Title

Using Site-Level Factors to Model Areas at High Risk of Deep-Vehicle Collisions on Arkansas Highways

Authors

Tappe, Philip A.
Enderle, Donald I.M.

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Using Site-Level Factors to Model Areas at High Risk of Deer-Vehicle Collisions on Arkansas Highways

Philip A. Tappe (870-460-1352, tappe@uamont.edu) and
Donald I.M. Enderle (770-270-7678, denderle@photoscience.com), Arkansas Forest Resources Center and School of Forest Resources, University of Arkansas, Monticello, AR 71656 USA

Abstract: Deer-vehicle collisions (DVCs) are increasing across the United States, including Arkansas. These collisions involve risk of human injury and fatality, property damage, and loss of wildlife. The annual number of DVCs in Arkansas may be as great as 18,000 (13.6% of the reported legal deer harvest in 2005) with an estimated property damage of $35 million. Numerous studies have examined the impacts and causes of DVCs; however, few studies have utilized a state-wide approach to increase understanding of the factors involved.

We evaluated the influence of site-level factors on the number of DVCs reported during 1998-2001 along all state and federal highways in Arkansas. Site-level factors included landcover patterns, landcover characteristics, and number of stream/highway intersections within 400, 800, and 1200 m of collision sites; landcover crossing types and maximum topographic relief within 100 m of collision sites; and distances to nearest forest and to nearest water. A total of 3,170 DVC locations were compared with an equal number of randomly-chosen highway locations based upon proportions of DVCs within each physiographic region of Arkansas. Logistic regression analysis was used to develop and test a state-wide model and six physiographic region models to identify high risk areas along highways. Akaike information criterion values were used to select the best model for the entire state and for each physiographic region. We randomly selected 25% of the DVC sites and randomly-located highway sites to exclude from model development in order to test the predictive ability of each model.

Over 1,000 variables were considered prior to model development. However, exclusion of intercorrelated variables and variables that did not differ between collision and random sites reduced the variable set to 31. These 31 variables revealed a variety of differences between known DVC locations and randomly-selected locations. Twenty-six variables were more associated with known DVC locations than with random locations. Five variables were more associated with randomly selected highway locations than with known DVC locations. The state-wide model had an overall correct classification rate of 62%. Most models developed for individual physiographic regions performed as well or better than the state-wide model: Arkansas River Valley (62%), Boston Mountains (69%), Gulf Coastal Plain (59%), Mississippi River Delta (70%), Ouachita Mountains (67%), and Ozark Mountains (60%). Almost all variables included in the state model were also included in at least one physiographic region model, and most variables of each physiographic region model were also found in the state model. Five groups of factors that were strongly correlated with DVC locations were apparent in all models: (1) the presence and amount of water in terms of distance to the nearest source, number of streams intersecting within 400 m, and amount of water within 1200 m; (2) the presence of a diverse association of land cover types in close proximity to a highway; (3) the amount and size of urban area within 1200 m; (4) forested area (deciduous and/or coniferous) in close proximity to a highway, particularly in terms of higher density of coniferous forest and greater size and irregularity of deciduous forest patches; and (5) the density of pasture and crop patches, and the density of pasture edge in particular, within 1200 m of a highway.

These results and models may be used to produce maps indicating potential segments of highways at high risk for the occurrence of DVCs. Additionally, they may aid in planning and road construction. Finally, these results provide a foundation for future research in examining more specific deer-vehicle interactions, and can aid in the evaluation of appropriateness and effectiveness of proposed methods to reduce DVCs in Arkansas.

Introduction

Deer-vehicle collisions (DVCs) are of increasing safety and economic concern. The consequences of deer-vehicle collisions include risk of human injury or fatality, property damage, and loss of wildlife, with associated costs estimated at over $1 billion dollars in the United States (Conover et al. 1995). The annual number of DVCs in Arkansas may be as great as 18,000 (13.6% of the reported legal deer harvest in 2005) with an estimated property damage of $35 million (Tappe 2005).

Several studies have focused on investigating factors that may influence the probability of occurrence of a DVC at a specific location or along a segment of roadway (e.g., Bashore et al. 1985, Finder et al. 1999, Hubbard et al. 2000). However, few studies have utilized a state-wide approach to increase understanding of the factors involved. Additionally, relatively few of these investigations have occurred in the Southeastern region of the United States, with most being conducted in the Midwestern or Northeastern regions. Results and conclusions have been mixed regarding which specific factors play important roles in DVC occurrences and locations; though, most studies have indicated that the proximity of forested areas to a roadway is influential. Given variation in geographic, biotic, and climatic factors, it is important to understand the nature and/or circumstances of DVCs in different regions. Identification of factors contributing to DVCs can provide information on the interactions of deer populations with habitat, road, and human influences; aid in the identification of areas at high risk for DVCs; and help efficiently target available resources for addressing the problem. Thus, our objectives were (1) to identify and evaluate site-level factors relating to DVCs along state and federal highways in Arkansas, and (2) to develop and validate regional models based upon site-level characteristics to predict occurrence of DVCs in Arkansas.

Methods

Study Area

This study was conducted using land cover within 1200 m of the state and federal highways in the state of Arkansas. Arkansas is composed of 6 physiographic regions: Arkansas River Valley, Boston Mountains, Gulf Coastal Plain, Mississippi River Alluvial Floodplain, Ouachita Mountains, and Ozark Mountains (figure 1). These regions were used as a basis for the comparison of deer-vehicle collision locations with randomly selected locations along state and federal highways.

