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Factors affecting autumn deer–vehicle collisions in a rural Virginia county

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Abstract: Vehicular collisions with white-tailed deer (*Odocoileus virginianus*) are a safety and economic hazard to motorists. Many efforts to reduce deer–vehicle collisions (DVCs) have proven unsuccessful, but deer reduction has been a primary management tool in several states. The Virginia Department of Transportation geo-located all known DVCs in Clarke County, Virginia, from August through December 2005 (n = 246) and 2006 (n = 259). We estimated harvest intensity, deer population density, amount of forest and housing development, presence of row crops, and traffic volume and speed for 228 road segments (each 500 m in length) within the county to determine which factors are correlated with increased DVCs. A step-wise general linear model indicated that deer density (range 5–47 deer/km^2), and deer harvest levels (range 1–18 deer/km^2 for 9-km^2 blocks) were not correlated with the location of DVCs. Road attributes (traffic volume and road type) and the amount of housing development were important attributes of road segments when predicting DVCs. The locations of DVCs during the rut were not markedly different from collisions outside the rut. Over the range of deer densities and harvest levels found in this rural county, there was little evidence that these factors influence the number of DVCs. Management efforts should include changing motorist behavior or road attributes.

Key words: deer density, deer–vehicle collision, human–wildlife conflict, *Odocoileus virginianus*, Virginia, white-tailed deer, wildlife damage management

Human–wildlife conflicts usually arise over property or crop damage by wildlife. A matrix of forest and agricultural crops is generally the ideal habitat for white-tailed deer (*Odocoileus virginianus*) and can contain the highest deer densities among rural counties (Hansen et al. 1997, Roseberry and Woolf 1998). Deer–human conflicts are to be expected most when these counties experience rapid growth in human populations (Storm et al. 2007). The most common interaction between deer and humans are deer–vehicle collisions (DVCs). A nationwide estimate found that 29,000 injuries and >$1 billion in property damage occurs each year from DVCs (Conover et al. 1995, Conover 1997). Opinions about deer are inversely related to the degree of damage individuals have experienced; reducing DVCs would improve people's attitudes toward deer (Cornicelli et al. 1993). Storm et al. (2007) found that DVCs were a concern for 84% of respondents to a deer survey in exurban Carbondale, Illinois.

High DVC rates are associated with multiple factors, including high deer densities, high human densities, habitat composition, and road characteristics (Hussain et al. 2007, Grovenburg et al. 2008, Ng 2008). The principle decision for managers is whether to focus efforts on the deer or the motorist population. Deer dispersal and breeding activities in the fall coincided with the high occurrences of DVCs in Nebraska (Case 1978), Pennsylvania (Puglisi et al. 1974, Feldhamer et al. 1986), and Michigan (Allen and McCullough 1976, Sudharsan et al. 2006). Etter et al. (2002) suggested that hunter activity increases the movement of deer and, therefore,

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contributes to an autumn peak in DVCs. For motorists, it is unclear whether high vehicle speed (Pojar et al. 1975, Case 1978) and volume are among the main causes of DVCs (Pojar et al. 1975, Bissonette and Kassar 2008). There may not be a direct causal relationship between DVCs and either motorist or deer populations, as DVCs over a 20-year period on European highways have been far greater than increases in either ungulate population density or traffic volume (Bruinderink and Hazebroek 1996).

One solution suggested to mitigate DVCs has been to reduce deer densities (DeNicola and Williams 2008, Mastro et al. 2008, Rutberg and Naugle 2008). Allen and McCullough (1976) first suggested that reducing deer densities may be an effective management tool for reducing the number of DVCs. State management plans often correlate high deer densities with high DVCs (e.g., Deer Management Planning Committee 2007), and state management agencies in both Michigan and Illinois use deer herd reduction as a tool to lower DVCs (Romin and Bissonette 1996). In comparisons among counties in Alabama, Hussain et al. (2007) found lower DVCs where counties have higher hunting license sales and deer bag limits.

