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16. Abstract Deer vehicle collisions (DVCs) are a major economic and social problem in Michigan. The aim of this research was to better understand environmental factors affecting the frequency and rate of DVCs and to develop models that predict DVC occurrence. The study area comprised of Monroe, Washtenaw, and Oakland counties in southeastern Michigan. A random sample of 450 DVC and 450 non-DVC points along roadways was selected within each county. Information regarding road class, number of lanes, traffic volume, speed limit, habitat suitability, and dominant land cover was data built into each point. Contingency tables comparing DVC to non-DVC points were generated and relative risk calculated. Based on a conceptual model of DVCs 8 *a priori* models of DVCs were evaluated. The order of importance of causal factors (highest to lowest) of DVCs was habitat suitability index, traffic volume, and speed. Relative risk between DVC and non-DVC locations for all 3 counties was higher on rural roads than urban roads, and on roads with traffic volume > 120 vehicles/hr than ≤ 120 vehicles/hr. High speed roads with > 2 lanes had the highest relative risk in Monroe County whereas medium speed roads with > 2 lanes had the highest relative risk in Washtenaw and Oakland counties. Vegetation management that reduces forage quality for deer along roadways, so as to not attract deer, may be helpful in reducing number of DVCs. Other vegetation management practices that may reduce DVCs include increasing the sight distance of drivers through removal of trees and particularly shrubs. Actions that reduce traffic volume or speed in moderate quality habitats for deer will result in fewer DVCs.

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ENVIRONMENTAL FACTORS AFFECTING THE FREQUENCY AND RATE OF DEER-VEHICLE CRASHES (DVCs) IN SOUTHERN MICHIGAN

By

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A FINAL REPORT

January 31, 2006

EXECUTIVE SUMMARY

Michigan has the greatest number of reported deer-vehicle collisions (DVCs) in the Midwest. An estimated 65,000 DVCs annually create total direct costs of nearly $149 million statewide. Assuming a reporting rate of approximately 47% (Marcoux 2005) total societal costs may be much greater than previously anticipated.

The goal of this project was to improve the quality of life for Michigan citizens by alleviating the number of annual DVCs through a better understanding of environmental factors affecting DVCs. Project objectives included: 1) identify and assess environmental factors affecting the frequency and rate of DVCs in southern Michigan, 2) develop predictive models that explain why DVCs occur on the landscape, and 3) based on knowledge gained in objectives 1 and 2, provide management recommendations on how environmental factors could be managed to reduce the frequency of DVCs.

The study area for the project comprised of 3 counties in southeast Michigan: Monroe, Washtenaw, and Oakland. These 3 counties were chosen because they represent a gradient of human settlement, land-use, traffic patterns, and deer habitats expected to occur throughout southern Michigan in the future.

South East Michigan Council of Governments (SEMCOG) provided digitized DVC locations (1999 – 2001) that were analyzed using ArcView 3.2 Geographic Information Systems. A sample of 450 DVC points was selected within each county with 150 points from each year, 1999-2001. DVC locations had month and day of week associated with them. Randomly selected non-DVC points (450 total) were also placed on roadways.

Buffers (area at a uniform distance around the points) 800m in length were built around DVC and non-DVC locations and clipped (process akin to using a cookie cutter on dough) from a GIS land cover layer. Digitized DVC and non-DVC locations contained information on:

- Number of lanes (≤ 2 lanes, > 2 lanes),
- Speed limit (low = ≤ 40 mph, medium = 40 < 60 mph, high = ≥ 60 mph)
- Road class (urban, rural),
- Traffic volume (≤ 120 vehicles/hr, >120 vehicles/hr),
- Habitat suitability index (very low, low, medium, and high).

Frequencies of DVC and non-DVC locations were tabulated for different 2 variable combinations (i.e. contingency tables were created); chi-square tests of mutual independence were conducted on the contingency tables. Eight *a priori* models of DVCs were evaluated.

