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Species composition and temporal patterns of wildlife–vehicle collisions in southwest Virginia, USA

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Abstract: Mitigating wildlife–vehicle collisions (WVCs) is becoming a major wildlife conservation focus, particularly in areas characterized by increased anthropogenic development. Concomitantly, wildlife managers and transportation planners need better information regarding spatiotemporal patterns of WVCs to develop measures that mitigate negative impacts on wildlife. To address this need, in 2015 we conducted a yearlong WVC study in the Appalachian Mountains of Virginia, USA to determine the species composition of WVCs across mammals, birds, and herpetofauna. In addition, we compared patterns of WVC road mortalities across 2 adjacent routes with different vehicle traffic volumes and evaluated the relationships between temporal variations in WVC frequency and seasonal activity of focal taxa. The mean weekly WVC mortality rate across all species ($n = 65$) was 13.8 ± 1.73 per 100 km. The WVC mortalities were not evenly distributed across routes, with overall differences driven primarily by the relative abundance of meso-mammals. Temporal WVC rates differed for woodchucks (*Marmota monax*), eastern box turtles (*Terrapene carolina carolina*), and eastern ratsnakes (*Pantherophis alleghaniensis*), with contrasting peaks in frequency for passerine birds and birds of prey. Because of the substantial differences we observed in WVC mortality rates relative to traffic volumes and seasonal activity patterns of the taxa studied, any WVC mitigation strategies implemented will need to be site-specific.

Key words: Appalachian Mountains, mitigation, mortalities, seasonal activity, traffic volumes, Virginia, wildlife–vehicle collision

Roads are a major wildlife conservation concern, particularly in areas characterized by a high degree of anthropogenic development. Roads may contribute to negative impacts for biodiversity in numerous ways, including direct habitat loss due to road-building activities and indirect edge effects in linear corridors of intact habitat adjacent to roadways (Forman and Alexander 1998, Fahrig and Rytwinski 2009). Road corridors can also serve as foci for the establishment and spread of invasive taxa, given their environmental differences relative to intact, adjacent habitats (Hansen and Clevenger 2005).

Wildlife–vehicle collisions (WVCs) are of concern because they may be a major source of mortality for some taxa. In some cases, WVC-related mortalities are occurring at rates that may affect population persistence. In the Netherlands, WVCs and associated road impacts have been linked to a near 30% reduction in population density for some taxa (Huijser and Bergers 2000). Researchers have reported similar concerns regarding the effects of WVCs on population stability in other regions (Fahrig et al. 1995, Trombulak and Frissell 2000, Jaeger et al. 2005). Wildlife–vehicle collision rates may increase seasonally when roads that support large traffic volumes bisect with migratory corridors (Sullivan et al. 2004). In some cases, WVCs may exceed 10 individuals/km/day (Aresco 2005).

In addition, WVCs are of concern to human safety. Vehicle repair costs from collisions with large mammals such as deer have been estimated at >$1 billion USD annually (Conover et al. 1995), with >20,000 people involved in deer–vehicle collisions across a 6-year period in Utah, USA alone (Bissonette et al. 2008).

Knowledge of the spatiotemporal patterns of WVCs is essential to developing measures that aim to mitigate these impacts. For example, past work in WVC mitigation has found that traffic volume is a strong correlate of WVC rates at a