Reported DVCs in Virginia have increased 10-fold during the last 40 years (Metropolitan Washington Council of Governments 2006), a period that coincides with increases in both human and deer populations. Clarke County in rural Virginia has undergone a 12% human population increase from 2000 to 2005 (U. S. Census Bureau 2006). Yet, the county still maintains a rural landscape (Virginia National Land Cover Data 2003). DVCs are common in Clarke County. In a recent landowner survey for the county, 289 of 613 (47%) households had experienced a DVC (McShea, National Zoological Park, unpublished data). Clarke County has many of the attributes associated with high DVCs in Alabama (Hussain et al. 2007): high deer density, location on the edge of a metropolitan area, and a high proportion of cropland relative to forest.

Most DVC studies (Hubbard et al. 2000, Hussain et al., 2007) use county-wide estimates of deer density and harvest due to the coarse resolution of the state agency data. Within a single county, we hypothesized that DVCs should be positively correlated with deer density and negatively correlated with deer harvest levels. In this study, we analyzed multiple characteristics that have been associated with DVCs (e.g., habitat composition, land use, road characteristics, harvest intensity, and deer population density) to determine which factors significantly contributed to the frequency of Clarke County DVCs during the autumns of 2005 and 2006, months when the highest number of DVCs occur (Allen and McCullough 1976, Etter et al. 2002, Hussain et al. 2007). We included a period of increased deer movement (i.e., rut) regardless of harvest pressure on deer populations (Sudharsan et al. 2006). Our analysis is intended to assist wildlife managers and land-use planners in setting priorities for management activities that would effectively reduce DVCs.

Methods

Clarke County, Virginia, encompasses 457 km^2 in northwest Virginia and is located approximately 140 km west of Washington, D.C. (Figure 1). The dominant land cover of Clarke County is agricultural fields, either pasture (55%) or row crops (3%). Forest comprises 38% of land, mostly along the Blue Ridge Mountains in the eastern portion of the county (Virginia National Land Cover Data, http://fisher.lib.virginia.edu/collections/gis/vagaz). More than 95% of the land in the county is privately owned.

Virginia Department of Transportation (VDOT) state employees collected and geolocated all known vehicle-killed deer in Clarke County during 2 week intervals from August 1 to December 30, 2005 and 2006. Though deemed important, the age and sex of the animals were not included in analyses due to inconsistencies in data collection. DVCs were historically highest during the rut and hunting season, due to dispersal and breeding activities (Case 1978, Sudharsan et al. 2006, Hussain et al. 2007). We assumed all retrieved deer represent sites of a DVC during the previous 2 weeks.

We used 3 road characteristics for this study: traffic volume, speed limit, and road size (i.e., primary or secondary). Traffic volume for each road was obtained from the VDOT Mobility Management Division's 2003 count of the average daily number of vehicles traveling along each section of road within Clarke

