures of the same animal twice. We counted each identifiable animal in a photograph as a single animal use of a culvert, equivalent to a crossing. Each culvert cell was generally surveyed for 24 hours per day on a roughly seasonal rotating basis over the course of 14 days. We sampled at least twice per season over a multi-year period at each culvert from August 28, 2008 to January 3, 2011 (i.e., at least 9 seasonal sampling periods). Technical difficulties, stolen cameras, high water, and several logistical problems sporadically affected the number of camera-trap days. Approximately 83% of surveys comprised 14 days; however, surveys ranged from as few as 10 days to as many as 36 days. Camera-trap effort (no. cameras/km^2) was nearly equal among the Appalachian Mountain (1.356×10^{-4}), Piedmont (1.407×10^{-4}), and Western Shore (1.348×10^{-4}), while it was considerably less on the Eastern Shore (0.394×10^{-4}).

Crossings during a survey period were standardized to number per culvert per trap day by dividing the total captures of a species by the number of sample days at each culvert. We compared species, seasonal, and regional differences in crossings/culvert/day by using 3-way analysis of variance (Zar 1999; PASW Statistics v. 17.0.3 SPSS: An IBM Company). Data were transformed using $Y = \log_{10}(X + 1)$ to minimize skewness and kurtosis. One-way analysis of variance or Kruskal-Wallis test (SigmaPlot 13, Systat Software, Inc., San Jose, California, USA), with multiple comparison procedures to isolate the groups that differ from the others, was used in follow-up analysis.

Results

From a database of 57 species observed inside culverts, we selected 9 small- to medium-sized mammalian species and 1 bird species (≤10 kg in weight) that occurred in >30 culverts for evaluation of seasonal and regional culvert use (Table 1). The species ranked in order of culvert cells used included the northern raccoon (*Procyon lotor*), Virginia opossum (*Didelphis virginiana*), free-ranging domestic cat (*Felis catus*), woodchuck (*Marmota monax*), great blue heron (*Ardea herodias*), red fox (*Vulpes vulpes*), eastern gray squirrel (*Sciurus carolinensis*), Norway rat (*Rattus norvegicus*), common gray fox (*Urocyon cinereoargenteus*), and white-footed mice (*Peromyscus* spp.). A 3-way analysis of variance resulted in no 3-way interactions ($P = 0.948$) in crossings/culvert/day between species, season, and region; furthermore, there was no 2-way interaction ($P = 0.420$) between season and region. However, there were 2-way interactions between species and season ($P = 0.008$) and species and ecoregion ($P = 0.01$). Therefore, each species was analyzed separately for differences among seasons and also among ecoregions.

Several species exhibited seasonal patterns, with the highest crossings/culvert/day occurring primarily in summer, and the lowest rates in winter; however, this trend was highly variable (Figure 2). These seasonal patterns differed ($P \leq 0.05$) for the northern raccoon and Virginia opossum. The proportion of culverts used by the opossum was also much lower in winter compared to other seasons; however, the raccoon used a comparable proportion of culverts regardless of season (Figure 3). The proportion of culverts used by many other species was also much lower in winter than in other seasons (e.g., the woodchuck and gray squirrel used <10 culverts in winter, and the Norway rat also used very few culverts in winter).

More species demonstrated regional differences ($P \leq 0.05$). Crossing rates of northern raccoon, Virginia opossum, free-ranging domestic cat, great blue heron, red fox, and Norway rat differed among ecoregions ($P \leq 0.05$; Figure 4). Northern raccoon and red fox had their highest crossings/culvert/day in the Piedmont ecoregion compared to other ecoregions. Crossing rates were very low to non-existent for both red and gray foxes, respectively, on the Eastern Shore of Maryland. In contrast, Virginia opossums and free-ranging domestic cats had their highest crossings/culvert/day in the Appalachian Mountain ecoregion. The great blue heron tended to have an increasing culvert crossing rate from west to east, with significantly higher crossing rates in culverts on the Eastern Shore in comparison to the Appalachian Mountain ecoregion.

