2008

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Human–Wildlife Conflicts 2(1):48–59, Spring 2008

Factors affecting road mortality of white-tailed deer in eastern South Dakota

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Abstract: White-tailed deer (*Odocoileus virginianus*) mortalities (n = 4,433) caused by collisions with automobiles during 2003 were modeled in 35 counties in eastern South Dakota. Seventeen independent variables and 5 independent variable interactions were evaluated to explain deer mortalities. A negative binomial regression model (Ln Y = 1.25 – 0.12 [percentage tree coverage] + 0.0002 [county area] + 5.39 [county hunter success rate] + 0.0023 [vehicle proxy 96–104 km/hr roads], model deviance = 33.43, χ^2 = 27.53, df = 27) was chosen using a combination of *a priori* model selection and AIC_c. Management options include use of the model to predict road mortalities and to increase the number of hunting licenses, which could result in fewer DVCs.

Key words: deer–vehicle collision, human–wildlife conflict, *Odocoileus virginianus*, regression modeling, South Dakota, white-tailed deer

White-tailed deer *(Odocoileus virginianus)* numbers have increased dramatically in density and distribution during the twentieth century in the United States (McShea and Underwood 1997, Hubbard et al. 2000). In the early 1900s, the North American deer population was estimated at 500,000 animals. Today, the population exceeds 20 million animals (Cook and Daggett 1995, Hubbard et al. 2000). In the last 20 years, transportation infrastructure has increased, and the volume and speed of traffic on public highways, including interstates and improved arterials, also have increased (Cook and Dagget 1995, Forman and Alexander 1998, Hubbard et al. 2000, Mysterud 2004).

Collisions between deer and vehicles have increased throughout most of the country (Allen and McCullough 1976, Gleason and Jenks 1993, Conover 2002) and the developed world (Conover et al. 1995, Groot-Bruinderink and Hazebroek 1996, Romin and Bissonette 1996, Malo et al. 2004). In the 1990s, about 1 million deer–vehicle collisions (DVCs) annually in the United States were reported, causing more than $1 billion in vehicle damage and >200 human fatalities (Conover et al. 1995, Cook and Dagget 1995, Romin and Bissonette 1996, Hubbard et al. 2000, Nielsen et al. 2003, Bissonette et al. 2008). Conover (2002) estimated that the actual number of DVCs occurring annually (including those not reported) was approximately 1.5 million. Human injuries occur in approximately 4% to 5% of collisions with medium-sized animals, such as *Odocoileus* spp. (Hansen 1983, Conover et al. 1995, Biggs et al. 2004, Malo et al. 2004), and in approximately 14% to 18% of collisions with larger mammals, such as moose (*Alces alces*; Farrell et al. 1996, Joyce and Mahoney 2001, Malo et al. 2004). Globally, several million collisions with large mammals occur annually (Conover et al. 1995, Groot-Bruinderink and Hazebroek 1996, Romin and Bissonette 1996, Malo et al. 2004). In some urban areas, DVCs have become the most common proximate cause of mortality of ungulates (Lopez et al. 2003, Mysterud 2004).

Studies have been conducted to evaluate habitat effects on deer mortalities resulting from DVCs, including effects of habitat composition (Gleason and Jenks 1993), landscape patterns (Hubbard et al. 2000. Nielsen et al. 2003, Hussain et al. 2007), and habitat modification (Jaren et al. 1991, Romin and Bissonette 1996). Additional evaluations of deer mortality resulting from DVCs include deer movements onto and across highways (Puglisi et al. 1974), seasonality (Allen and McCullough 1976, Gleason and Jenks 1993), observability of deer (Zagata and Haugen 1974), fences (Ludwig and Bremicker 1983, Clevenger et al. 2001, Malo et al. 2004), cautionary road signs (Pojar et al. 1975, Biggs et al. 2004, Malo et al. 2004), road modifications (Lehnert and Bissonette 1997, Keller 1999, Clevenger and Waltho 2000, Malo et al. 2004), vehicle-mounted whistles (Romin and Dalton 1992, Malo et al. 2004, West 2008), and wildlife warning reflectors (Ujvári et al. 1998). Few studies have developed predictive models of factors influencing deer mortalities on a landscape level in North America. Number and location of deer mortalities are dependent on traffic volume and vehicle speed (Pojar et al. 1975, Bashore et al. 1985, Hubbard et al. 2000, McShea et al. 2008). However, deer population dynamics, landscape features, and cover types also influence the frequency of DVCs (Groot-Bruinderink and Hazebroek 1996, Hubbard et al. 2000, Mastro et al. 2008). The purpose of this study was to develop a predictive model to best explain deer mortalities on a county landscape basis for eastern South Dakota. We hypothesized that the number of people living in a county, habitat, road characteristics, and variables related to deer density would explain variation in deer mortalities across both years and counties.

Study area

The study was conducted in a 35-county area in eastern South Dakota, also known as Regions 3 and 4, South Dakota Game, Fish and Parks Department (SDGFP; Figure 1). In this region of South Dakota, SDGFP manages deer populations on a county-by-county basis, with county boundaries representing deer management units. The total area for these counties was 66,320 km² (U.S. Census Bureau 2000). The total human population for these counties was 474,679 people during 1999 (U.S. Census Bureau 2000).