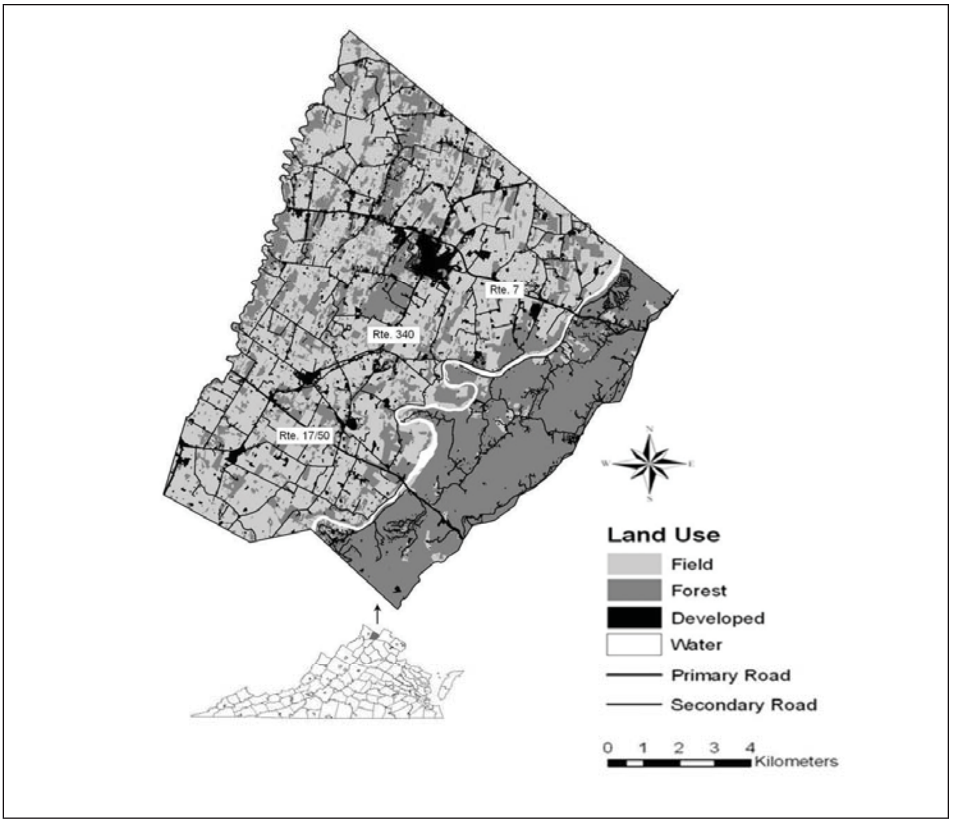

FIGURE 1. Land-use map of Clarke County, Va., based on 2002 digital orthophotos. Land-use categories are: forest (dark gray), includes edge and managed nature; field (light gray), includes pasture and crops; and development (black). Primary and secondary roads are indicated, and primary roads are identified.

County (C. Monroe, Clarke County VDOT, personal communication). We also recorded the posted speed limit for each road segment. We considered primary roads those roads with both high traffic volume (>10,000 vehicles/day) and higher speed limits (>83 km/hr) and identified 3 primary roads in Clarke County (U.S. Routes 340, 7, and 17/50). The mean traffic volume of primary and secondary roads was 15,001 vehicles/day and 864 vehicles/day, respectively. Ultimately, we classified 581 km as secondary roads and 119 km as primary roads in Clarke County.

We used Geographic Information Systems (GIS) software (ArcMapTM 9.1, Environmental Systems Research Institute, Redlands, Calif.) to digitize all deer retrieval locations onto a Clarke County road layer. We generated 175 random points at least 500 m apart along this road layer using a random point generator in Hawth's Tools v.3.23 Extension (http://www.spatialecology.com/htools) in ArcMap (79 points on primary roads and 96 points on secondary roads). Each point was the center of a 500-m segment of road and the number of DVCs that occurred within the segment was added to road and habitat attributes. Few of the initial segments along secondary roads contained DVCs (n = 11); thus, we added 47 segments that contained DVCs in 2005. We used the 175 random segments to examine DVC site characteristics, but we included the 47 known-DVC segments when examining only secondary road characteristics.

We digitized land cover polygons for Clarke County, Virginia, using 2002 digital orthophotos and ArcMap at a scale of <1:5000 m. We initially classified land cover into 8 categories: developed, row crops, pasture, forest, edge forest (woodland patches 40- to 99-m wide), managed forest (orchards, tree farms, or golf courses), road, and water. For this study, we combined forest, edge forest, and managed forest into a single category (i.e., forest) and combined crops and pasture into a single category (i.e., field; Figure 1).

We placed a 200-m buffer around each 500-m road segment to quantify habitat composition: percentage of forest cover, and presence/absence of row crops.

We used estimated deer density using distance sampling techniques (Buckland et al. 2001). We

Table 1. Deer density estimates based on distance sampling protocols for 7 zones in Clarke County, Va., in 2005 and 2006 and pooled in 2005–2006 (see Figure 2 for location of the zones).

Zone	Transect length (km)	Area (km^2)	Density estimates (deer/km^2)								
			2005			2006			Both years pooled		
			n	$\bar{x}$	CV[1]	*n*	$\bar{x}$	CV	*n*	$\bar{x}$	CV
1	39.2	84.0	65	15.0	0.24	84	18.7	0.11	149	15.1	0.18
2	21.4	46.7	57	9.8	0.22	17	---	---	74	5.8	0.13
3	32.4	80.4	54	20.8	0.16	66	24.9	0.15	120	23.1	0.22
4	41.8	88.6	80	21.0	0.23	---	---	---	80	21.0	0.23
5	37.8	74.5	75	34.8	0.19	112	29.4	0.28	187	44.8	0.25
6	22.6	50.8	63	23.5	0.18	32	---	---	95	38.0	0.16
7	25.2	72.3	57	36.9	0.18	25	---	---	82	21.6	0.17
Total									**787**	**26.9**	**0.13**