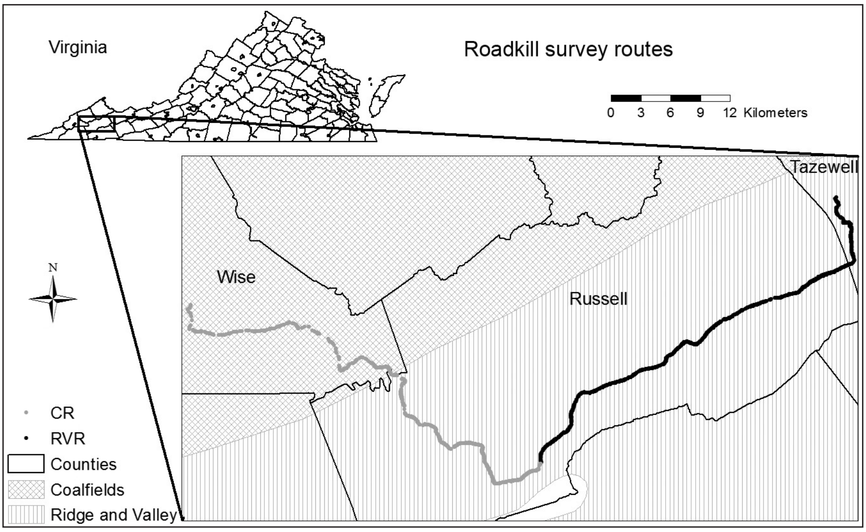

Figure 1. Locations of wildlife–vehicle collisions along 2 adjacent routes (CR = Coalfield Route, RVR = Ridge and Valley Route) in southwest Virginia, USA in 2015. Points along each route denote the location of wildlife–vehicle collisions recorded during the study period. Shaded areas denote the location of physiographic provinces across the counties (Tazewell, Russell, and Wise) within the region.

coarse scale for some taxa (Inbar and Mayer 1999, Hussain et al. 2007, Arnold et al. 2018), with more heavily traveled roadways generally producing higher rates of WVCs. In addition, previous investigation has shown that WVC rates are correlated with the seasonal activity of nearby taxa, often peaking during periods of migratory behavior, courtship/breeding activities, or movements to seasonal hibernacula (Bernardino and Dalrymple 1992, Ashley and Robinson 1996, Sullivan et al. 2004, Smith-Patten and Patten 2008). At a finer scale, features such as road topography and the configuration of the roadway relative to small-scale habitat features can influence the location and rate of wildlife–vehicle encounters (Gunson et al. 2011, Ng et al. 2008, Neumann et al. 2012).

However, most of this pre-existing knowledge has been gained through studies of large vertebrate taxa, primarily ungulates and large carnivores (Sullivan and Messmer 2003). Relatively less work has been performed to understand if the aforementioned trends in WVC frequency and timing hold for smaller taxa—including birds, small mammals, and herpetofauna—especially across a broad spatial scale containing longer road routes that are not focused on singular habitat features that are important to certain taxa (e.g., wetlands, riparian corridors). With conservation concern about the impacts of roads on populations of these taxa increasing (Andrews et al. 2008, Kociolek et al. 2011, Loss et al. 2014), this knowledge is essential to understanding if and how WVC impacts can best be mitigated. In addition, little work on WVC frequency has occurred in the central Appalachians of the eastern United States, an area that harbors a dense human population (Wear and Bolstad 1998, Radeloff et al. 2005) and hotspots of diversity for several vertebrate groups (Stein et al. 2000). With both human population size and conservation concern for many taxa increasing across this area, it is imperative to understand if trends in WVCs found elsewhere in North America hold for this region.

Here we address this lack of knowledge through an analysis of WVCs from 2 distinct highway routes in the Appalachian Mountains of Virginia, USA. Our primary objectives were to: 1) determine the species composition of WVCs across mammals, birds, and herpetofauna, 2) compare patterns of road mortality across 2 adjacent routes containing differing vehicle densities, and 3) compare temporal variation in WVC frequency to the seasonal activity of focal taxa. We also recommend relatively low-cost mitigation measures for these routes and outline future goals for research seeking to mitigate WVC impacts.

Study area

We sampled for WVCs on 2 adjacent highway routes in southwest Virginia, USA with differing traffic densities (Figure 1): a 48-km portion of US Highway 19 and Virginia State Route 609 (hereafter Ridge and Valley Route, or RVR) and a 49-km portion of US Highway 58 Alternate and Virginia State Route 706 (hereafter Coalfield Route, or CR). The RVR is along the strike of the Ridge and Valley physiographic province, and the CR is across the strike of the Ridge and Valley province into the Coalfields province.