No single factor could be determined to account for the number and rate of DVCs. Yet, the order of importance of factors (highest to lowest) affecting number of DVCs was habitat suitability index, traffic volume, and speed limit. Relative risk (ratio between probabilities of being in a certain category) between DVC and non-DVC locations for all 3 counties was higher on rural roads than urban roads. Relative risk was also higher on roads with traffic volume > 120 vehicles/hr than ≤ 120 vehicles/hr roads. High speed roads, > 2 lanes had the greatest relative risk in Monroe County but medium speed roads, > 2 lanes had the greatest relative risk in Washtenaw and Oakland counties. Roads > 2 lanes, > 120 vehicles/hr had the highest relative risk in Monroe and Washtenaw counties but roads ≤ 2 lanes, > 120 vehicles/hr had the highest relative risk in Oakland County. The number of DVCs is greatest during October, November, and December (peaks on November 15) due to increased movement of deer during the breeding season. Greater number of DVCs occurred on weekdays than weekends, presumably due to increased traffic volumes associated with commuter traffic.

To meet their physiological and behavioral needs deer regularly cross roads that traverse through their habitats. The probability of drivers hitting deer is partially related to the number of deer crossings on roads the drivers use. Roads traversing landscapes comprised of moderate quality deer habitat appear to have more deer crossings and DVCs than either very low or high quality habitats. The probability of a deer crossing a road without being hit by a vehicle decreases with increases in traffic volume and speed. Those areas with high traffic volume, high speed, or a combination of high traffic volume and high speed appear to have more DVCs. An exception to this rule is when traffic volumes reach a high enough level because of human development that the quality of deer habitat decreases.

It is a widespread notion that DVCs are random events on the landscape. Our data indicate that there are patterns as to where DVCs occur and that context, or location, matters. Specific factors that cause DVCs change with changes in the landscape (i.e. rural, urban, or rural/urban mix). In rural landscapes, high traffic volume, high speed roads had the greatest frequency of DVCs. However, high traffic volume, high speed roads in urban landscapes may become a barrier to deer making other road types more risky for DVCs.

Management implications: Land use planning –

- Our research provides a basis for predicting where DVCs will be most likely to occur when planning road or other land use development.
- Any action that either reduces traffic volume or traffic speed in moderate quality deer habitats can be expected to reduce DVCs.

- Vegetation management along roadways may be helpful in reducing number of DVCs.
  - Forage that does not attract deer provides less incentive for deer to be near roads. Consultation with the Department of Natural Resources Wildlife Division is recommended to select road side vegetation that does not attract deer.
  - If traffic speed cannot be reduced, manipulation of vegetation that increases drivers' sight distance, although not measured in this study, likely would reduce the number of DVCs because it gives deer and driver more time to react when high speeds are involved.
  - There will be a tradeoff made between increasing driver sight distances along roadways and not producing more palatable forage for deer. In most cases, the link between DVCs and speed limits suggests DVCs are more likely to be reduced through increasing the sight distance of drivers.
- Driver education campaigns to reduce DVC numbers should warn them about increased risk of encountering deer on roadways during the months of October, November, and December.

Funding for this project was provided by the the Michigan Department of Transportation and Michigan Department of Natural Resources. Considerable data and advice was provided by personnel from the Office of Highway Safety and Planning, the Southeast Michigan Council of Governments, and faculty at Michigan State University.

ABSTRACT

ENVIRONMENTAL FACTORS AFFECTING THE FREQUENCY AND RATE OF DEER-VEHICLE CRASHES (DVCs) IN SOUTHERN MICHIGAN

By

Krishnan Sudharsan

Deer vehicle collisions (DVCs) are a major economic and social problem in Michigan. The aim of this research was to better understand environmental factors affecting the frequency and rate of DVCs and to develop models that predict DVC occurrence. The study area comprised of Monroe, Washtenaw, and Oakland counties in southeastern Michigan. A random sample of 450 DVC and 450 non-DVC points along roadways was selected within each county. Information regarding road class, number of lanes, traffic volume, speed limit, habitat suitability, and dominant landcover was built into each point. Contingency tables comparing DVC to non-DVC points were generated and relative risk calculated. Based on a conceptual model of DVCs 8 *a priori* models of DVCs were evaluated. The order of importance of causal factors (highest to lowest) of DVCs was habitat suitability index, traffic volume, and speed. Relative risk between DVC and non-DVC locations for all 3 counties was higher on rural roads than urban roads, and on roads with traffic volume > 120 vehicles/hr than ≤ 120 vehicles/hr. High speed roads with > 2 lanes had the highest relative risk in Monroe County whereas medium speed roads with > 2 lanes had the highest relative risk in Washtenaw and Oakland counties. Vegetation management that involves planting low quality forage along roadways for deer may be most helpful in reducing number of DVCs. Actions that reduce traffic volume or speed in moderate quality habitats for deer will result in fewer DVCs. High speed, high volume roads in urban landscapes may become a barrier to deer.