[1] cv = coefficient of variation

Figure 2. Deer–vehicle collisions and deer density in Clarke County, Va., in 2005 and 2006. Overlapping collision sites were slightly offset for effect. Deer-density calculations represent combined 2005 and 2006 data (see Table 1); increasing gray scale indicates higher deer density. The zones listed in Table 1 are indicated.

divided the county into 7 zones using major roads and natural barriers (e.g. Shenandoah River). We sighted deer and their distance to the road along 213 km of public roads by means of spotlighting (1 million candlepower, Brinkmann Corp.) from 1800 hours to 2200 hours on selected nights in October and November. The addition of distance sampling considerations to spotlighting protocols resolved most of the problems typically associated with using spotlighting as a density estimator (Focardi et al. 2001). Spotlighting has been used to successfully estimate wildlife densities (Koenen et al. 2002, Ruette et al. 2003, Stapp and Guttilla 2006).

We estimated deer density for all zones in 2005, with each zone surveyed 3–6 nights until sufficient observations were achieved. In 2006 we completed sufficient observations for analysis in only 3 of the 7 zones, with the remaining zones left incomplete due to regulatory problems; an ANOVA indicated no significant difference in density estimates between 2005 and 2006 for the 3 completed zones in 2006 (Table 1; Figure 2), so we combined all the data for each zone and calculated a single estimate for each zone.

We estimated deer harvest intensity through a survey sent to every landowner with >4 ha of land in Clarke County in 2005. The survey, which also was distributed through community organizations and meetings, included 6 questions about land use, including the number of deer harvested on landowners' property the previous year. Overall, 762 individuals, representing 35% of county land parcels, completed the survey. When we combined these parcels with known deer-harvest areas, we obtained harvest rates for 249 km^2 (54%) of county land (Figure 3). Using a 9-km^2 grid overlaid on a land holder layer within ArcMap, we estimated the average number of deer harvested/km^2 for each grid cell. We estimated harvest levels only for grid cells where we had information on >20% of the land. For each 500-m road segment, we assigned the deer harvest estimate for its particular cell. We also calculated the amount of developed land/ha within each grid cell and assigned this value to each road segment.

To examine whether DVCs during the rut were a unique subset of collisions, we examined both the entire 5-month sampling period