Major highways within the regions included 2 interstates and 14 federal and state highways. The area also contained numerous secondary

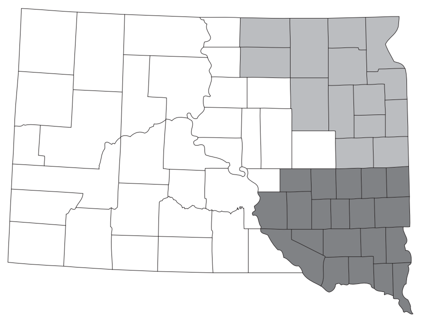

Figure 1. Study area comprised 35 counties in eastern portion of South Dakota encompassing South Dakota Game, Fish and Parks, Regions 3 (south, dark shading) and 4 (north, light shading).

arterial roads, as well as paved and gravel county roads. Linear kilometer totals for interstate highways, federal and state highways, and county highways in the study area were 621 km, 4,258 km, and 546 km, respectively (K. Marks, South Dakota Department of Transportation, unpublished data).

This region of eastern South Dakota includes the Coteau des Prairies, James River Lowlands, and Missouri Coteau physiographic regions, which are characterized by rolling hills with glacial wetlands (Westin and Malo 1978, Gleason and Jenks 1993). Primary watersheds in the study area include the Big Sioux, James, Missouri, and Vermillion rivers. Land ownership was predominantly private. Agriculture and pasture were the 2 primary land uses in the study area (Smith et al. 2002).

Native vegetation of the region was tall-grass and mid-grass prairie (Westin and Malo 1978, Gleason and Jenks 1993), but much has been converted to agricultural use, producing corn (*Zea mays*), soybeans (*Glycine max*), alfalfa (*Medicago sativa*), and small grains (Gleason and Jenks 1993). These agricultural fields were intermixed with deciduous and coniferous wind breaks.

The South Dakota climate is continental with extremes of heat and cold (Gleason and Jenks 1993) ranging from 38°C in summer to –29°C in winter (Kramlich 1985). Moisture is variable, with most precipitation occurring during the spring and winter. Mean annual precipitation was 56 cm, and mean annual temperature was 6.7°C (Gleason and Jenks 1993).

Methods

Information on deer mortalities from DVCs was reported by officers of the South Dakota Highway Patrol, SDGFP, and local law enforcement agencies, as well as the general public. Information was available for calendar year 2003 and included date, location (mile marker), highway, and reporting agency or officer (South Dakota Department of Game, Fish and Parks, unpublished data).

We tabulated data about deer carcasses into a central database. Information was logged on a monthly basis by county and road type based upon the posted speed limit for the road. We then used the annual deer mortality total for each county in our models. We used linear kilometers of road type per county (K. Marks, South Dakota Department of Transportation, unpublished data) for the 3 classifications (interstate highway, federal and state highway, and county highway) of road. Percentage of county land usage data (Smith et al. 2002) provided hectares of land usage in the following categories: agricultural, development density, water, trees, pasture and grassland, wetlands, riverine wetlands, and permanent wetlands. We combined hectares of low density (farm buildings) and high density (cities, towns) development into a single development variable. Hayfields, idle grass, and pasture were combined into pasture and grassland; deciduous trees, eastern red cedar (*Juniperus virginiana*), and bur oak (*Quercus macrocarpa*) were combined into trees; and semipermanent, seasonal, and temporary wetlands were combined into wetlands.

We used hunter success rate by county for combined white-tailed deer and mule deer (*Odocoileus hemionus*) hunter harvest (South Dakota Department of Game, Fish and Parks, unpublished data) as a percentage of county permits issued. County population and county area in km² also were included as variables in the basic regression template. We used county population divided by linear kilometers of each of the 3 road types as vehicle proxies.

Analytical methods

For each county, we evaluated 17 independent variables in our model to predict deer mortalities: county human population (range of 2,295–148,281/county), kilometers of interstate highways (range of 0–75 km/county), kilometers of federal and state highways (range of 34–282 km/county), and kilometers of county roads (range of 0–68 km). Percentages of county land usage in the following categories were used to evaluate habitat effects: agricultural (range of 28–76%), development density (range of 0–3%), water (range of 0–0.6%), trees (range of 1–5%), pasture and grassland (range of 17–58%), wetlands (range of 3–14%), riverine wetlands (range of 0–2%), and permanent wetlands (range of 0–5%). County area (range of 282–4,437 km²), county hunter success rate of deer harvest (range of 44–70%), and county vehicle traffic proxy (interstate, highway, and county roads) also were used in our modeling. We also included 5 variable interactions: county population and linear kilometers of interstate highways, county population and linear kilometers of federal and state highways, county population and linear kilometers of county roads, county population and development density, and development density and county hunter success rate.