Both routes travel through a mix of forested and agricultural habitat, as well as rolling terrain and steep escarpments typical of the Appalachian Plateau and Ridge and Valley physiographic provinces. With route elevations in the 520–680 m range, the climate is generally characterized as humid subtropical with warm, humid summers and cool to cold winters. Both routes are bounded by large tracts of public conservation lands, including the Clinch Mountain Wildlife Management Area (RVR) and the Jefferson National Forest (CR), and include primarily 4-lane highways divided by a vegetated (grass, shrub cover) median. Annual average daily traffic (AADT) estimates were lower throughout the study period for the Coalfields Route (7521 AADT) than the Ridge and Valley Route (11009 AADT; Virginia Department of Transportation 2015).

Methods

Data collection

We surveyed each route biweekly. These surveys were single-observer/driver surveys, in which both directions of the roadway were surveyed twice per week from January 1, 2015 through December 31, 2015, with the exception of periods of severe weather conditions. The first survey each week was performed while driving at a speed of approximately 70 kph, with the second survey for each week performed at a speed of 90 kph. For all surveys, the observer stopped at every detected carcass and recorded the location of the WVC, species, and number of individuals killed. The location of each WVC was recorded using a handheld global positioning system unit. Carcasses were marked on either side with road-marking paint to avoid duplicate counting of WVCs and were left undisturbed, unless it was necessary to move the carcass to identify the organism to the species level. We used species accumulation curves (Fisher et al. 1943) to examine sampling effort on each route, with curves that reached or approached an asymptote indicating a sufficient sampling of taxa involved in WVCs.

Data analysis

We used a Chi-Square goodness of fit test to test the null hypothesis that WVCs for each detected taxon would be evenly distributed across routes, with a similarity percentage (SIMPER) analysis used to examine which species were responsible for driving any observed differences in the relative abundance of each species between routes. We used a One-Way Analysis of Variance (ANOVA) to test for differences in WVC rates across months for all taxa and for the 8 taxa in our dataset that had enough WVCs detected to ensure a robust comparison across the study period. Since this resulted in multiple analyses being run on the same dataset, we used an adjusted significance level of $\alpha = 0.018$ for our temporal analyses to account for the increased chance of Type I error resulting from multiple comparisons, following the modified false discovery rate method (Benjamini and Yekutieli 2001).

Results

We completed 148 surveys during the study period, totaling 15,022 km. We were unable to conduct surveys during 5 weeks throughout the study period due to severe weather conditions or other circumstances that hindered the safety and/or feasibility of a survey. All surveys detected ≥1 WVC.

We recorded WVC mortalities for 65 species across both routes, with more species (59 total) recorded on the Ridge and Valley Route than those on the Coalfield Route (45 species). Thirty-nine species were associated with WVCs for both routes, while the RVR had more species unique to it than the CR (20 vs. 6 species, respectively; Table 1). Species accumulation curves for both routes approached an asymptote (Figure 2), suggesting that sampling on each route was sufficient to detect most impacted taxa.

The number of WVC mortalities for each taxon recorded during surveys was not evenly distributed across routes ($\chi^2 = 43.20$, $P < 0.001$). The SIMPER analyses indicated that these overall differences observed were primarily affected

Table 1. Species detected in wildlife–vehicle collisions (WVCs) on 2 adjacent routes (CR = Coalfield Route, RVR = Ridge and Valley Route) in southwest Virginia, USA in 2015. These WVC data are presented as the total number of organisms of each species detected during surveys, as well as the mean weekly rate of WVCs for each species per 100 km.