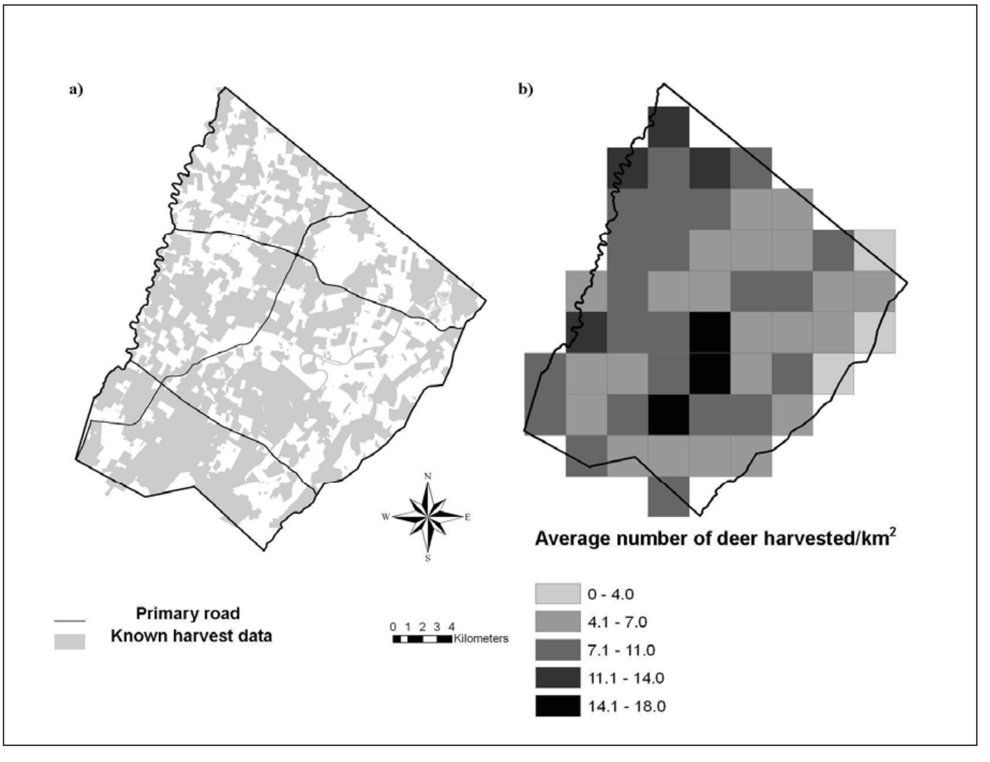

Figure 3. (a) Landholdings where harvest levels were known, due either to completed land-use surveys, 2005–2006, or zoning ordinances. (b) Estimated harvest intensity based on known land for each 9-km^2 cell in Clarke County, Va., USA.

and a 6-week period coinciding with the peak of the rut (October 15–November 30). We based the peak of rut on fetal data collected from a nearby facility (D. Kocka, Virginia Department of Game and Inland Fisheries [VDGIF], unpublished data), with a 2-week buffer added to each end of the conception range.

Our dependent variable was the number of deer carcasses retrieved from a random selection of segments along public roads in the county. We combined 2005 and 2006 data and examined both the entire dataset and just those deer retrieved during the rut (October 15–November 30). For analysis, we used a stepwise (backwards) general linear model (GLM; Systat® 11.0) with $P < 0.05$ for a variable to be removed from the model and models with $P < 0.05$ considered significant predictors of DVCs. Several values (e.g., forest cover, traffic volume, and DVCs) were log-transformed prior to analysis to conform more closely to a normal distribution. For estimated deer density, some primary road segments fell on the boundary between density zones; for these segments we initially ran the analysis using each of 3 sets of values (i.e., average of the zones, the lower density zone, or the higher density zone) and found no differences in analyses; we, therefore, present average density values for these segments. The variable measuring development exhibited a bimodal distribution of values, so we created a class variable with >10% development area within the 9-km^2 cell designated as high development.

The 2006 deer season in Clarke County included an archery season (October 7–November 17), a muzzleloader season (November 11–November 17), and a firearms season (November 18–January 6), with a similar distribution in 2005. According to state records, 1,861 deer (4.07 deer/km^2) were harvested in Clarke County in 2005, and 1,922 deer (4.20 deer/km^2) were harvested in 2006. We requested the Virginia deer biologist to calculate the county's deer population based on harvest numbers, and his estimates ranged from 7,481 to 12,615 (M. Knox, VDGIF, personal communication).

Results

In 2005, 236 dead deer were collected along roads from August through December (1.6 deer/day); 148 of these deer were collected during the rut (October 15–November 30; 3.5 deer/day), and 88 deer were recovered during the non-rut period (0.8 deer/day). In 2006, 259 deer were collected from August through December (1.7 deer/day), with 156 of these deer (3.7 deer/day) collected during the rut (Table 2). The DVC rates during the non-rut period (0.68 deer/day) were again lower than the DVC rates during the rut. Primary roads comprised only 17% of the total number of roads in Clarke County, but 68% of all DVCs occurred on them (Figure 4).

Deer density estimates for each zone ranged from 5.8 to 44.8 deer/km^2 (Table 1) or approximately 12,334 (range 9,569–15,903) deer in the entire county. Our estimate is within the range estimated by the state deer biologist (7,481–12,615 deer) and was based on 100% of the county land being suitable for deer; exclusion of developed areas (9%) would lower our county-wide estimate to a range of 8,694 to 14,476 deer. According to the results of landowner surveys and areas with local and federal ordinances prohibiting hunting, deer are not harvested on 38% of the land in Clarke County. For land where deer were harvested, the mean harvest rate was 8.6 deer/km^2. There was no significant correlation between deer harvest rates and deer density estimates for the 7 county zones ($r^2 = 0.09$, $P > 0.1$). Our data indicate that more deer are harvested in the county than state deer check records indicate

Table 2. The number of deer carcasses retrieved along public roads by Virginia Department of Transportation employees during each month of the study in Clarke County, Va., 2005 and 2006.