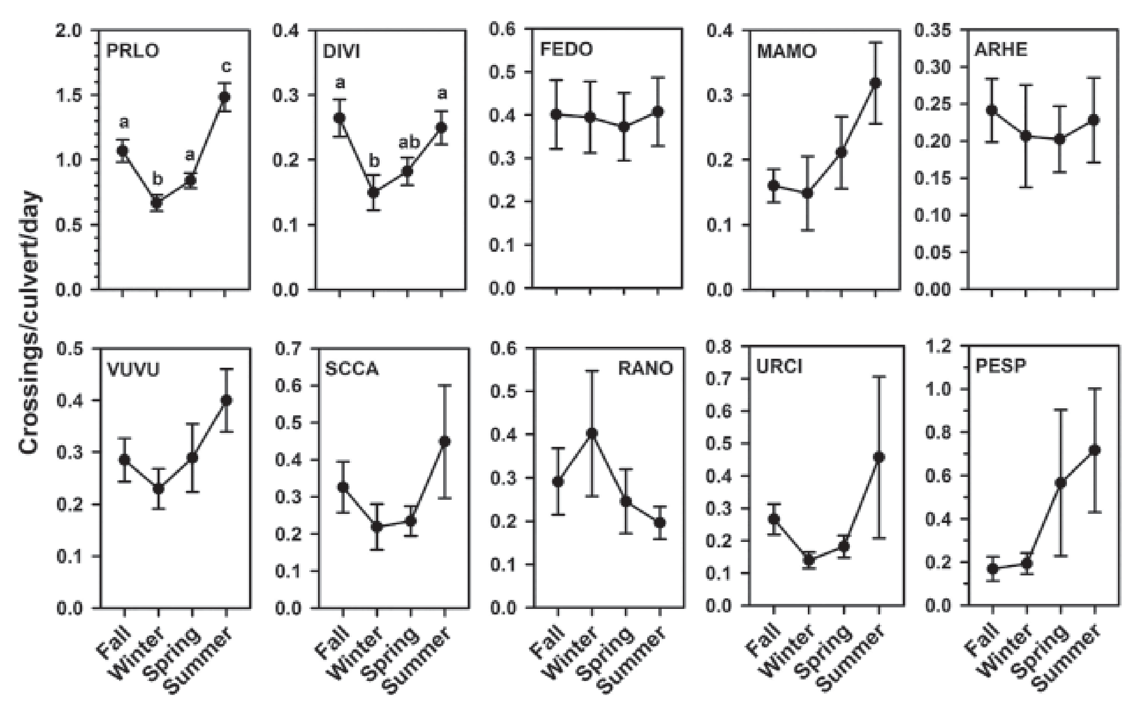

Figure 2. Seasonal crossings/culvert/day (x ± SE) of 10 common animal species in Maryland, USA from August 28, 2008 to January 3, 2011. Alpha codes are found in Table 1. Seasons are bracketed by the spring and fall equinoxes and summer and winter solstices. Means with the same letters are not different ($P > 0.05$).