We used regression analysis with variance inflation (Allison 1999) to eliminate variables with high colinearity. The remaining variables constituted our global model. We next used negative binomial regression to test 12 *a priori* models and our global model to test the hypothesis that a relationship existed between deer mortalities and road speed limits, habitat, and population variables to formulate a usable model for predicting deer mortalities. Variables for each model tested were selected based upon importance in explaining mortality rates of white-tailed deer. In addition, we wanted to evaluate effects of road speed limits, habitat variables, interactions between speed limits and population, and development and hunter success on DVCs. It was important to include speed and habitat variables within the model because high speed limits (Gleason and Jenks

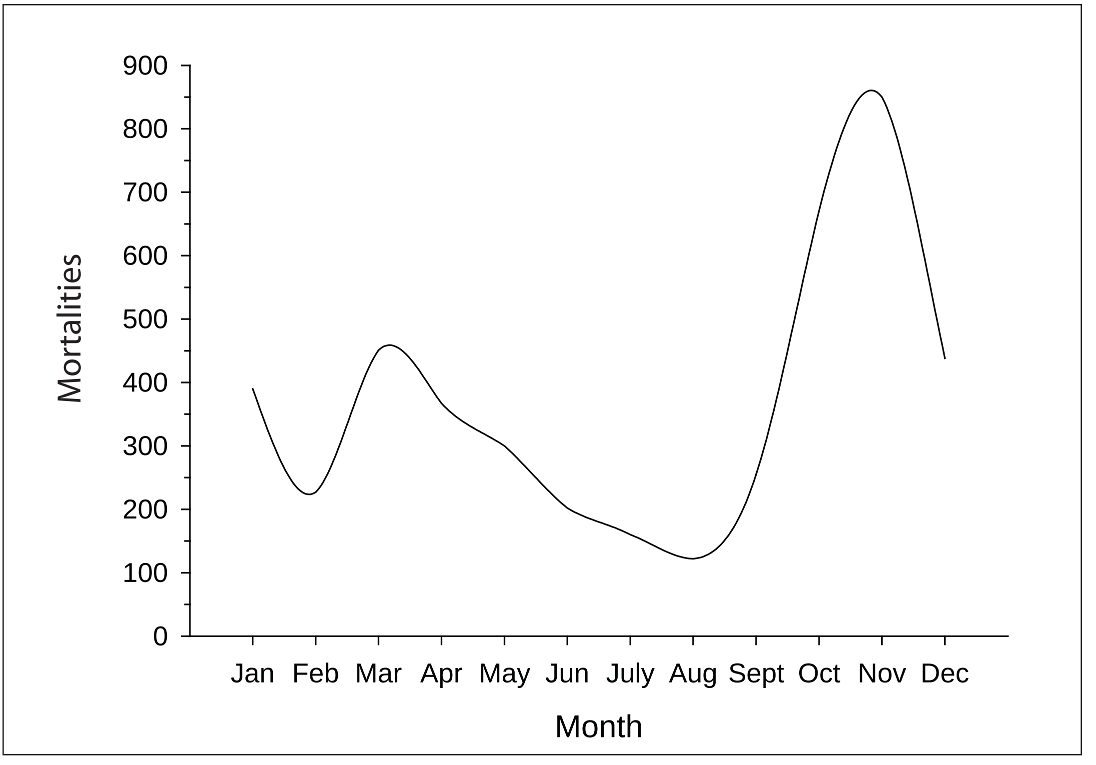

Figure 2. Monthly deer mortalities due to DVCs for 35 counties in eastern South Dakota, 2003. Source of data: South Dakota Game, Fish and Parks Department.

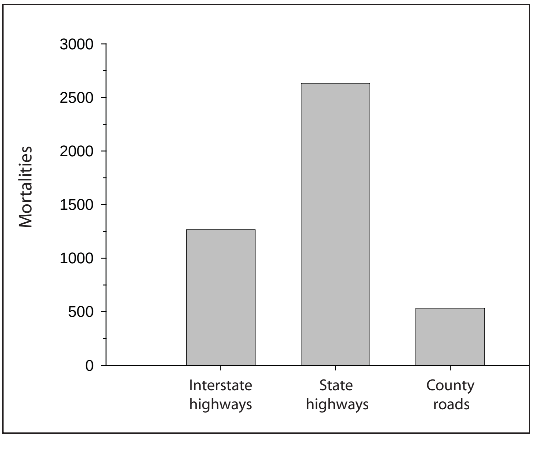

Figure 3. Annual deer mortality totals due to DVCs during 2003 in 35 counties in eastern South Dakota by the 3 classifications of road type: interstate highways, state highways, and county roads.

1993) and the availability of wetland areas that serve as hiding and thermal cover (Petersen 1984, Naugle et al. 1997) might contribute to high rates of DVCs. Hunter success was included in the modeling because it was the only temporal variable that could be manipulated. AIC_c (Burnham and Anderson 2002) values were calculated for all models and then ranked according to Δ_i ($\Delta_i = AIC_i - AIC_{min}$) and AIC_c weights (w).

Results

Deer mortality data collected by SDGFP from each county was correlated ($r^2 = 0.76$, $P < 0.0001$) with data collected by the South Dakota Department of Transportation (SDDOT). In our analysis, we used deer mortality data from SDGFP because in most (68%) counties the data were more complete, containing higher numbers of DVCs than those recorded by SDDOT.

A total of 4,433 deer mortalities was reported due to DVCs within the study area for 2003, with seasonal peaks in spring and fall (Figure 2). Of the total, 1,266 deer mortalities occurred along interstate highways, 2,633 along federal and state highways, and 534 along county roads (Figure 3). Minnehaha (n = 707) and Brown (n = 478) counties had the highest total number of deer mortalities caused by DVCs (Table 1), while Clark County (n = 14) had the fewest number of deer mortalities. Charles Mix (n = 3),

Table 1. Summary of 13 negative binomial regression models for deer mortality due to DVCs in eastern South Dakota, including the model deviance, χ^2, $\hat{c}$, the ML estimated mean square error (σ^2), AIC_c, Δ value for AIC_c, Akaike weight (w) based on AIC_c, the total number of estimable parameters (K), and the variable definitions. Models are ordered in terms of Δ for AIC_c.