Data

We obtained hard-copy motor vehicle/animal accident reports from the Arkansas State Police Department Headquarters in Little Rock, AR. These reports represented the most extensive and accessible source of information available on DVCs in Arkansas (Tappe 2005). However, the reports included only accidents that occured on state and federal highways, not on county or municipality maintained roads, and that were serious enough to involve the state police. Locations (road section and log mile) of DVCs from the years 1998 to 2001 were selected and entered in a database. Of the 5,858 reports, 2,444 lacked sufficient information (section and log mile) to be geo-referenced. We sent location data from the remaining 3,414 reports to the Arkansas Highway and Transportation Department (AHTD) for geo-referencing by means of an in-house parsing program and transformation into an ArcView® shape file for incorporation into ArcView® GIS software ([ESRI] 2000). Of these locations, 244 failed to be geo-referenced due to incorrect section and/or log mile information. Thus, 3,170 collisions were successfully geo-referenced and were available for further analyses.

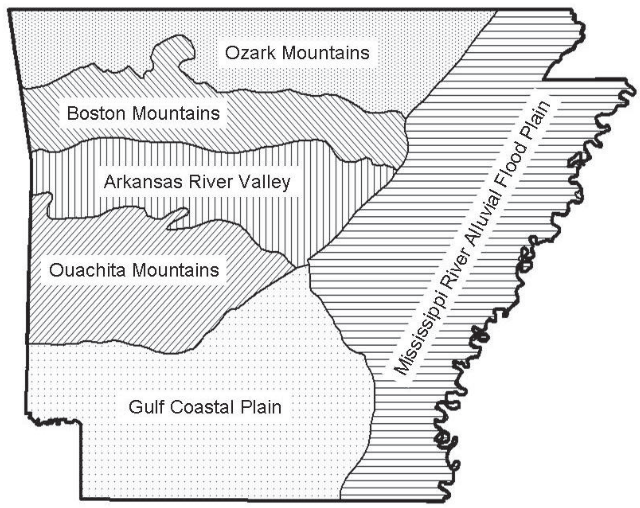

Figure 1. Physiographic regions of Arkansas.

Other data used in this study included roads, streams, land use/land cover, and elevation (table 1) for the entire state of Arkansas. The two raster data sets, land use/land cover and elevation, were each resampled and aligned to an identical cell size resolution of 30 m. This resampling was performed to facilitate combination with the other data sets while maintaining a degree of uniformity by ensuring that the cells in each raster data set would align correctly for data analysis. All spatial analyses were performed in ArcView® version 3.2a GIS software. The ArcView® Spatial Analyst Extension and ArcView® Geoprocessing Wizard Extension were utilized within ArcView® to perform many of the spatial analyses.

In order to compare characteristics of DVC locations, we selected a proportional number of randomly selected locations along highways by physiographic region. In order to accomplish this, state and federal highways were converted to points spaced 30 m apart. We randomly selected 25% of the random and collision locations in each physiographic region to be excluded from model development in order to test and validate resulting models.

In order to simplify the use of land cover data, we reclassified the 50 land cover classes of the Arkansas land cover data set into the following 10 classes: urban, water, coniferous forest, deciduous forest, mixed forest, pasture, crops, old field, and barren. We chose these classes based on their general use and significance as found in other DVC studies and to remove classification bias by consolidating multiple land cover types into broad classes.

Table 1: Primary datasets utilized for modeling deer-vehicle collision locations in Arkansas

Data Set	Source
Deer-vehicle collision locations	Hard-copy motor vehicle – animal accident reports (1998 – 2001), Arkansas State Police headquarters, Little Rock, Arkansas
State and federal highways	County mapping files (2000), Arkansas Highway and Transportation Department
Landuse/landcover	1998 and 1999 multi-temporal LANDSAT V and VII Thematic Mapper satellite imagery, Center for Advanced Spatial Technologies, University of Arkansas
Streams and rivers	USGS 1:100,000 Digital Line Graph data, 1989
Elevation	USGS National Elevation Dataset, 1999

We evaluated the influence of land cover characteristics within varying distances of collision and random locations by using three buffer distances in determining land cover characteristics: 400, 800, and 1200 m. We used FRAGSTATS software (McGarigal and Marks 1995) in batch mode to compute several categories of class and landscape metrics (table 2). These calculated metrics were then linked to each collision and random location for statistical analysis and model development.

We reclassified the land cover data into forest and non-forest to determine distance to nearest forest from each DVC and random location. Likewise, we reclassified the land cover data into water and non-water to determine distance to nearest water from each DVC and random location. We determined the numbers of stream/highway intersections (i.e., bridges) within 400, 800, and 1200 m buffer distances from each collision and random location. Additionaly, we computed differences in right-of-way topography between collision and random locations by calculating maximum relief within a 100 m buffer of each point.

In order to determine crossing types (defined as dominant vegetation or land cover types on opposite sides of the road) at each point, we reclassified land cover data into the following 6 classes: urban, water, forest, field, crop, and barren. As this variable involved dominant land cover classes adjacent to a highway, we used a 100 m buffer distance to identify crossing type classes.