Species common name (scientific name)	Mean weekly rate per 100 km ± SE	Number observed	Route
Virginia opossum (*Didelphis virginiana*)	2.72 ± 0.27	408	Both
Northern raccoon (*Procyon lotor*)	1.97 ± 0.26	272	Both
Woodchuck (*Marmota monax*)	1.26 ± 0.17	161	Both
Eastern cottontail (*Sylvilagus floridanus*)	0.91 ± 0.11	127	Both
Domestic cat (*Felis silvestris catus*)	0.75 ± 0.14	99	Both
Striped skunk (*Mephitis mephitis*)	0.68 ± 0.11	98	Both
Northern gray squirrel (*Sciurus carolinensis*)	0.58 ± 0.10	79	Both
Fox squirrel (*Sciurus niger*)	0.46 ± 0.09	58	Both
Eastern box turtle (*Terrapene carolina carolina*)	0.38 ± 0.12	43	Both
White-tailed deer (*Odocoileus virginianus*)	0.33 ± 0.06	53	Both
Snapping turtle (*Chelydra serpentina*)	0.22 ± 0.07	24	Both
American robin (*Turdus migratorius*)	0.17 ± 0.06	17	Both
Eastern screech owl (*Megascops asio*)	0.17 ± 0.04	27	Both
Domestic dog (*Canis lupus familiaris*)	0.14 ± 0.03	22	Both
Northern black racer (*Coluber constrictor*)	0.11 ± 0.04	13	Both
Northern cardinal (*Cardinalis cardinalis*)	0.11 ± 0.03	13	Both
Eastern ratsnake (*Pantherophis alleghaniensis*)	0.11 ± 0.03	13	Both
European starling (*Sturnus vulgaris*)	0.09 ± 0.04	10	Both
Eastern chipmunk (*Tamias striatus*)	0.07 ± 0.03	8	Both
Eastern gray fox (*Urocyon cinereoargenteus*)	0.07 ± 0.02	10	Both
Coyote (*Canis latrans*)	0.06 ± 0.02	8	Both
Gray catbird (*Dumetella carolinensis*)	0.05 ± 0.03	5	Both
Norway rat (*Rattus norvegicus*)	0.05 ± 0.03	7	Both
Red fox (*Vulpes vulpes*)	0.05 ± 0.02	6	Both
American crow (*Corvus brachyrhynchos*)	0.04 ± 0.02	5	Both
Turkey vulture (*Cathartes aura*)	0.04 ± 0.02	5	Both
Common muskrat (*Ondatra zibethicus*)	0.04 ± 0.02	6	RVR
Unknown	1.24 ± 0.24	162	Both
Total[a]	13.8 ± 1.73	1,837	Both

[a] Other species with <5 observations include beaver (*Castor canadensis*), American red squirrel (*Tamiasciurus hudsonicus*), bobcat (*Lynx rufus*), long-tailed weasel (*Mustela frenata*), American mink (*Mustela vison*), American black bear (*Ursus americanus*), wild turkey (*Meleagris gallopavo*), ruffed grouse (*Bonasa umbellus*), barred owl (*Strix varia*), red-tailed hawk (*Buteo jamaicensis*), sharp-shinned hawk (*Accipiter striatus*), yellow-bellied sapsucker (*Sphyrapicus varius*), yellow-throated vireo (*Vireo flavifrons*), orchard oriole (*Icterus spurius*), killdeer (*Charadrius vociferus*), Eastern kingbird (*Tyrannus tyrannus*), cedar waxwing (*Bombycilla cedrorum*), American goldfinch (*Spinus tristis*), American coot (*Fulica americana*), Eastern wood-pewee (*Contopus virens*), chimney swift (*Chaetura pelagica*), barn swallow (*Hirundo rustica*), song sparrow (*Melospiza melodia*), pied-billed grebe (*Podilymbus podiceps*), Eastern bluebird (*Sialia sialis*), common grackle (*Quiscalus quiscula*), Eastern meadowlark (*Sturnella magna*), brown thrasher (*Toxostoma rufum*), blue jay (*Cyanocitta cristata*), black vulture (*Coragyps atratus*), common pigeon (*Columba livia*), Baltimore oriole (*Icterus galbula*), mallard (*Anas platyrhynchos*), Eastern towhee (*Pipilo erythrophthalmus*), red-winged blackbird (*Agelaius phoeniceus*), indigo bunting (*Passerina cyanea*), mourning dove (*Zenaida macroura*), and domestic chicken (*Gallus gallus domesticus*).