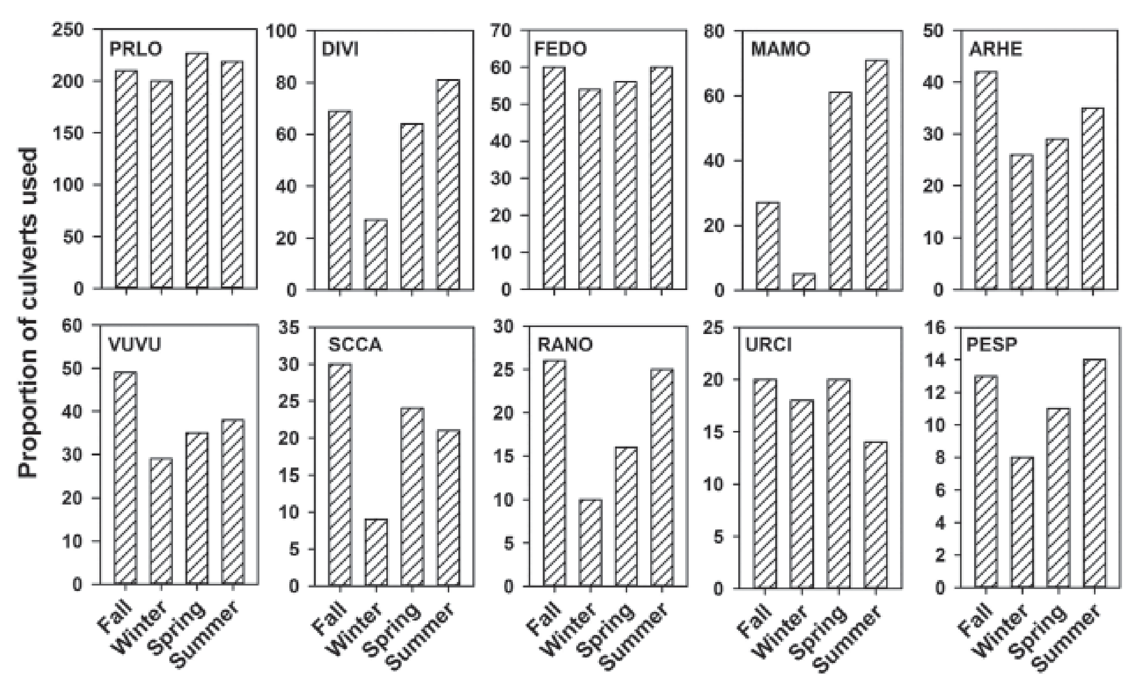

Figure 3. Proportion of culverts used at least once in a season by 10 common animal species in Maryland, USA from August 28, 2008 to January 3, 2011. Alpha codes are found in Table 1. Seasons are bracketed by the spring and fall equinoxes and summer and winter solstices.