Table 2: Summary of FRAGSTATS metrics used to describe land cover characteristics of collision and random locations at 400, 800, and 1200 m buffer distances

Category	Metric	Scale
Area/Density/Edge	Percent of Landscape	Class/Landscape
	Patch Density	Class/Landscape
	Edge Density	Class/Landscape
	Patch Area Distribution[1]	Class/Landscape
Shape	Shape Index Distribution[1]	Class/Landscape
Nearest Neighbor	Euclidean Nearest Neighbor Distance Distribution[1]	Class/Landscape
Edge Contrast	Contrast-Weighted Edge Density	Class/Landscape
	Total Edge Contrast Index	Class/Landscape
	Edge Contrast Index Distribution[1]	Class/Landscape
Contagion/Interspersion	Clumpiness Index	Class
	Aggregation Index	Class/Landscape
	Interspersion and Juxtaposition Index	Class/Landscape
Diversity	Patch Richness Density	Landscape
	Relative Patch Richness	Landscape
	Shannon's Diversity Index	Landscape
	Simpson's Diversity Index	Landscape
	Shannon's Evenness Index	Landscape
	Simpson's Evenness Index	Landscape

[1]This metric involved the calculation of mean, area-weighted mean, median, range, standard deviation, and coefficient of variation.

Statistical Analyses

We evaluated all variables for normality and used Mann-Whitney U-tests to determine whether variables differed between collision and random locations. A significance level of 0.05 was used as a cutoff value to exclude statistically non-significant variables from further consideration. We computed Pearson correlation coefficients between all variables and eliminated variables from further consideration if they were strongly correlated ($|r| \geq 0.600$) with other variables. We selected one variable from each group of intercorrelated variables to represent that group in further analyses based upon three criteria: interpretability, biological significance, and greatest (or one of the greatest) Mann-Whitney U-test statistic. Thus, the resulting list of variables to be considered for inclusion in logistic regression analyses included 31 variables that were statistically different between collision and random locations, were not correlated ($|r| \leq 0.60$) with other selected variables, and were both interpretable and biologically significant (Table 3).

Table 3: Variables selected for development of models to predict deer-vehicle collision locations on state and federal highways in Arkansas

Variable	Abbreviation
At least one side forest - 100 m	CT03_ONE
Water both sides - 100 m	CT02_02
Forest across from urban - 100 m	CT03_01
Forest across from field - 100 m	CT03_04
Forest across from crop - 100 m	CT03_05
Field across from urban - 100 m	CT04_01
Distance to nearest water (m)	D2NW
Number of stream/highway intersections - 400 m	NSHI04
Mean nearest neighbor distance of similar patch types for the entire landscape (m) - 400 m	L_N_MN04
Range of nearest neighbor distance of similar patch types for the entire landscape (m) - 400 m	L_N_RA04
Shannon's Diversity Index of all patches in the landscape - 400 m	L_SHDI04
Mean nearest neighbor distance of similar patch types for the entire landscape (m) - 800 m	L_N_MN08
Area-weighted mean nearest neighbor of similar patch types for the entire landscape (m) - 800 m	L_N_AM08
Edge contrast index range of all patches in the landscape - 800 m	L_E_RA08
Median shape index of all patches in the landscape - 1200 m	L_S_MD12
Area-weighted mean nearest neighbor of similar patch types for the entire landscape (m) - 1200 m	L_N_AM12
Urban percent of landscape (%) - 1200 m	C01PLA12
Urban patch density (no./100 ha) - 1200 m	C01PD12
Water percent of landscape (%) - 1200 m	C02PLA12
Water patch density (no./100 ha) - 1200 m	C02PD12
Coniferous forest patch density (no./100 ha) - 400 m	C04PD04
Mean area of deciduous forest patches (ha) - 400 m	C05AMN04
Mean shape index of deciduous forest patches - 400 m	C05SMN04
Mean area of deciduous forest patches (ha) - 1200 m	C05AMN12
Mean shape index of deciduous forest patches - 1200 m	C05SMN12
Pasture patch density (no./100 ha) - 1200 m	C07PD12
Pasture edge density (m/ha) - 1200 m	C07ED12
Crop patch density (no./100 ha) - 1200 m	C08PD12
Barren patch density (no./100 ha) - 800 m	C10PD08
Mean area of barren patches (ha) - 1200 m	C10AMN12
Area-weighted mean shape index of barren patches - 1200 m	C10SAM12

We used logistic regression analysis to develop and test a state-wide model and six physiographic region models to identify high risk areas along highways. We evaluated models composed of all possible combinations of variables that were selected through a stepwise process that used $P = 0.05$ to enter the model, $P = 0.10$ to be removed from the model, 20 iterations, and a classification cutoff of 0.50. We then used Akaike information criterion values to select the best models.

After we selected the best models, we used the randomly selected collision and random locations that were not included in model development (25% of all locations) to test each models' validity. A location was classified as a DVC location if its predicted probability was ≥ 0.50 and as a non-collision location if its predicted probability was < 0.50. The predicted values were examined to determine each model's classification rate.

Results

State-Wide Model

The analyses resulted in five competing models that performed better than all others considered table 4). Due to intercorrelations between interactions and main-effects variables, none of the interactions entered into the stepwise procedure significantly added to the models when included with the main effects.

Table 4: Comparison of the five best statewide models predicting likelihood of a location being a known deer/vehicle collision site.

			Overall Model Test			Overall classification	
Model	-2LL	AIC	X^2	*df*	*P*	Model data	Test data
1[1]	6196.88	6228.88	396.34	15	<0.001	61.9%	62.0%
2	6201.05	6231.05	392.17	14	<0.001	62.2%	62.1%
3	6213.21	6237.21	380.01	11	<0.001	61.5%	62.4%
4	6218.77	6240.77	374.45	10	<0.001	61.4%	62.2%
5	6222.26	6242.26	370.96	9	<0.001	61.3%	62.4%

[1]Model 1 was selected as the final statewide model.