Model	Variables	Deviance	χ^2	$\hat{c}$	σ^2	AIC_c	Δ	w	K
Chosen model	8,13,14,16	33.43	27.53	1.02	3553.67	125.62	0.00	0.94487	6
11	2, 3, 8, 13, 14, 16, 18, 21	33.50	27.14	1.18	3362.57	132.85	7.23	0.025435	10
2	18, 21	34.01	38.10	1.31	8017.38	132.93	7.31	0.0244591	4
8	16, 17, 18, 21	33.77	35.65	1.32	7955.19	136.82	11.20	0.0034946	6
4	2, 3, 4, 8,14, 21	33.43	36.44	1.46	7018.24	139.08	13.46	0.00113	8
9	2, 3, 4, 16, 17, 18	33.70	35.45	1.42	8031.92	140.95	15.33	0.0004425	8
1	2, 3, 4	34.11	34.63	1.24	14477.61	143.14	17.52	0.0001481	5
5	8, 10, 11, 12, 14	33.74	37.92	1.46	16191.12	148.70	23.08	9.216E-06	7
7	2…4, 7…14, 16, 17	33.42	29.91	1.66	5347.17	149.29	23.67	6.833E-06	15
Global model	2…4, 7…14, 16, 17, 18, 21	33.52	28.77	1.80	4834.00	151.89	26.27	1.867E-06	17
3	2, 3, 4, 8, 10, 11, 12	33.89	34.27	1.43	15402.08	152.00	26.38	1.765E-06	9
10	2, 3, 4, 8, 9, 10, 11, 12	33.85	33.72	1.47	15866.78	154.42	28.79	5.282E-07	10
6	2, 3, 4, 8, 10, 11, 12, 14	33.45	32.51	1.41	16464.43	154.93	29.31	4.085E-07	10

Variable—Definition

1 County population
2 Linear kilometers of interstate
3 Linear kilometers of state highway
4 Linear kilometers of county highway
5 Agriculture (%)
6 Development density (%)
7 Water (%)
8 Trees (%)
9 Pasture/Grassland (%)
10 Wetlands (%)
11 Riverine wetlands (%)
12 Permanent wetlands (%)
13 County area (km^2)
14 County hunter success rate (%)
15 County vehicle traffic proxy—interstate
16 County vehicle traffic proxy—65 mph (state) highways
17 County vehicle traffic proxy—55 mph (county) highways
18 County population interacted with linear kilometers of interstate
19 County population interacted with linear kilometers of state highway
20 County population interacted with linear kilometers of county highway
21 County population interacted with development density
22 Development density interacted with county hunter success rate

Douglas (n = 6), and Kingsbury (n = 5) counties were excluded from modeling due to insufficient information on deer mortalities resulting from DVCs. Removal of these data resulted in a total deer mortality of 4,419.

We evaluated all 17 independent variables and 5 variable interactions using variance inflation to eliminate variables with colinearity. This eliminated the categories of county population, percentage of county land used for agriculture, and percentage of county land containing standing water. Additionally, the variables county vehicle traffic proxy (interstate), the interaction of county population and kilometers of federal and state highways, the interaction of county population and kilometers of county highways, and the interaction of development density and county hunter success rate were removed using variance inflation. Remaining parameters constituted the global model (i.e., the most parameterized model) for our regression modeling. Twelve models were then created and modeled using negative binomial regression, and AIC_c (Burnham and Anderson 2002) values were calculated for these models in addition to the global model (Table 1).

The chosen model was (Ln Y = 1.2537 – 0.1181 [percentage of tree coverage] + 0.0002 [county area] + 5.39 [county hunter success rate] + 0.0023 [vehicle proxy for vehicles on federal and state highways], model deviance [the discrepancy between observed data and fitted values in light of the random variation described by the statistical distribution] = 33.43, χ^2 = 27.53, df = 27). The selected model had the lowest AIC_c value (125.6), with a weight (w) of 0.94 (Table 1).

We then removed Minnehaha and Brown counties, the 2 counties with the highest number of deer mortalities from DVCs, to determine if the model would fit the remaining counties. We again used variance inflation to eliminate variables with high colinearity and negative binomial regression to evaluate our global model and 12 a priori models (Table 2). Our best model (Ln Y = 1.2537 – 0.1181 [percentage of tree coverage] + 0.0002 [county area] + 5.39 [county hunter success rate] + 0.0023 [vehicle proxy for vehicles on federal and state highways], model deviance = 31.36, χ^2 = 25.90, df = 25) was ranked with lowest AIC_c value (109.5370) and a weight (w) of 0.2580 (Table 2).

We obtained reported deer mortality data from SDDOT for 2001, 2002, and 2004 to test our model. Complete data from SDGFP was not available for those years. Regression was conducted on actual reported deer mortalities versus the predicted values for 2001 (r^2 = 0.68, P < 0.0001), 2002 (r^2 = 0.68, P < 0.0001), and 2004 (r^2 = 0.74, P < 0.0001), which indicated that a significant percentage of variance was explained by the model.