Year	Road type	August	September	October	November	December
2005	Primary	10	10	44	82	32
	Secondary	9	16	8	25	13
2006	Primary	6	8	48	74	33
	Secondary	3	13	17	27	30

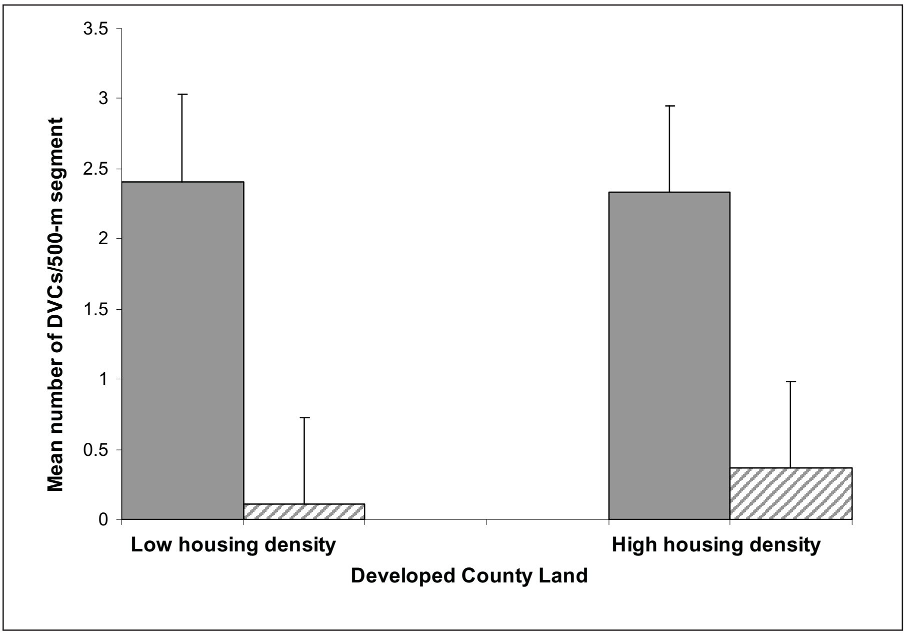

FIGURE 4. The mean number of deer–vehicle collisions for 500-m segment of road for primary (gray) and secondary roads (hatched) in developed and undeveloped sections of Clarke County, Va.

(2,437 for landowner surveys versus deer-check records of 1,861 deer during 2005 and 1,922 deer during 2006.).

For the randomly-selected road segments (n = 175), there was a significant positive correlation between the number of DVCs occurring in each segment in 2005 and 2006 ($r^2 = 0.48$, $P < 0.001$). This annual consistency in DVC sites was on both primary ($r^2 = 0.34$, $P = 0.03$) and secondary ($r^2 = 0.26$, $P = 0.02$) road segments. The location of DVCs during the rut was significantly correlated with the location of collisions outside the rut period in 2005 ($r^2 = 0.53$, $P < 0.001$), and in 2006 ($r^2 = 0.26$, $P = 0.006$). In summary, when comparing the rut to the period just prior and subsequent, the number of DVCs during the rut was approximately 4 times higher, but the location of DVCs was similar.

For randomly-selected segments of roads within the county, road type (e.g., primary or secondary) and the amount of housing development were the 2 significant predictors of DVCs (GLM; df = 2,172; $r^2 = 0.49$; partial $F = 145.9$; P < 0.0001 and $F = 5.00$, $P = 0.027$, respectively; Figure 4). When we used only DVCs from the rut, road type alone was in the final model (GLM; df = 1,173; $r = 0.46$; partial $F = 155.7$; $P < 0.0001$). Deer density or deer harvest level were not significantly correlated with DVCs.

We examined primary and secondary roads separately to determine if the pattern of DVCs differed. For segments along primary roads (n = 79), none of our variables was a significant predictor of DVCs. For segments along secondary roads (n = 145), traffic volume was the best predictor of DVC numbers (GLM; df = 1,144; $F = 30.44$; $P < 0.001$; $r^2 = 0.18$), with increased volume resulting in increased DVCs.