We selected a final state model that was composed of 15 parameters, including occurrence/nonoccurrence within the Arkansas River Valley or Mississippi River Alluvial Floodplain physiographic regions (table 5). Based on both the Wald Chi-squared test statistics and the standardized estimates for the parameters, the six most important predictors were C07ED12, ECONEW(2), C01PD12, NSHI04, C05AMN04, and D2NW.

The model discriminated well between known DVC locations and random highway locations. Sixty-three percent of the known collision locations (n = 2,378) had a probability of ≥ 0.50 of being a known deer-vehicle collision location. Sixty-one percent of the random highway locations (n = 2,378) had a probability of < 0.50 of being a known deer-vehicle collision location. From the 1584 test locations (50% from known collision locations and 50% from random highway locations), the final state model correctly predicted 498 (63%) known collision locations (n = 792) and 484 (61%) random highway locations (n = 792).

Physiographic Region Models

Our analyses of models for each of the physiographic regions resulted competing models that performed better than all others considered (table 6). Due to intercorrelations between interactions and main-effects variables, none of the interactions entered into the stepwise procedure significantly added to the models when included with the main effects.

We selected final models that were composed of 6 – 10 parameters (tables 7 – 12). Almost all variables included in the state model were also included in at least one physiographic region model, and most variables of each physiographic region model were also found in the state model. Most models developed for individual physiographic regions performed as well or better than the state-wide model (62%): Arkansas River Valley (62%), Boston Mountains (69%), Gulf Coastal Plain (59%), Mississippi River Delta (70%), Ouachita Mountains (67%), and Ozark Mountains (60%).

Table 5: Parameter estimates for the final statewide logistic regression model predicting the likelihood of a location being a known deer/vehicle collision site

			Wald X^2 Test			
Parameter	Estimate (B)	SE	Statistic	*P*	Standardized estimate (?)	Odds ratio (exp(B))
CT02_02	-2.3539	1.0935	4.6335	0.0314	-0.0558	0.0950
D2NW	-0.0002	0.0001	13.2699	0.0003	-1.0741	0.9998
NSHI04	0.2243	0.0437	26.3272	<0.0001	0.0888	1.2514
L_SHDI04	0.2291	0.0991	5.3436	0.0208	0.0567	1.2575
C01PLA12	-0.0054	0.0024	5.2356	0.0221	-0.0505	0.9946
C01PD12	0.3978	0.0774	26.4414	<0.0001	0.1066	1.4885
C02PLA12	0.0143	0.0071	4.0215	0.0449	0.0391	1.0144
C04PD04	0.0123	0.0042	8.4024	0.0037	0.0633	1.0124
C05AMN04	0.0303	0.0068	19.8549	<0.0001	0.0922	1.0308
C05SMN12	0.3668	0.1215	9.1115	0.0025	0.0573	1.4432
C07PD12	0.1053	0.0496	4.5170	0.0336	0.0510	1.1111
C07ED12	0.0151	0.0021	53.2714	<0.0001	0.1839	1.0152
C08PD12	0.1459	0.0722	4.0806	0.0434	0.0426	1.1571
ECONEW[1]	---	---	62.9830	<0.0001	---	---
ECONEW(1)[2]	-0.1920	0.0813	5.5723	0.0182	-0.0830	0.8253
ECONEW(2)[3]	0.7593	0.1147	43.8419	<0.0001	0.3282	2.1368
INTERCEPT	-1.7677	0.2088	71.7008	<0.0001	---	0.1707

Table 6: Comparison of the best physiographic region models predicting the likelihoods of locations being known deer/vehicle collision sites

				Overall Model Test			Overall Classification	
Physiographic Region	Model	-2LL	AIC	χ^2	*df*	*P*	Model data	Test data
Arkansas River Valley	AV1	1535.02	1557.02	125.76	10	<0.001	63.1%	61.5%
	AV2	1540.17	1560.17	120.61	9	<0.001	62.6%	62.3%
Boston Mountains	B1	511.97	525.97	67.50	6	<0.001	67.2%	69.3%
	B2	516.15	528.15	63.32	5	<0.001	68.2%	67.9%
Gulf Coastal Plain	GC1	1090.78	1104.78	70.94	6	<0.001	61.8%	58.6%
	GC2	1095.33	1107.33	66.38	5	<0.001	61.2%	57.2%
Mississippi River Alluvial Flood	MR1	1065.87	1081.87	195.66	7	<0.001	69.2%	69.7%
Plain	MR2	1070.34	1084.34	191.19	6	<0.001	69.8%	70.4%
Ouachita Mountains	OU1	734.53	748.53	86.16	6	<0.001	66.4%	67.3%
	OU2	741.94	753.94	78.75	5	<0.001	66.2%	66.3%
Ozark Mountains	OZ1	1069.86	1083.86	39.18	6	<0.001	61.0%	60.2%
	OZ2	1073.91	1085.91	35.13	5	<0.001	58.0%	56.4%

Table 7: Parameter estimates for the final Arkansas River Valley physiographic region model predicting the likelihood of a location being a known deer/vehicle collision site

			Wald χ^2 Test			
Parameter	Estimate (B)	S.E.	Statistic	*P*	Standardized estimate (β)	Odds ratio (exp(B))
D2NW	-0.0005	0.0002	6.0768	0.0137	-0.0890	0.9995
NSHI04	0.3217	0.0784	16.8244	<0.0001	0.1462	1.3795
C01PLA12	-0.0094	0.0034	7.8439	0.0051	-0.1146	0.9906
C01PD12	0.4267	0.1373	9.6617	0.0019	0.1251	1.5322
C04PD04	0.0194	0.0077	6.3206	0.0119	0.0946	1.0196
C05AMN12	0.1288	0.0376	11.7306	0.0006	0.1588	1.1374
C07PD12	0.1935	0.0814	5.6456	0.0175	0.0890	1.2135
C08PD12	0.2627	0.1018	6.6593	0.0099	0.1034	1.3004
C10PD08	-0.1217	0.0538	5.1154	0.0237	-0.0917	0.8854
C10SAM12	0.3773	0.1231	9.3912	0.0022	0.1227	1.4584
INTERCEPT	-1.0124	0.2031	24.8533	<0.0001	---	0.3633