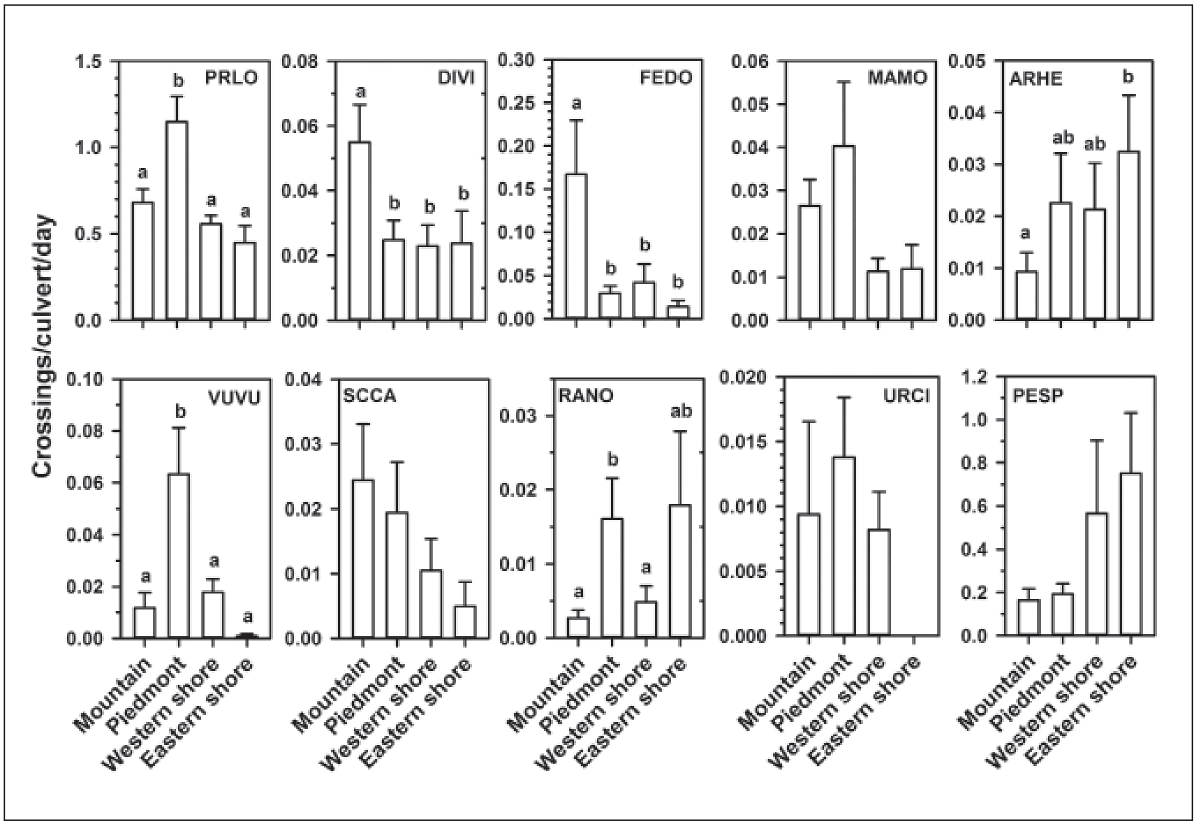

Figure 4. Regional crossings/culvert/day (x ± SE) by 10 common animal species in Maryland, USA from August 28, 2008 to January 3, 2011. Alpha codes are found in Table 1. Means with the same letters are not different (*P* > 0.05). The number of culverts surveyed per ecoregion equal 61 for the Appalachian Mountain, 82 for the Piedmont, 88 for the Western Shore, and 34 for the Eastern Shore.

The Norway rat had higher crossing rates in the Piedmont and Eastern Shore ecoregions. Although crossing rates were not different for gray squirrel and white-footed mice among ecoregions, crossing rates for the gray squirrel declined and those of white-footed mice increased from the Appalachian Mountain to the Eastern Shore ecoregions.

Discussion

We detected seasonal and regional variability in animals crossing roadways using culverts. Our observations provide insights for managers desiring to assess seasonal movements for the species we studied. For example, the relatively high crossing rates of the raccoon and opossum in summer, along with possibly fall for the opossum, would appear to be productive times of year for assessing their movements. The opossum also used a high proportion of culverts in the summer and fall. However, the proportion of culverts used by raccoons in each season was similar, indicating that differences in crossing rates were largely due to changes in activity or number of individuals using culverts at particular times of the year.

Many mammals are more likely to be active in spring and summer due to warmer weather and increased availability of food (plants, insects, and other prey items); populations of many species are also likely growing due to the addition of young of the year (Smith 1980, Bronson 2009). In the winter months, many mammals restrict their movements during colder weather, spending more time in dens and other retreats (Stuewer 1943).

For instance, raccoons remain in hollow trees for extended periods during exceptionally cold weather (Lotze and Anderson 1979); low ambient temperature also contributes to the low (17%) maximum activity of opossums in winter (McManus 1974, Kanda et al. 2005). Although our data failed to show any seasonal differences in crossings/culvert/day for 8 of the 10 species, several species had similar seasonal patterns as the above 2 species, and most had lower proportions of culvert use during winter. This lack of any differences in crossings/culvert/

day for most species was perhaps due to the degree of variation in these data.

Species more common in agriculture and fragmented forest lands used culverts more frequently in the Piedmont ecoregion, including raccoons and red foxes. We expected this result because the Piedmont forests are highly fragmented and land use is dominated by agriculture. However, residential development and expansion of the urban centers of Baltimore and Washington, D.C., continue to reduce these preferred LULCs. In spite of this, populations of raccoons and foxes are often very high in more urbanized habitats (Hoffman and Gottschang 1977, Harris and Rayner 1986, Prange et al. 2003, Randa and Yunger 2006).