We estimated the goodness-of-fit of our model using the variance inflation factor $\hat{c}$ and estimated $\hat{c}$ by dividing the model χ^2 value by the model degrees of freedom (McCullagh and Nelder 1989, Allison 1999). This gave a value of $\hat{c}$ = 1.02 for our chosen model and $\hat{c}$ = 1.80 for our global model. We chose to use the χ^2 value in our $\hat{c}$ calculation rather than model deviance because the theory of quasi-likelihood estimation indicates the use of χ^2 (McCullagh and Nelder 1989, Allison 1999). This value ($\hat{c}$ > 1) indicated slight overdispersion in the data. Our results indicate significant goodness-of-fit between the model and the observed data, and, thus, we accepted the model as an approximate mathematical representation of the data.

Discussion

Seasonal variation in reported deer mortality due to DVCs exhibited similar peaks to those documented in other studies (Reilly and Green 1974, Allen and McCullough 1976, Fraser 1979, Gleason and Jenks 1993, Hubbard et al. 2000). Peak mortality occurred during November (Figure 2), which can be attributed to a peak in rutting activity (Dahlberg and Guettinger 1956, Jahn 1959, Reilly and Green 1974, Allen and McCullough 1976, Gleason and Jenks 1993). Of less importance were movements attributed to the hunting season (upland bird and big game seasons; Puglisi et al. 1974, Gleason and Jenks 1993) and seasonal migration (Brinkman et al. 2005). An additional contributing factor to the November mortality peak may be the fall harvest of agricultural crops. Deer use of crop fields during summer is high, and by November, all soybeans and small grain crops have been harvested, and corn harvest is nearing completion (Kramlich 1985, DeVault et al. 2007). The presence of large farm machinery moving through fields along with a decreasing amount of cover available in agricultural fields

Table 2. Summary of 13 negative binomial regression models for deer mortality as a result of DVCs in eastern South Dakota, including the model deviance, χ^2, $\hat{c}$, the ML estimated mean square error (σ^2), AIC_c, Δ value for AIC_c, Akaike weight (w) based on AIC_c, the total number of estimable parameters (K), and the variable definitions. Models are ordered in terms of Δ for AIC_c. Modeling excluded data from Minnehaha and Brown counties.

Model	**Variables**	**Deviance**	χ^2	$\hat{c}$	σ^2	AIC_c	Δ	w	K
Chosen model	8, 13, 14, 16	31.36	25.90	1.04	1783.60	109.54	0.00	0.2580373	6
7	8, 11, 14…16	31.40	25.63	1.07	1674.21	110.71	1.17	0.1434341	7
3	2…4, 14	31.14	27.54	1.10	1964.28	110.79	1.26	0.1376107	6
5	2, 3, 8, 14	31.17	24.60	0.98	1985.36	110.93	1.40	0.1283654	6
6	14, 15, 16	31.26	26.66	1.03	2389.04	111.35	1.81	0.1044553	5
8	19, 20, 21	31.39	25.98	1.00	2581.31	112.35	2.82	0.0630844	5
1	2, 11, 14, 15, 16	31.30	26.75	1.11	1933.75	112.59	3.05	0.0560826	7
9	2…4, 21	31.29	30.13	1.21	2270.44	112.68	3.14	0.0535552	6
11	2, 3, 8, 11, 14, 15, 16	31.49	25.58	1.16	1490.14	113.19	3.65	0.0415119	9
2	2…4, 8, 9	31.24	27.65	1.15	2419.46	115.51	5.97	0.0130243	7
10	8…12	31.52	23.06	0.96	3691.42	121.01	11.48	0.0008306	7
4	2…4, 7…12	31.35	26.63	1.33	4161.30	130.57	21.04	6.976E-06	11
Global model	2, 3, 4, 7…17, 19, 20, 21	31.90	26.83	2.06	1901.69	134.35	24.81	1.058E-06	18

Variable—Definition

1 County population
2 Linear kilometers of interstate
3 Linear kilometers of state highway
4 Linear kilometers of county highway
5 Agriculture (%)
6 Development density (%)
7 Water (%)
8 Trees (%)
9 Pasture/Grassland (%)
10 Wetlands (%)
11 Riverine wetlands (%)
12 Permanent wetlands (%)
13 County area (km²)
14 County hunter success rate (%)
15 County vehicle traffic proxy—interstate
16 County vehicle traffic proxy—65 mph (state) highways
17 County vehicle traffic proxy—55 mph (county) highways
18 County population interacted with linear kilometers of interstate
19 County population interacted with linear kilometers of state highway
20 County population interacted with linear kilometers of county highway
21 County population interacted with development density
22 Development density interacted with county hunter success rate

may force additional deer movement onto and across roadways, resulting in increased deer mortality due to collisions with vehicles.

Highway–vehicle traffic proxy was a significant variable in our regression model for deer mortality. Highways can have major impacts on ecological systems, and their related traffic can affect the behavior of cervids (Rost and Bailey 1979, Lyon 1983, Putnam 1997, Forman and Alexander 1998, Trombulak and Frissell 2000, Ng et al. 2008). While Gleason and Jenks (1993) found that 51% of deer mortalities occurred along the interstate highways in eastern South Dakota, our findings are in accord with Allen and McCullough (1976), who observed more mortalities due to DVCs on 2-lane paved roads than on divided highways and interstates in Michigan. Of the 4,433 deer mortalities reported during 2003 in Regions 3 and 4 of eastern South Dakota, 3,167 (71%) occurred on 2-lane paved roads (combined federal and state highways and county roads). Differences in total mortalities between the 3 road types might be attributed to variable topographies, reporting rates, or deer densities.