Table 8: Parameter estimates for the final Boston Mountains physiographic region model predicting the likelihood of a location being a known deer/vehicle collision site

			Wald χ^2 Test			
Parameter	Estimate (B)	S.E.	Statistic	*P*	Standardized estimate (β)	Odds ratio (exp(B))
CT03_ONE	-0.5050	0.2474	4.1664	0.0412	-0.1392	0.6035
L_SHDI04	1.2499	0.4456	7.8675	0.0050	0.2315	3.4898
L_N_MN08	-0.0102	0.0049	4.2794	0.0386	-0.1649	0.9898
C01PD12	0.7436	0.2797	7.0669	0.0079	0.2127	2.1036
C05AMN12	0.0549	0.0213	6.6307	0.0100	0.1741	1.0565
C07ED12	0.0215	0.0074	8.3429	0.0039	0.2178	1.0217
INTERCEPT	-1.3016	0.8243	2.4934	0.1143	---	0.2721

Table 9: Parameter estimates for the final Gulf Coastal Plain physiographic region model predicting the likelihood of a location being a known deer/vehicle collision site

			Wald X^2 Test			
Parameter	Estimate (B)	S.E.	Statistic	P	Standardized estimate (β)	Odds ratio (exp(B))
L_SHDI04	0.4641	0.2192	4.4825	0.0342	0.0891	1.5906
C01PD12	0.4797	0.1832	6.8592	0.0088	0.1174	1.6157
C05AMN04	0.0768	0.0262	8.5644	0.0034	0.1617	1.0798
C07ED12	0.0214	0.0053	16.3595	0.0001	0.1771	1.0216
C08PD12	-0.9839	0.3131	9.8770	0.0017	-0.1531	0.3738
C10SAM12	0.5851	0.1618	13.0725	0.0003	0.1561	1.7951
INTERCEPT	-1.6909	0.3245	27.1599	<0.0001	---	0.1844

Table 10: Parameter estimates for the final Mississippi River Alluvial Plain physiographic region model predicting the likelihood of a location being a known deer/vehicle collision site

			Wald ^{2} Test			
Parameter	Estimate (B)	S.E.	Statistic	P-value	Standardized estimate (β)	Odds ratio (exp(B))
CT03_ONE(1)	0.5191	0.2237	5.3835	0.0203	0.1113	1.6806
NSHI04	0.3338	0.1208	7.6299	0.0057	0.1224	1.3962
C01PLA12	-0.0118	0.0058	4.1526	0.0416	-0.0887	0.9883
C02PD12	0.2014	0.0821	6.0228	0.0141	0.1109	1.2231
C05SMN04	0.3256	0.1283	6.4426	0.0111	0.1302	1.3849
C05SMN12	0.4780	0.2009	5.6583	0.0174	0.1140	1.6128
C07ED12	0.0303	0.0044	46.8902	<0.0001	0.3606	1.0308

Table 11: Parameter estimates for the final Ouachita Mountains physiographic region model predicting the likelihood of a location being a known deer/vehicle collision site

			Wald X^2 Test			
Parameter	Estimate (B)	S.E.	Statistic	P-value	Standardized estimate (β)	Odds ratio (exp(B))
CT03_01	2.1951	1.0577	4.3071	0.0380	0.1900	8.9813
NSHI04	0.2503	0.1191	4.4197	0.0355	0.1045	1.2844
C04PD04	0.0465	0.0103	20.3642	<0.0001	0.2292	1.0476
C07PD12	0.4639	0.1368	11.4965	0.0007	0.2008	1.5903
C07ED12	0.0116	0.0053	4.8232	0.0281	0.1251	1.0116
C10AMN12	0.6226	0.2778	5.0231	0.0250	0.1960	1.8637
INTERCEPT	-2.1856	0.2903	56.6796	<0.0001	---	0.1124

Table 12: Parameter estimates for the final Ozark Mountains physiographic region model predicting the likelihood of a location being a known deer/vehicle collision site

			Wald X^2 Test			
Parameter	Estimate (B)	S.E.	Statistic	P-value	Standardized estimate (β)	Odds ratio (exp(B))
C01PD12	0.3297	0.1301	6.4220	0.0113	0.1050	1.3906
C02PD12	0.3355	0.1291	6.7516	0.0094	0.1165	1.3986
C04PD04	0.0318	0.0160	3.9412	0.0471	0.0822	1.0324
C05AMN04	0.0391	0.0113	11.9665	0.0005	0.1786	1.0399
C07ED12	0.0101	0.0043	5.3601	0.0206	0.0990	1.0101
C10AMN12	-0.8355	0.3191	6.8555	0.0088	-0.1389	0.4337
INTERCEPT	-0.8506	0.2481	11.7586	0.0006	---	0.4271

Discussion

Logistic regression analysis on the statewide level produced a fifteen-variable model to predict occurrence of DVCs on state and federal highways in Arkansas. Four of these variables, CT02_02, D2NW, C01PLA12, and ECONEW(1), tended to decrease the odds of a location being a collision site. The remaining eleven variables, NSHI04, L_SHDI04, C01PD12, C02PLA12, C04PD04, C05AMN04, C05SMN12, C07PD12, C07ED12, C08PD12, and ECONEW(2), tended to increase the odds of a location being a collision site.