We detected higher Norway rat crossing rates in the Piedmont and Eastern Shore ecoregions. This species is present in lowland and coastal regions and is a human commensal (Ruedas 2008). Habitat features associated with Norway rats include urban, suburban, agricultural, and riparian areas. The Piedmont ecoregion has one of the highest human population densities in Maryland (USCB 2010), which may have contributed to higher crossing rates by Norway rats in that ecoregion. The northcentral part of the state, which includes the Piedmont ecoregion, and the upper Eastern Shore also have the greatest extent of farmland in Maryland (<http://msa.maryland.gov/msa/mdmanual/01glance/html/agri.html>, accessed April 11, 2017, unpublished data). The Norway rat can be a problem in such areas as it consumes and contaminates vast quantities of food stored for humans and their livestock (Nowak and Paradiso 1983).

The Virginia opossum and free-ranging domestic cats were detected using culverts in the Appalachian Mountain ecoregion more frequently than in the other 3 ecoregions. Virginia opossums are known to inhabit a wide variety of habitats, but prefer deciduous forests near water (Llewellyn and Dale 1964, McManus 1974). Free-ranging cats may concentrate in certain localities due to feeding by humans, resulting in feral cat colonies; most occur in rural areas, small towns, or around farmsteads (Warner 1985, Centonze and Levy 2002, Schmidt et al. 2007). However, it is unclear why both species had the highest crossing rates in the Appalachian Mountain ecoregion.

In contrast, the great blue heron had higher crossing rates on the Eastern Shore than in the Appalachian Mountain ecoregion. Great blue herons are most common in the fresh and brackish marshes of the Coastal Plain in Maryland (McKearnan 1996). Their breeding areas or rookeries are also more common in the eastern part of the state. Herons likely enter culverts seeking prey such as fish, frogs, crayfish, and snakes.

Although camera trap surveys can provide useful information on culvert use by different wildlife species, use of this method to sample or monitor population activity has sampling errors that can affect data interpretation (Burton et al. 2015). For example, crossings/culvert/day by individuals of specific animal species and proportion of culverts used by those individuals may not be related. Additionally, to use camera trap data to ascertain the relative importance of a culvert to specific animal species would require knowledge of the proportion of individuals in the population utilizing the culvert as well as the proportion crossing the road. Because we were not able to distinguish between individuals of a species, we do not know the actual number of individuals represented by multiple crossings. Our results are actually a measure of activity; however, whether it is 10 individuals crossing once or 1 individual crossing 10 times, the end result is nonetheless a reduced likelihood of becoming road kill. Another source of sampling error in camera trap surveys is imperfect detection, where individuals or species are not always detected within a sampling area (Burton et al. 2015). Small body size and rapid movement may make some species difficult to detect with camera trap surveys.

The availability or suitability of habitats and their components within each ecoregion likely have a major effect on population density and potential use of culverts, making extrapolation of results from 1 ecoregion to another problematic. We previously noted that proximity to water was a key habitat component for several species irrespective of ecoregion, which highlights the statewide importance of culverts in providing both a channel for water and a source of water for wildlife, particularly those culverts containing perennial streams (see Sparks and Gates 2012). Lastly, because seasonal and regional differences in the behavior and ecology of wildlife species can influence culvert crossing rates and use, such differences should be taken into consideration when predicting animal crossing rates or use of culverts, designing studies to document animal use of culverts elsewhere, or retrofitting existing culverts to enhance crossings by particular animal species.

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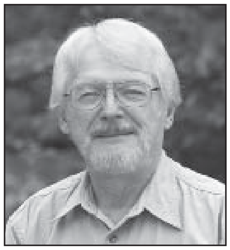

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