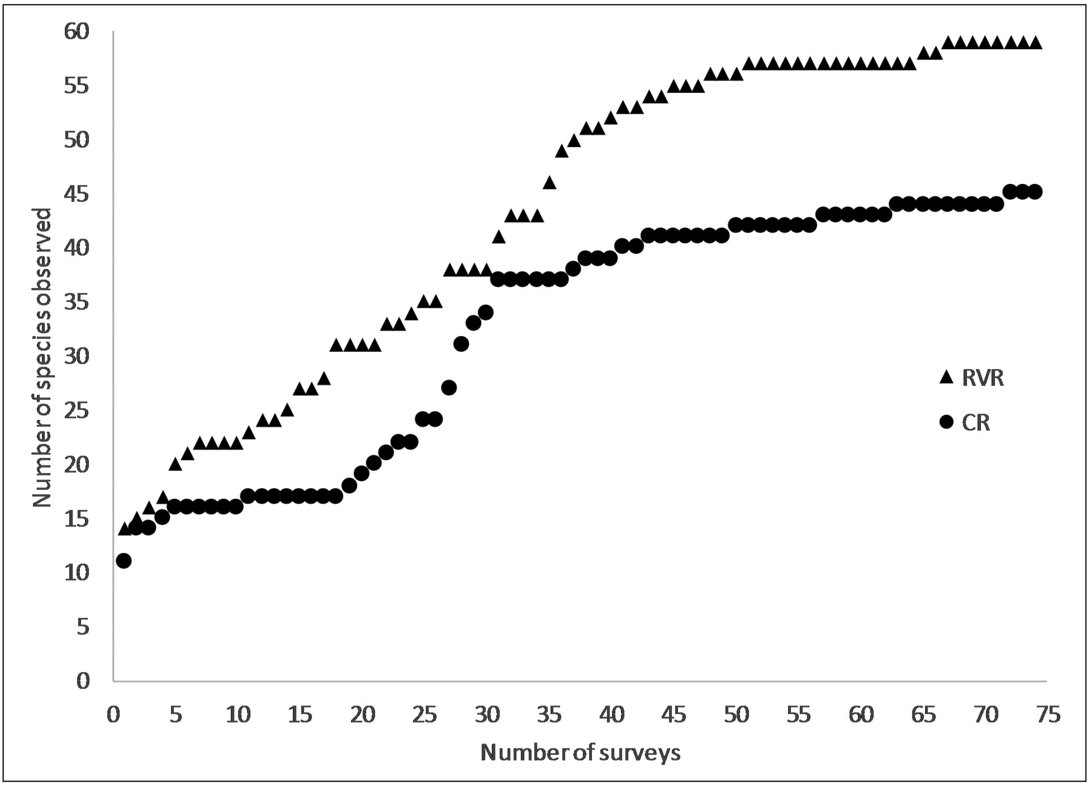

Figure 2. Species accumulation curves for 2 adjacent routes (CR = Coalfield Route, RVR = Ridge and Valley Route). Curves that approach an asymptote indicate sufficient sampling of taxa involved in wildlife–vehicle collisions on each route. Data collected in 2015.

Table 2. Similarity percentage (SIMPER) analysis results showing the percent contribution (by species) to the overall dissimilarity of wildlife–vehicle collision composition between 2 adjacent routes in southwest Virginia, USA during 2015.

Species common name (scientific name)	Percent contribution
Virginia opossum (*Didelphis virginiana*)	18.73
Northern raccoon (*Procyon lotor*)	16.59
Striped skunk (*Mephitis mephitis*)	7.52
Northern gray squirrel (*Sciurus carolinensis*)	7.33
Woodchuck (*Marmota monax*)	6.07
Domestic cat (*Felis silvestris catus*)	5.93
Eastern cottontail (*Sylvilagus floridanus*)	4.49
Fox squirrel (*Sciurus niger*)	4.24

by the relative abundance of meso-mammal WVC mortalities across both routes (Table 2). Specifically, Virginia opossums (*Didelphis virginiana*), northern raccoons (*Procyon lotor*), and striped skunks (*Mephitis mephitis*) contributed more to the overall abundance of WVC mortalities in the RVR compared to the CR. The opposite was true for northern gray squirrels (*Sciurus carolinensis*), which contributed more to the overall abundance of mortalities in the CR than the RVR. Cumulatively, these 4 species accounted for 50.2% of the observed dissimilarity in species composition for WVCs between routes.