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ORGANIZATION OF THIS REPORT

This report is organized into 4 chapters and follows the style prescribed by the Journal of Wildlife Management. Chapter 1 is the main focus of the report and investigates how environmental factors affect frequency and rates of deer-vehicle collisions (DVCs) in southern Michigan. Chapter 2 evaluates the impact of fall firearm hunting season on the frequency of DVCs in Michigan. Chapter 2 was submitted to and accepted by the Journal of Wildlife Management for publication in early 2006. Chapter 3 reports on DVC patterns across 3 ecoregions in Michigan and was presented at the Wildlife Damage Management Conference in Grand Traverse, Michigan, May 2005. Chapter 3 will be published as part of the Conference proceedings. Chapter 4 pertains to the management implications of the research done on DVCs in southern Michigan in the last 3 years. The appendices section reviews DVC literature and aspects of road ecology as related to white-tailed deer (*Odocoileus virginianus*).

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CHAPTER 1

ENVIRONMENTAL FACTORS AFFECTING THE FREQUENCY AND RATE OF DEER-VEHICLE CRASHES (DVCs) IN SOUTHERN MICHIGAN

INTRODUCTION

Animal-vehicle collisions likely began shortly after the invention of wheeled transportation. Henry David Thoreau explained a turtle hit by a wagon wheel as early as the mid-nineteenth century, and Barbour noted birds killed by Nebraska railroads in 1895 (Forman et al. 2003). Americans now own more than 230 million motor vehicles of which 89% are used for daily travel (Forman et al. 2003). The United States of America (US) has 6.3 million kilometers (3.9 million miles) of public roads that provide 13.2 million lane kilometers (8.2 million miles) (Forman et al. 2003). Nearly 1.1% of the US is road or road corridor. An estimated 1 million animals are killed every day on America's roadways (Turbak 1999).

Animal-vehicle collisions are a problem wherever vehicles and wildlife co-exist (Bruinderink et al. 1996, Kaji 1996). Ungulate-vehicle collisions throughout Europe (Russia not included) are estimated in excess of 507,000 collisions annually, with 300 fatalities, 30,000 injuries, and costs approaching $1 billion (Bruinderink et al. 1996).

Deer-vehicle collisions (DVCs) in the US annually cause an estimated 29,000 human injuries, 200 human fatalities (Conover et al. 1995), and over $1 billion in property damage (Conover 1997). If the cost of human life and deer killed is included the total annual cost of DVCs may exceed $2 billion.

In Michigan more than 65,000 DVCs occur annually (Michigan Crash Data, Office of Highway Safety Planning; Figure 1) and affect the health, safety, and economic well being of its citizens. This represents a 230% increase since 1982. At an average estimated cost of $2,300 per

DVC (AAA Michigan, personal communication), more than $149 million are expended annually on vehicle damage alone in Michigan. Total social costs of DVCs likely are greater due to human injury, trauma, absence from work, and additional costs of highway safety officers (Hansen 1983). Allen and McCullough (1976) estimated 91.5% of the deer involved in DVCs in Michigan are killed. If we assume the monetary value of a single deer to be $1,313 (Romin and Bissonette 1996) the total cost of dead deer may amount to an additional $78 million in Michigan. Reported DVCs may be a gross underestimate of total number of collisions. Marcoux (2005) found that 53% of DVCs in southeast Michigan were not reported to police or to insurance companies.

Research is urgently needed to assess the relative importance of environmental factors affecting frequency of DVCs, and how these factors may be managed to alleviate DVCs. Data or analyses on environmental and landscape characteristics associated with DVCs is lacking. A multi-agency task force recommended a plan of action as early as 1987 to lower the number of DVCs in Michigan (Langenau and Rabe 1987). Chief outcomes of that work were hypotheses about causal factors of DVCs and recommendations for management based on minimal analyses. State-of-the-art knowledge about DVCs is needed in transportation management as well as in development of any educational programs focused on reducing the risk of DVCs.

OBJECTIVES

The project goal is to improve the quality of life in Michigan by increasing the knowledge base on which to reduce the frequency and rate of DVCs.