Percentage of county tree coverage was a significant variable in the regression model for deer mortalities due to DVCs. The selected model showed the level of tree coverage in counties as negatively correlated with deer mortalities. Tree concentrations, which were scarce in eastern South Dakota, were often found near roads. Deer tend to concentrate in or near these few pockets of tree coverage. Long et al. (2005) documented that deer dispersal distances were greater in habitats with less forest cover. This greater dispersal distance would increase the probability of deer encountering roads. As tree coverage increases, deer concentrations become diffused away from roadways. This contradicts Malo et al. (2004), whose logistic model of all habitat variables in Soria Province, Spain ($P < 0.0001$, $R^2 = 0.642$) predicted that high collision areas had a higher cover of non-riparian forest than low-collision areas (51% versus 22%). Bashore et al. (1985) and Finder et al. (1999) determined that the distance of roads to forest cover was important to white-tailed deer collisions with vehicles, while Feldhamer et al. (1986) were unable to document a relationship between deer mortalities due to DVCs and either habitat or topography. The counties studied by Bashore et al. (1985) had between 76% and 79% forest cover, while tree cover in eastern South Dakota ranged from 1% to 6%. Because of the limited tree cover availability in our study area, trees are an important cover habitat for deer in the Great Plains, especially in areas with few wetlands (Naugle et al. 1997).

County hunter success rate also was a significant variable in the model; the coefficient was positive, and, thus, hunter success increased with the number of DVCs. Hunter success was composed of the number of harvest permits issued and the number of deer harvested in each county. Hunter success rates probably are highest in counties with high deer densities and few hunters. This suggests that by increasing the number of hunters in a county, it would be possible to reduce the number of DVCsbecause more hunters should result in lower deer densities (Storm et al. 2007). Additionally, an increase in hunters can cause deer to change their behavior and their propensity to cross roads (Conover 2001). Our findings are in agreement with McCaffery (1973), who showed that a long-term trend in DVCs is closely related to harvest size and traffic volume. The use of sharpshooters (DeNicola 2008) and immunocontraception of deer (Curtis et al. 2008, Miller et al. 2008, Rutberg and Naugle 2008) could also be used to reduce deer densities.

The number of deer mortalities is increasing in eastern South Dakota. During 1993, approximately 1,000 deer mortalities occurred in the 44-county region of eastern South Dakota (Gleason and Jenks 1993). Data collected for this study indicated that during 2003, there were 4,433 deer mortalities in 35 of those same 44 counties, an increase of 343% over the 10-year period. This increase might be attributed to an increasing deer population, increasing number of vehicles on the road, increasing human population, change in land usage, or a combination of these factors.

Management implications

The selected model that best explained DVCs included a variable that can be manipulated to decrease the projected number of DVCs in eastern South Dakota. Hunter harvest success rate, if lowered by issuing more deer harvest permits, may lower the number of predicted deer mortalities for county management units.

Our study identified counties where rates of DVCs are above average. State resources could be targeted to these high-risk areas and thereby maximize the benefits of limited governmental resources. Additionally, within these high-risk areas, the specific factors attributed to high numbers of collisions could be identified and solutions implemented that are target-specific. Schwabe et al. (2002) recommended that by establishing effective strategies to reduce DVCs and coupling them with deer management strategies, both vehicle drivers and hunters would benefit.

Acknowledgments

Information and assistance was provided by the South Dakota Department of Game, Fish and Parks and the South Dakota Department of Transportation. We appreciate support provided by the Department of Wildlife and Fisheries Sciences at South Dakota State University. A. E. Smith provided comments on earlier drafts of our manuscript.

Literature cited

Allen, R. E., and D. R. McCullough. 1976. Deer–car accidents in southern Michigan. Journal of Wildlife Management 40:317–325.

Allison, P. D. 1999. Logistic regression using the SAS system: theory and application. SAS Institute, Cary, North Carolina, USA.

Bashore, T. L., W. M. Tzilkowski, and E. D. Bellis. 1985. Analysis of deer–vehicle collision sites in Pennsylvania. Journal of Wildlife Management 49:769–774.

Biggs, J., S. Sherwood, S. Michalak, L. Hansen, and C. Bare. 2004. Animal-related vehicle accidents at the Los Alamos National Laboratory, New Mexico. Southwestern Naturalist 49:384–394.

Bissonette, J. A., and C. Kassar. 2008. Locations of deer–vehicle collisions are unrelated to traffic volume or posted speed limit. Human–Wildlife Conflicts 2:122–130.

Bissonette, J. A., C. Kassar, and L. J. Cook. 2008. An assessment of costs associated with deer–vehicle collisions: human death and injury, vehicle damage, and deer loss. Human–Wildlife Conflicts 2:17–27.

Brinkman, T. J., C. S. DePerno, J. A. Jenks, and B. S. Haroldson. 2005. Movement of female white-tailed deer: effects of climate and intensive row-crop agriculture. Journal of Wildlife Management 69:1099–1111.