We detected differences in temporal variation in WVC rates across the study area for certain taxa, but there was no difference in average monthly WVC rates across all taxa ($F_{35,11} = 2.19$, $P = 0.039$). The WVC mortality rates did not differ across months for raccoons ($F_{35,11} = 1.32$, $P = 0.255$), Virginia opossums ($F_{35,11} = 1.20$, $P = 0.326$), striped skunks ($F_{35,11} = 1.33$, $P = 0.251$), and northern gray squirrels ($F_{35,11} = 0.95$, $P = 0.509$). However, WVC rates for woodchucks (*Marmota monax*) were

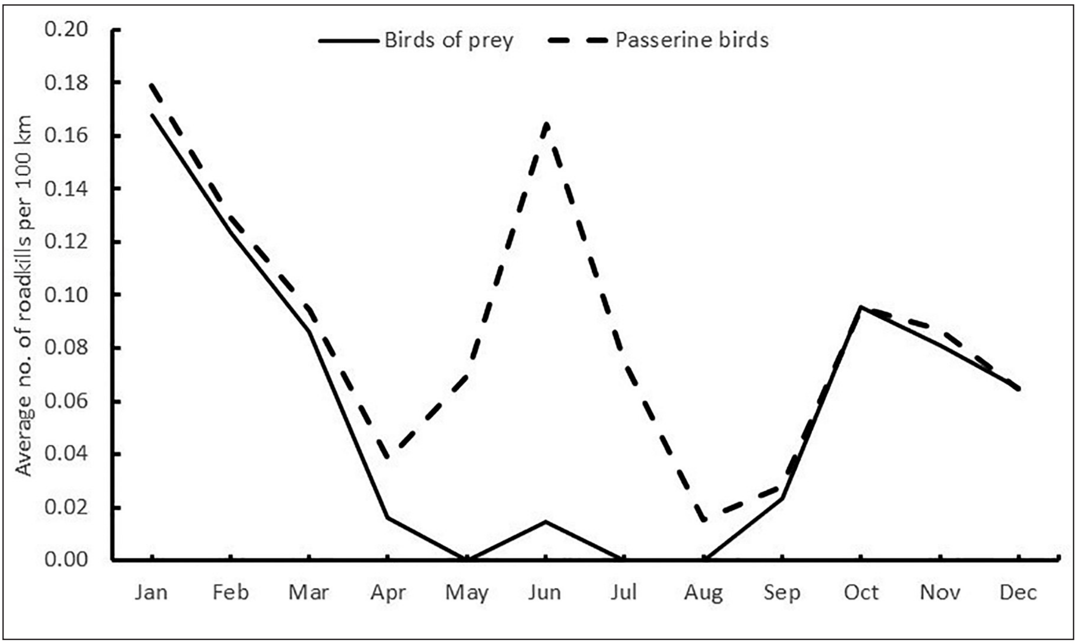

Figure 3. Temporal variation in wildlife–vehicle collision rates for birds of prey and passerine birds across 2 routes in southwest Virginia, USA in 2015. Data represent mean rates (averaged across biweekly surveys) per 100 km for each month.

higher in June and July ($F_{35,11} = 5.77$, $P < 0.001$).