The most important site-level factor found to predict the probability of DVCs was the density of pasture edge within 1200 m of a location. The positive contribution of pasture edge density supports the idea that edge, particularly edge between woods and fields, represents the close proximity of food and cover requirements for deer (Halls 1984, Sealander and Heidt 1990,Gerlach et al. 1994, Hiller 1996). This edge effect is considered the result of three primary factors. First, grasses and broad-leaved herbs (commonly referred to as forbs) are among the food preferred by deer and are commonly available in fields and pastures (Sealander and Heidt 1990). Second, other foods preferred by deer, such as leaves, twigs and shoots (commonly referred to as browse) often occur along the edge between woods and fields (Sealander and Heidt 1990). Third, the woods provide cover for deer, particularly when bedding down during the day (Whitaker and Hamilton 1998).

An abundance of edge, particularly edge between woods and fields or pasture, provides an ideal situation providing both food and cover for deer in a relatively small area (Hiller 1996). Thus, a high density of pasture edge over a constant area (1200 m buffer) suggests three things: a large number of pasture patches, a small mean patch size, and potentially more irregularly shaped patches of pasture, all of which denote more edge between pasture and other land cover types. Edge allows deer greater access to food and cover in a smaller area by minimizing the travel requirements between them, which can lead to smaller home ranges and potentially higher densities of deer.

Occurrence of a given location within the Mississippi River Alluvial Floodplain physiographic region increased the probability of that location being a collision site. Of all the physiographic regions, the Mississippi River Alluvial Floodplain had the smallest proportions of randomly selected locations within 800 and 2400 m of known collision locations (9% and 24%, respectively). If the characteristics of known collision locations are truly different from the characteristics of random highway locations, then having few random locations in close proximity to known collision locations could enhance a model's discrimination ability. In contrast, having a majority of random locations in close proximity to known collision locations could potentially reduce a model's discrimination ability. Thus, by virtue of the spatial separation of known collision locations and random locations, the Mississippi River Alluvial Floodplain physiographic region increased the state model's discrimination ability.

The density of urban patches within a 1200 m buffer was also positively related to the probability of a given location being a collision site. In other words, the likelihood that a given location was a known collision location increased as the amount of urban patches within a 1200 m buffer increased. A high urban patch density implies a large number of urban patches and a small mean urban patch size. This variable describes not deer habitat, but characteristics influencing traffic levels and human population densities. Thus, an increased density of urban areas suggests the presence of human residences and/or proximity to urban areas, where local traffic levels are likely to be greater and increase the risk of collisions with deer, especially if this density of urban patches occurs in conjunction with good deer habitat.

The number of stream/highway intersections within a 400 m buffer was positively related to the probability of a given location being a collision site. There are three potential explanations for this relationship. First, intersections of streams and highways often indicate potential travel corridors for deer moving within their home ranges or dispersing (Hubbard et al. 2000). Second, these intersections indicate the presence of water in the proximate area, which is another requirement for deer, particularly during late summer and early fall (Hiller 1996). Third, in areas with intensively managed timberland or heavily utilized agricultural lands, streams are likely less disturbed, providing additional habitat and edge for deer.

The mean area of deciduous forest patches within a 400 m buffer also was positively related to the probability of a given location being a collision site. In other words, as the mean area of deciduous forest within 400 m of the road increased, the probability of that location being a collision site also increased. There are two potential reasons for this relationship. The first reason is food, particularly hard mast such as acorns that is available in deciduous forests and along their edges (Whitaker and Hamilton 1998). With a larger mean area of deciduous forest patches, there is a greater likelihood that older trees (mast producers) are present to provide this preferred deer food during the fall season. The second reason is that the woods in these patches provide cover to deer.

The distance to the nearest water body was negatively related to the probability of a given location being a collision site. In other words, locations where water was close to the road were more often associated with collision sites than locations where water was further from the road. Proximity to water is an important component of deer habitat (Hiller 1996). Thus, when water sources are close to the highway it is more likely that deer will utilize the area, especially when other important components of deer habitat are also present. Likewise, as the nearest water source is further away from the highway (even if the local area has other characteristics of deer habitat) those deer that may utilize the habitat near the highway would have to travel further for water, decreasing the likelihood that deer would heavily use this habitat.

The mean shape index of deciduous forest patches within a 1200 m buffer was positively related to the probability of a given location being a collision site. In other words, as the mean shape of deciduous forest patches became more irregular within 1200 m of a given location, the likelihood of that location being a collision site increased. There are two potential explanations of this relationship. First, the greater irregularity of shape of deciduous forest patches would imply a greater amount of forest edge, which would potentially allow more favorable browse/forage along the edge of these deciduous forest patches (Hiller 1996). This increase in edge would thereby enhance the habitat for deer. A second possible explanation is that irregularly shaped forest patches are less likely being intensively managed for timber and thus are more likely to contain older, mast-producing trees.

The density of coniferous forest patches within a 400 m buffer was positively related to the probability of a given location being a collision site. Coniferous forest patches, when in close proximity to deer feeding sites, often provide necessary cover for deer during times of relative inactivity, such as during the day (Gerlach et al. 1994). A greater density of coniferous forest patches over a constant amount of area would suggest not only more patches, but also smaller mean patch sizes. This would imply that the area within 400 m of the highway is relatively open and the coniferous forest patches are dispersed among other patch types. The distances from cover provided by these coniferous forest patches to food found along the forest edges and/or in nearby pastures, crops, or deciduous forest, are therefore shorter than otherwise, leading to potentially smaller home ranges and greater deer densities. Another result of a large density of coniferous forest patches is a greater amount of edge habitat.