Burnham, K. P., and D. R. Anderson. 2002. Model selection and multimodel inference. Second edition. Springer-Verlag, New York, New York, USA.

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., B. Churszcz, and K. E. Gunson. 2001. Highway mitigation fencing reduces wildlife–vehicle collisions. Wildlife Society Bulletin 29:646–653.

Conover, M. R. 2001. Effects of hunting and trapping on wildlife damage. Wildlife Society Bulletin 29:521–532.

Conover, M. R. 2002. Resolving human–wildlife conflicts: the science of wildlife damage management. Lewis, Boca Raton, Florida, USA.

Conover, M. R., W. C. Pitt, K. K. Kessler, T. J. DuBow, and W. A. Sanborn. 1995. Review of human injuries, illnesses, and economic losses caused by wildlife in the United States. Wildlife Society Bulletin 23:407–414.

Cook, K. E., and P. M. Daggett. 1995. Highway roadkill: associated issues of safety and impacts on highway ecotones. Task Force on Natural Resources, Transportation Research Board. National Research Council, Washington, D.C., USA.

Curtis, P. D., M. E. Richmond, L. A. Miller, and F. W. Quimby. 2008. Physiological effects of gonadotropin-releasing hormone immunocontraception on white-tailed deer. Human–Wildlife Conflicts 2:68–79.

Dahlberg, B. L., and R. C. Guettinger. 1956. The white-tailed deer in Wisconsin, Technical Wildlife Bulletin 14. Wisconsin Conservation Department, Madison, Wisconsin, USA.

DeNicola, A. J., and S. C. Williams. 2008. Sharpshooting suburban white-tailed deer reduces deer–vehicle collisions. Human–Wildlife Conflicts 2:28–33.

DeVault, T. L., J. C. Beasley, L. A. Humberg, B. J. MacGowan, M. I. Retamosa, and O. E. Rhodes Jr. 2007. Intrafield patterns of wildlife damage to corn and soybeans in northern Indiana. Human–Wildlife Conflicts 1:205–213.

Farrell, T. M., J. E. Sutton, D. E. Clark, W. R. Horner, K. I. Morris, K. S. Finison, G. E. Menchen, and K. H. Cohn. 1996. Moose–motor vehicle collisions. An increasing hazard in northern New England. Archives of Surgery 131:377–381.

Feldhamer, G. A., J. E. Gates, D. M. Harman, A. J. Loranger, and K. R. Dixon. 1986. Effects of interstate highway fencing on white-tailed deer activity. Journal of Wildlife Management 50:497–503.

Finder, R. A., J. L. Roseberry, and A. Woolf. 1999. Site and landscape conditions at white-tailed deer–vehicle collision locations in Illinois. Landscape and Urban Planning 44:77–85.

Forman, R. T. T., and L. E. Alexander. 1998. Roads and their major ecological effects. Annual Review of Ecology and Systematics 29:207–231.

Fraser, D. 1979. Sightings of moose, deer, and bears on roads in northern Ontario. Wildlife Society Bulletin 7:181–184.

Gleason, J. S., and J. A. Jenks. 1993. Factors influencing deer–vehicle mortality in east central South Dakota. Prairie Naturalist 25:281–288.

Groot-Bruinderink, G. W. T. A., and E. Hazebroek. 1996. Ungulate traffic collisions in Europe. Conservation Biology 10:1059–1067.

Hansen, C. S. 1983. Costs of deer–vehicle accidents in Michigan. Wildlife Society Bulletin 11:161–164.

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.

Hussain, A., J. B. Armstrong, D. B. Brown, and J. Hogland. 2007. Land-use pattern, urbanization, and deer–vehicle collisions in Alabama. Human–Wildlife Conflicts 1:89–96.

Jahn, L. R. 1959. Highway mortality as an index of deer population change. Journal of Wildlife Management 23:187–197.

Jaren, V., R. Andersen, M. Ulleberg, P. H. Pedersen, and B. Wiseth. 1991. Moose–train collisions: the effects of vegetation removal with a cost-benefit analysis. Alces 27:93–99.

Joyce, T. L., and S. P. Mahoney. 2001. Spatial and temporal distributions of moose–vehicle collisions in Newfoundland. Wildlife Society Bulletin 29:281–291.

Keller, V. 1999. The use of wildlife overpasses by mammals: results from infrared video surveys in Switzerland, Germany, France and the Netherlands. Pages 27–28 *in* Infra eco network Europe, 5th infra eco network Europe meeting. Swedish National Road Administration, Stockholm, Sweden.

Kramlich, T. J. 1985. Evaluation of seasonal habitat use by white-tailed deer in eastern South Dakota. Thesis, South Dakota State University, Brookings, South Dakota, USA.

Lehnert, M. E., and J. A. Bissonette. 1997. Effectiveness of highway crosswalk structures at reducing deer–vehicle collisions. Wildlife Society Bulletin 25:809–818.

Long, E. S., D. R. Diefenbach, C. S. Rosenberry, B. D. Wallingford, and M. D. Grund. 2005. Forest cover influences dispersal distance of white-tailed deer. Journal of Mammalogy 86:623–629.