Reptiles showed variable temporal trends in WVC rates. The WVCs involving eastern box turtles (*Terrapene carolina carolina*) showed significant temporal variation ($F_{35,11} = 3.53$, $P = 0.0021$), with rates higher in May, June, and July. No WVCs involving this species were detected from November to March. Similarly, rates for eastern ratsnakes (*Pantherophis alleganiensis*) differed between months ($F_{47,11} = 2.78$, $P = 0.011$), with higher rates occurring in May and June. No WVCs involving this species were detected from October to April. Lastly, both passerine taxa and birds of prey showed significant temporal variation in WVC rates. We recorded more birds of prey WVC mortalities in winter ($F_{43,3} = 5.05$, $P = 0.004$; Figure 3), with WVCs for passerine taxa being higher in May, June, and July ($F_{35,11} = 12.65$, $P < 0.001$; Figure 3).

Discussion

Wildlife–vehicle collisions pose substantial threats to both wildlife populations and human safety. Our study recorded WVCs across a wide range of taxa within the central Appalachian Mountains of North America, an area with both high levels of vertebrate diversity and a large human population with associated road networks. This is, to our knowledge, the first large-scale examination of WVCs from these physiographic regions, and our data indicate that WVCs are a widespread occurrence across this area, numbering >1,800 individual collisions and encompassing 65 species during our study period.

The frequency of WVCs has been shown to vary in response to traffic volumes (Inbar and Mayer 1999, Sullivan et al. 2004, Hussain et al. 2007, Arnold et al. 2018). Our WVC mortality data supported this phenomenon. We recorded approximately 300 more WVCs and 14 more species killed by vehicles from our more heavily traveled route than those recorded from a nearby route of similar length and road type. These 2 routes are adjacent to each other, occur within the same regional species pool of vertebrate taxa, and cross similar habitat types along their length, suggesting that the characteristics of WVCs may vary substantially from route to route in response to traffic volume within our study region, even across a narrow geographic extent.

One caveat of this finding is that our dataset did not allow for a detailed comparison of habitat features and road design contexts that might shape patterns in WVCs within each route. We did not feel comfortable making such a comparison, given the broad taxonomic scope of our dataset and the fact that habitat requirements and impacts from road design vary heavily across the organisms recorded in our study. Regardless, our results suggest caution for those attempting to extrapolate WVC patterns from 1 route to another within the central Appalachian region, and further research is necessary to determine the proximate and ultimate causes of regional variability in WVC patterns, beyond coarse differences in traffic volume.

Additionally, we found evidence of sub-stantial temporal variability in WVCs among taxa. The most abundant mammal species killed by vehicles in our study area did not exhibit significant seasonal variation in WVC mortality frequency, with WVCs occurring at a relatively consistent frequency for these species. This is logical, given that these species—Virginia opossums, raccoons, striped skunks, and northern gray squirrels—are abundant residents of developed edge habitats like those found along roadways, do not exhibit seasonal migratory behavior that would lead them to be more likely to encounter roadways during particular seasons, and are generally active year-round within our study area (Bixler and Gittleman 2000, Barding and Nelson 2008, Sparks and Gates 2012).

By contrast, we did find evidence of significant seasonal variability in WVC mortalities for woodchucks, with WVC rates for this species peaking in summer months and dropping to near zero during the winter season. This again is a logical result since woodchucks are obligate hibernators, residing in underground dens in colder months (Armitage 2017). Woodchucks were abundant in our study area and occur in large numbers in cleared edge habitats along highway road shoulders—a phenomenon noted in past work on this species (Woodward 1990). Given their proximity to roadways and their relative abundance in our WVC dataset, this seasonal pattern may be important for transportation officials and others seeking to develop mitigation measures to minimize vehicle collisions with this species. The identification of burrow systems and hibernacula may be used in concert with this information, for example, to locate fencing and/or culvert systems that can minimize roadway interactions during periods of high seasonal activity, as has been noted in past work on this species (Sparks and Gates 2012, Martinig and Belanger-Smith 2016).