Occurrence of a given location within the Arkansas River Valley physiographic region was negatively related to the probability of a location being a collision site. The reasons may be similar to those of the variable for occurrence of a location within the Mississippi River Delta ecoregion, although with the opposite outcome. Whereas the Mississippi River Alluvial Floodplain physiographic region had the lowest number of reported collisions weighted by area (about 7 collisions per 100 km of highway), the Arkansas River Valley physiographic region had the greatest number of reported collisions weighted by area (about 19 collisions per 100 km of highway). One result of this greater "density" of collisions in the Arkansas River Valley is that a large proportion of randomly selected highway locations were within 800 and 2400 m of known collision locations, 28% and 62% respectively. This high proportion of random locations in close proximity to known collision locations could create a blurring of any distinctions between collision and random locations. If the characteristics of known collision locations are truly different from the characteristics of random highway locations, then a set of collision and random locations having a majority of random locations in close proximity to known collision locations may be less distinguishable.

The Shannon's Diversity Index for all patches within a 400 m buffer was positively related to the probability of a location being a known collision location. Shannon's Diversity Index takes into account the richness of patch types in an area and the evenness of the distribution of area among the patch types (McGarigal and Marks 1995). This index tends to be more sensitive to richness than evenness, meaning that rare patch types have an influence on diversity that is not proportional to the area of such patch types (McGarigal and Marks 1995). Therefore, a large diversity index reflects a large number of patch types and/or an increase in the proportional distribution of area among these patch types.

In terms of deer habitat, an area with more types of patches and/or a more even distribution of area of such patch types (especially in an area within 400 m of the highway) suggests the probability that the local area around the highway has a combination of land cover providing a proper distribution of food, cover, and water for deer. With such a high diversity of land cover within a 400 m buffer, the distances between any given pair of patch types would be shorter. Thus, the home ranges of deer in this area could be much smaller than other areas and thereby allow for a greater density of deer supported in the area if the habitat is suitable (Hiller 1996).

The percent of urban land cover within a 1200 m buffer was negatively related to the probability of a location being a collision site. The loss of deer habitat to competing urban land uses is reflected in this negative relationship (Gerlach et al. 1994). A greater proportion of land put to urban uses would imply that a location is closer to or within a town, city, or metropolitan area. Furthermore, more land used for urban purposes potentially means a smaller amount of area available as food or cover for deer. Another possible reason for this negative relationship is that urban centers and greater traffic flow could act as a barrier to deer desiring to cross a highway (Bellis and Graves 1978).

The presence of water across from water within a 100 m buffer also decreased the probability of a given location being a collision site. This finding makes sense because a dominance of water within 100 m on either side of a highway suggests that the location is on a bridge crossing a large body of water where deer are perhaps least likely to occur. As bridges have little if any form of vegetation on them, either in terms of potential food or cover, it is less likely for deer to move onto them during their daily or seasonal movements. Also, the magnitudes of both the coefficient and the odds ratio of this variable suggest that the presence of this factor may override the influence of other factors in determining whether or not a location is a probable collision site.

The density of pasture patches within a 1200 m buffer was positively related to the probability of a given location being a collision site. Pasture land and fields can provide food for deer, particularly during the spring, when grasses and forbs are most palatable to deer (Rue 1989, Whitaker and Hamilton 1998). A greater density of pasture patches suggests more pasture bordering with other patch types, with this increased edge having a high probability of containing plant species favorable for deer browse.

The density of crop patches within a 1200 m buffer was also positively related to the probability of a given location being a collision site. There are several potential reasons for this relationship. A high crop density implies more crop patches and smaller mean patch sizes of crops, which suggests that the area is not under intensive agriculture where large blocks of land are managed. Additionally, a greater crop density suggests a greater diversity of land cover types and more edge habitat available to deer. Finally, several of the crops grown on these lands are potential food for deer, and smaller field sizes would increase the availability of this food to deer.

Finally, the percentage of water within a 1200 m buffer was positively related to the probability of a given location being a collision site. This result may seem to contradict the finding of this study that the presence of water across from water within 100 m decreases the probability of being a known collision location. However, the reason for this seeming difference appears to be a matter of scale. Within the smaller 100 m buffer, a greater amount of water (being the dominant type) suggests the highway is crossing a river or other body of water, where deer are not as likely to be found. Within the larger 1200 m buffer, a greater amount of water (though not greater than 68% at any of the studied locations) suggests more water available within the locality, which, if combined with the presence of other food and cover-related factors, would suggest greater suitability for the presence of deer in that locality.

Logistic regression analysis on the physiographic region level resulted in six models which each included from 6 – 10 variables to predict occurrence of DVCs on state and federal highways in Arkansas. These six physiographic region models could be considered as subsets of the final state model. At least half of the variables in each physiographic region model could also be found in the state model with a similar influence on the probability of a location being a collision site. Additionally, all but four (two of which being the categorical variables describing physiographic region) of the fifteen variables in the state model could be found in at least one of the six physiographic region models. Furthermore, five general groups of factors appear in most, if not all, of the six physiographic region models.