Lopez, R. R., M. E. P. Vieira, N. J. Silvy, P. A. Frank, S. W. Whisenant, and D. A. Jones. 2003. Survival, mortality, and life expectancy of Florida Key deer. Journal of Wildlife Management 67:34–45.

Ludwig, J., and T. Bremicker. 1983. Evaluation of 2-m–4-m fences and one-way gates for reducing deer–vehicle collisions in Minnesota. Transportation Research Record 913:19–22.

Lyon, L. J. 1983. Road density models describing habitat effectiveness for elk. Journal of Forestry 81:592–595.

Malo, J. E., F. Suárez, and A. Díez. 2004. Can we mitigate animal–vehicle accidents using predictive models? Journal of Applied Ecology 41:701–710.

Mastro, L. L., M. R. Conover, and S. N. Frey. 2008. Deer–vehicle collision prevention techniques. Human–Wildlife Conflicts 2:80–92.

McCaffery, K. R. 1973. Road-kills show trends in Wisconsin deer populations. Journal of Wildlife Management 37:212–216.

McCullagh, P., and J. A. Nelder. 1989. Generalized linear models. Second edition. CRC, Boca Raton, Florida, USA.

McShea, W. J., C. M. Stewart, L. J. Kearns, S. Liccioli, and D. Kocka. 2008. Factors affecting autumn deer–vehicle collisions in a rural Virginia county. Human–Wildlife Conflicts 2:110–121.

McShea, W. J., and H. B. Underwood. 1997. The science of overabundance. Deer ecology and population management. Smithsonian Institution, Washington, D.C., USA.

Mysterud, A. 2004. Temporal variation in the number of car-killed red deer (*Cervus elaphus*) in Norway. Wildlife Biology 10:203–211.

Naugle, D. E., J. A. Jenks, B. J. Kernohan, and R. R. Johnson. 1997. Effects of hunting and loss of escape cover on movements and activity of female white-tailed deer, *Odocoileus virginianus*. Canadian Field-Naturalist 111:595–600.

Ng, J. W., C. Nielsen, and C. C. St. Clair. 2008. Landscape and traffic factors influencing deer–vehicle collisions in an urban environment. Human–Wildlife Conflicts 2:34–47.

Nielsen, C. K., R. G. Anderson, and M. D. Grund. 2003. Landscape influences on deer–vehicle accident areas in an urban environment. Journal of Wildlife Management 67:46–51.

Petersen, L. E. 1984. Northern Plains. Pages 441–448 *in* L. K. Halls, editor. White-tailed deer: ecology and management. Stackpole, Harrisburg, Pennsylvania, USA.

Pojar, T. M., R. A. Prosence, D. F. Reed, and R. H. Woodward. 1975. Effectiveness of a lighted, animated deer crossing sign. Journal of Wildlife Management 39:87–91.

Puglisi, M. J., J. S. Lindzey, and E. D. Bellis. 1974. Factors associated with highway mortality of white-tailed deer. Journal of Wildlife Management 38:799–807.

Putnam, R. J. 1997. Deer and road traffic accidents: options for management. Journal of Environmental Management 51:43–57.

Reilly, R. E., and H. E. Green. 1974. Deer mortality on a Michigan highway. Journal of Wildlife Management 38:16–19.

Romin, L. A., and J. A. Bissonette. 1996. Deer–vehicle collisions: status of state monitoring activities and mitigation efforts. Wildlife Society Bulletin 24:276–283.

Romin, L. A., and L. B. Dalton. 1992. Lack of response by mule deer to wildlife warning whistles. Wildlife Society Bulletin 20:382–384.

Rost, G. R., and J. A. Bailey. 1979. Distribution of mule deer and elk in relation to roads. Journal of Wildlife Management 43:634–641.

Rutberg, A. T., and R. E. Naugle. 2008. Deer–vehicle collision trends at a suburban immunocontraception site. Human–Wildlife Conflicts 2:60–67.

Schwabe, K. A., P. W. Schuhmann, and M. Tonkovich. 2002. A dynamic exercise in reducing deer–vehicle collisions: management through vehicle mitigation techniques and hunting. Journal of Agricultural and Resource Economics 27:261–280.

Smith, V. J., J. A. Jenks, C. R. Berry Jr., C. J. Kopplin, and D. M. Fecske. 2002. The South Dakota Gap Analysis Project. Final Report. Department of Wildlife and Fisheries Sciences, South Dakota State University, Brookings, South Dakota, USA.

Storm, D., C. K. Nielsen, E. M. Schaurber, and A. Woolf. 2007. Deer–human conflict and hunter access in an exurban landscape. Human–Wildlife Conflicts 1:53–59.

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

Ujvári, M., H. J. Baagøe, and A. B. Madsen. 1998. Effectiveness of wildlife warning reflectors in reducing deer–vehicle collisions: a behavioral study. Journal of Wildlife Management 62:1094–1099.

U.S. Census Bureau. 2000. County and city data book: South Dakota. U.S. Census Bureau, Washington, D.C., USA.

West, B. 2008. Echinacea and deer whistles: science and trust in the wildlife arena. Human–Wildlife Conflicts 2:7–8.

Westin, F. C., and D. L. Malo. 1978. Soils of South Dakota. South Dakota State College, Brookings, South Dakota, USA.

Zagata, M. D., and A. O. Haugen. 1974. Influence of light and weather on observability of Iowa deer. Journal of Wildlife Management 38:220–228.

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