If we examine collisions occurring only during the rut, the results are slightly different. Once again, no variables are important predictors of DVCs for primary roads, and for secondary roads, variables were traffic volume and average deer density (GLM; df = 2,142; $r^2 = 0.11$; partial $F = 6.33$; $P = 0.013$ and partial $F = 7.74$; $P = 0.006$, respectively; Figure 5). The single new variable, average deer density, was negatively correlated with DVCs.

The relationship between deer density and DVCs was not linear (Figure 5). With 4 density classes, deer density did significantly impact DVCs when road type was considered (ANOVA; partial $F = 2.93$; $P = 0.034$ and partial $F = 50.5$; $P < 0.0001$, respectively). When primary and secondary roads were considered separately, the difference between density classes was significant only on secondary roads (ANOVA; $F = 3.66$; $P = 0.01$). A Bonferroni test showed the

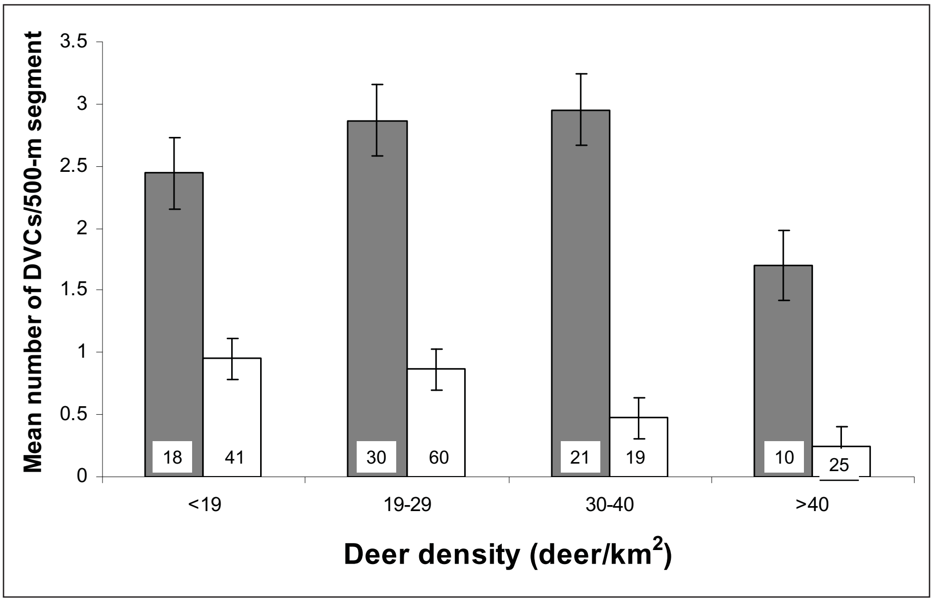

Figure 5. Mean number of DVCs/500-m road segment along primary (gray bars) and secondary (white bars) roads at 4 deer density classes found within Clarke County, Va., 2005–2006. Sample size for each segment is given at the base of each bar. Standard error bars are shown, and class divisions were based on sample size.

difference was due to DVCs within the highest density class (>40 deer/km^2) being lower than the first (<19 deer/km^2) class and second (19–29 deer/km^2) class ($P < 0.01$).

Discussion

The average monetary damage caused by a DVC has been estimated at $2,000 (Danielson and Hubbard 1998). If the deer retrieved by VDOT employees is a minimal estimate of the number of DVCs occurring in Clarke County, these represent $495,000 annually in automobile damage during 2 5-month periods in 2005 and 2006.

Whereas both deer density and harvest information are usually estimated at the county level (Hubbard et al. 2000, Hussain et al. 2007), we made a concerted effort to work at a finer resolution, which allowed us to compare geographic regions (i.e., neighborhoods) within the county. We found a wide range of both deer densities and harvest rates within the county and no significant correlation between the 2 measures. Our original hypotheses that DVCs in zones should negatively correlate with deer harvest and positively correlate with deer density were not supported. Our lack of evidence that deer harvest activity coincided with low levels of DVCs may be due to the low deer harvest rates within the county. Based on state deer-check data, <15% of the county's estimated deer population was removed annually. For most analyses, deer density was not a significant factor for indicating the probability of DVCs; when it was significant (e.g., secondary roads during the rut), DVCs were lowest in the areas with the highest deer densities. It is possible that historic removal of deer through DVCs has created the low deer density zones, but the DVCs we recorded represent <2% of the county's deer population, and we cannot see this incidental mortality being responsible for the pattern of deer density across the county. It is more likely that the movement of deer in the highest density zones was different from that of other sections of the county. The highest deer densities occurred near the Virginia State Arboretum, where hunting is prohibited (Zone 5), and in the forested zones of the county (Zones 6 and 7). The lowest deer densities and higher DVC rates were in the agricultural regions. Less movement from cover to feeding could be occurring in these high density areas, and deer movement is one correlate of DVCs (Etter et al. 2002)