We found similar patterns for reptile and bird taxa, in which temporal variation in WVC rates corresponded to known patterns of seasonal activity for individual species. Our WVC mortalities involving eastern box turtles and eastern ratsnakes, 2 of our study region's most common reptile taxa, occurred with the highest frequency in summer months, a time period when both species reach their maximum surface activity (Donaldson and Echternacht 2005, Sperry et al. 2010). Both species overwinter in hibernacula during colder months, and the increase in WVC mortality frequency from April to May noted for both taxa likely corresponds to the seasonal emergence of these species from hibernacula. While WVCs involving these organisms do not pose the same threats to human safety and property as do larger mammals, both species are of conservation concern in Virginia, particularly the eastern box turtle, which is listed as a species of high conservation need in the state due to ongoing declines (Virginia Department of Game and Inland Fisheries 2015). The seasonal peak for box turtles noted in our dataset may be valuable for managers seeking to better refine an understanding of if and how the temporal contexts of WVC activity in this species associate with ongoing declines or other demographic impacts.

Lastly, we found contrasting peaks in WVC mortality frequency for passerine birds and birds of prey. Passerine WVC mortality rates displayed a sharp peak in summer months—a result that is unsurprising, given that many of the passerine birds in our study region are migratory species that arrive from southern overwintering sites in late spring. The routes used in this study also overlap with a regional flyway identified in facilitating the movement of high numbers of seasonal passerine migrants (La Sorte et al. 2014). The presence of this migratory pathway, as well as the presence of breeding activity during warmer months, likely helps to drive the WVC mortality pattern noted for passerines in our dataset.

Birds of prey WVC mortality rates showed the opposite patterns of passerines, peaking in fall and winter months and showing a seasonal minimum frequency during the summer. While this result may seem surprising, most birds of prey in our region are year-round residents and do not exhibit large-scale migrations during winter months. Further, some birds of prey, such as red-tailed hawks (*Buteo jamaicensis*), may shift from actively hunting prey to feeding on carrion during winter months, presumably due to a lower rate of foraging success during seasonally inactive periods for more typical prey items (Sheffield and Jobe 1996, Peterson et al. 2001). This would place birds on or adjacent to highways, given the presence and abundance of animal carcasses resulting from WVC-related mortalities year-round. This factor, coupled with the fact that individuals from more northern locations may migrate south to join year-round residents of some species during the winter and supplement their numbers, provides a potential explanation for the winter peak in WVCs for birds of prey in our study.

Overall, our results suggest substantial variability in WVC mortality frequency across routes, seasons, and taxa in the central Appalachian Mountains—an area of high vertebrate diversity and an area of conservation concern due to ongoing rates of habitat loss. This presents a challenge to managers seeking to characterize WVC impacts regionwide. Specifically, the turnover in species noted between the 2 adjacent routes in our study suggests that extrapolating data on impacted species from 1 route to another may not accurately encompass the organisms being impacted across different routes at the regional scale. Detailed studies of individual routes or problem areas are likely needed to fully capture this variability, particularly when routes possess differing traffic volumes.

However, our findings about temporal variability in WVC mortality rates suggest some promise for the design of mitigation measures at the regional scale. We found that temporal patterns in WVC mortalities for the individual species recorded in our study were predictable, based on knowledge about each species' activity patterns, life history, and ecological associations. These patterns held across a broad taxonomic scope, including mammals, reptiles, and migratory birds. This suggests that managers and transportation officials may be able to overcome variability between differing routes by considering the activity patterns of focal taxa, especially when mitigation efforts are targeted at 1 or a few species of high conservation concern.

Seasonal signage, for example, has been found to be a successful and cost-effective short-term mitigation strategy in other geographic regions beyond our study system (Sullivan et al. 2004, Huijser et al. 2009). Similarly, seasonal slow speed zones, roadside animal detection systems, and other traffic-calming approaches have shown promise as strategies for WVC mitigation in past work (Meisingset et al. 2014, Grace et al. 2017). Such approaches may hold potential when applied seasonally in response to the peaks in WVC rates among focal taxa as noted in our study, although follow-up work would be necessary to monitor the efficacy of such approaches. Implementing these or related strategies within the context of the temporal patterns noted in our study presents an approach that may hold utility for addressing regional rates of WVC mortalities in future work.

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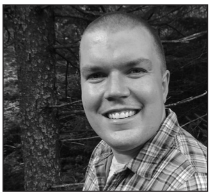

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