The first group of factors involves the effect of water on the occurrence of DVCs. Two physiographic region models, the Boston Mountains and Gulf Coastal Plains, did not have a variable related to water, which could be explained by the fact that these two had the smallest proportions of water (< 1%) of all six physiographic regions. The remaining four physiographic regions, each with greater proportions of water, had at least one water-related variable. Of further interest, the two physiographic regions with the greatest proportions of water (exceeding that of the state average) each had two water-related variables in their models.

The second group of factors involves the effect of a diverse land cover association in proximity to a highway on the occurrence of DVCs. This factor is embodied in the state model as the variable describing the Shannon's Diversity Index of all land cover patches within a 400 m buffer. This same variable was found in the Boston Mountains and Gulf Coastal Plains physiographic region models, suggesting a strong influence of diverse land cover types on DVCs in these regions. The influence of this factor on the other physiographic regions appears to be more indirect, with variables such as those involving density of land cover patches suggesting an indirect measure of some diversity in the landscape.

The third group of factors involves the effect of urban area on the occurrence of DVCs. All six physiographic region models had at least one variable describing urban area. The Arkansas River Alluvial Floodplain physiographic region model had two urban-related variables, both of which were found, with similar influences, in the state model. This finding should not be surprising, as the Arkansas River Valley is comprised of the greatest proportion of urban area in the state.

The fourth group of factors involves the effect of forested area on the occurrence of DVCs, particularly the influence of deciduous and/or coniferous forests. The density of coniferous forest patches within a 400 m buffer was included in three of the six physiographic region models: Arkansas River Valley, Ouachita Mountains, and Ozark Mountains. The first two physiographic regions mentioned had fairly large proportions of coniferous forest, with the Ouachita Mountains having the largest proportion, which would suggest a strong influence of coniferous forests on collisions in this physiographic region. However, the inclusion of coniferous forest patch density in the Ozark Mountains physiographic region is surprising, considering the proportion of coniferous forests in this region is not more than 1.2%, and is not included in the Gulf Coastal Plains physiographic region model, which has a large proportion of coniferous forest (23%). One possible explanation may be that the presence of coniferous forests in the Ozark Mountains, though scarce, is an important source of cover for deer, particularly during the winter months, which are more likely to be severe than in other portions of the state, such as the Gulf Coastal Plains. Variables describing the size or shape of deciduous forest patches were found in all but one of the physiographic region models: the Ouachita Mountains, which has already been described as predominately coniferous forest. These findings suggest the strong influence of deciduous forests on DVCs in the state, as brought out in the state model.

Finally, the fifth group of factors involves the effect of pasture and cropland on deer-vehicle collisions. The pasture edge density within a 1200 m buffer, found to be the most influential variable in the state model, was also found in all but one physiographic region, the Arkansas River Valley. A similar variable, pasture patch density within a 1200 m buffer, was found in the Arkansas River Valley physiographic region as well as in the Ouachita Mountains physiographic region. Thus, the distribution and edge of pastureland appears to be a strong influence in the state as a whole as well as within each physiographic region. The other part of this general factor, cropland, was found not in the physiographic region model of the Mississippi River Alluvial Floodplain, which has the majority of Arkansas's cropland, but in the physiographic region models of the Arkansas River Valley and Gulf Coastal Plains. Of interest are the opposite influences of crop patch density on DVCs in these two physiographic regions. In the Arkansas River Alluvial Floodplain, with 3.5%

cropland, density of crop patches within a 1200 m buffer was positively related to the likelihood of a location being a collision site, suggesting the potential use of these lands by deer. On the other hand, in the Gulf Coastal Plains, with 0.5% cropland, density of crop patches within a 1200 m buffer was negatively related to the likelihood of a location being a collision site.

Conclusions

We considered and evaluated 1,100 variables for comparisons between known collision locations and random highway locations. Although about 700 variables examined in this study had significant differences between known collision locations and random locations, a relatively small number were selected for consideration in logistic regression analysis based on intercorrelations among these variables. Hence, a variety of different variables could have been selected from such a large starting base. The variables selected and used in the logistic regression analyses should thus be viewed as representing and reflecting several classes of variables.

Five general conclusions arise from our study. First, the presence and amount of water accessible to deer, in terms of distance to the nearest source, number of streams intersecting within 400 m, and amount within 1200 m, are strongly related to the occurrence of DVCs. Second, the presence of a diverse association of land cover types in close proximity to the highway is also strongly related to the occurrence of DVCs. Third, the amount and size of urban area within 1200 m of a location has a strong relation to occurrence of DVCs. Fourth, forested area (deciduous and/or coniferous) in close proximity to the highway, particularly in terms of higher density of coniferous forest and greater size and irregularity of deciduous forest patches, is also strongly related to occurrence of DVCs. Finally, the density of pasture and crop patches, and the density of pasture edge in particular, within 1200 m of the highway are strongly related to DVCs.

Our results and models may be used to produce maps indicating potential segments of highways at high risk for the occurrence of DVCs. Additionally, they may aid in planning and road construction. Finally, these results provide a foundation for future research in examining more specific deer-vehicle interactions, and can aid in the evaluation of appropriateness and effectiveness of proposed methods to reduce DVCs in Arkansas.

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Biographical Sketches: Philip A. Tappe is a professor of wildlife ecology and management, Associate Director of the Arkansas Forest Resources Center, University of Arkansas Division of Agriculture; and Associate Dean of the School of Forest Resources, University of Arkansas at Monticello. He received his B.S. and M.S. from Stephen F. Austin State University, and his Ph.D. from Clemson University.

Donald I.M. Enderle is currently a GIS Analyst with Photo Science, Inc., Tucker, GA 30084. He received his B.S. from Auburn University and his M.S. from the University of Arkansas at Monticello.

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