Reducing DVCs remains a high priority for wildlife managers. Despite the importance of minimizing DVCs, published literature on methods is limited and mostly confined to non-peer-reviewed state agency publications (Romin and Bissonette 1996). Most studies are not experimental, and they demonstrate correlations between DVCs and multiple variables, while solutions are often limited to restricting deer access to highways (Putman 1997).

Deer reduction through public hunting or special permits is used to reduce DVCs in several states (e.g., Wildlife–Vehicle Collision Reduction Working Group 2006). Hussain et al. (2007) recommended increased hunter harvest at the county level to reduce DVCs in Alabama. Reducing deer populations has been an effective management tool for mitigating DVCs in urban or suburban areas. Successful sharpshooting efforts has been achieved in suburban or urban areas such as Princeton, New Jersey, Iowa City, Iowa, and Solon, Ohio, where high deer densities were concentrated (DeNicola and Williams 2008). Sharpshooting was an efficient strategy at these sites because deer were concentrated in smaller areas and were acclimated to human presence, making deer removal easier. Success with public sharpshooters, however, may be difficult to repeat in some counties, because so little land is accessible to hunters. For example, Storm et al. (2007) found only 19% of private land around Carbondale, Illinois, was hunted. In our study, we estimate that while 62% of the land was hunted and harvest rates on hunted land was high (8.6 deer/km^2), this rate still represents <20% of the county's deer population being harvested annually. We found no evidence within Clarke County that deer density or deer harvest were important for determining the frequency of DVCs at the scale of zones within a county. Clarke County may be indicative of rural or exurban counties where suitable habitat for deer is abundant and widespread and annual deer harvest rarely exceeds replacement rates within the population.

Road attributes, such as traffic volume and speed limits, and land-use qualities, such as development, were important variables in the predictive models of DVCs in Clarke County. In rural and exurban counties, we suggest that efforts to reduced the frequency of DVCs should include changing motorist behavior, in addition to efforts to reduce deer populations. Deer crossing signs are effective if motorists reduce their vehicle speed (Romin and Bissonette 1996, Sullivan et al. 2004). However, motorists become complacent and tend to ignore permanent deer-crossing signs unless the warning is reinforced by an actual experience (Putman 1997). Evidence of DVCs, however, can change motorists' behavior. Pojar et al. (1975) concluded that deer carcasses placed next to warning signs did significantly reduce vehicle speed, although the authors did not record the number of DVCs in the area. Sullivan et al. (2004) found that temporary signs are effective at increasing public awareness, reducing vehicle speeds, and limiting DVCs along migration routes of mule deer (*Odocoileus hemionus*).

We found a significant consistency in locations of DVCs over years (Figure 2). In addition, the bulk of DVCs occurred during a short 6-week period that coincided with the rut. This concentration of DVCs in time and space might make the problem amenable to focused action by managers; although, we do not see deer management agencies as the primary agent for solving DVCs in these focused areas. Rather, the responsibility should be shared among transportation departments, road engineers, community planners, landowners, and motorists. A combination of targeted enforcement of posted speeds and public awareness campaigns along corridors where DVCs are high prior to and during the rut may prove effective for all those involved.

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clarity of the manuscript.

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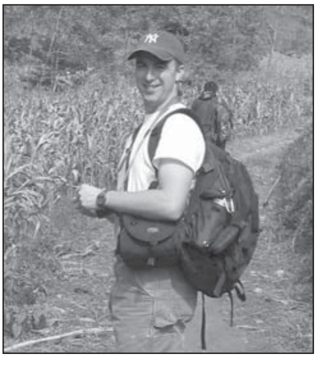

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