Specific project objectives were:

1. To identify and assess environmental factors affecting the frequency and rate of DVCs in southern Michigan.
2. Develop predictive models that that describe the pattern and frequency of DVCs in the southern Michigan landscape.
3. To provide management recommendations on how environmental factors may be managed to alleviate DVCs based on knowledge gained in objectives 1 and 2.

STUDY AREA

Monroe, Washtenaw, and Oakland counties in southeastern Michigan comprised the study area. The 3 counties selected in collaboration with personnel from Michigan Department of Transportation (MDOT), Michigan Department of Natural Resources (MDNR), Southeast Michigan Council of Governments (SEMCOG), Michigan Office of Highway Safety Planning (OHSP), were determined based on DVC characteristics, land-use, deer habitat characteristics, and other existing databases relevant to deer ecology and DVCs.

Justification for choosing these counties as study sites included:

1. SEMCOG had GIS data of DVC locations for these counties. GIS data of DVC locations is difficult to obtain, but SEMCOG compiles data for counties within its jurisdiction.
2. Monroe, Washtenaw, and Oakland are each unique and served as a comparison group of counties found throughout southern Michigan. These 3 counties differed in population demographics, as well as the general landscape present. The counties formed a gradient along different classes of land-use, traffic patterns, and deer habitat: rural (Monroe), suburban/rural (Washtenaw) and, suburban (Oakland).

3. The counties differed in DVC crash numbers, which in conjunction with the varied landscape, provided environmental variables hypothesized as contributing to DVCs. Oakland County had the greatest number of DVCs each year but the proportion of DVCs as a percentage of total crashes was the smallest (Table 1).

Monroe is the least populated county with 145,945 individuals, whereas Washtenaw is the second most populated with 322,895 individuals, and Oakland is the most populated with 1,194,156 individuals (2000 census, SEMCOG Community Profiles 2003). Cultivated, grassland, and shrubs occupying 73% and 59% of land area was the predominant land use in Monroe and Washtenaw counties while single-family residential occupying 34% of land area was the predominant land use in Oakland County (SEMCOG Community Profiles 2003). The causal factors for DVCs within these 3 counties may be different. The diversity of landscapes and people provide a comparison group for analyzing causal factors.

METHODS

Selecting an appropriate sample size

ArcView 3.2 Geograpic Information Systems (GIS, Environmental Systems Research Institute, Redlands, California) was used for all spatial analyses. A GIS layer may be defined as a collection of geographic objects that are similar (Ormsby et al. 2001). For Monroe, Washtenaw, and Oakland counties the most variable GIS layer available for analysis was land cover (Table 2). Variability is defined as the GIS layer with the most number of polygons. To determine the county with the most variable landscape the number of land cover polygons was divided by the total area of each county. This was done to standardize landscape across the counties. The most variable landscape was Oakland County (303.92 polygons/sq km), whereas Washtenaw County (214.48 polygons/sq km) was intermediate, and Monroe County (149.08 polygons/sq km) had the least variable landscape.

Random samples representing DVC points (50,100, 150 up to 500) were chosen in Oakland County. Buffers of size 0.8 km were built around these points and clipped from the Oakland land cover. Mean size and variance of 7 important land cover classes was calculated. The variance divided by the mean size of land cover classes was plotted as a function of number of points for Oakland County (Figure 2). Most of the variation in land cover classes stabilized after 100 points except for agricultural which showed some fluctuation. Based on Figure 2 it was determined that anything greater than 100 DVC points would be a sufficient sample size for each county. To be cautious however, the minimum sample size was increased to 450 DVC points per county.

Selecting a DVC Group versus Non-DVC Group

Since GIS data was available for 3 yrs (1999–2001) it was decided that 150 points would be chosen from each year to make up the total of 450 points per county. To examine landscape features around DVC locations a buffer with a radius of 0.8 km (0.5 miles) was built. This buffer size was selected because it falls within the bounds of radio-collared white-tailed does home range in southern Michigan (Pusateri 2003). The buffered area was 2.01 km^2 (0.785 $mile^2$) (π* 0.8^2) or 203.31 hectares (502.4 acres). The 150-buffered points for each year did not intersect with each other. Yet, buffered points from 1999 could intersect buffered points from 2000 and 2001. Areas with overlapping buffers indicated areas with higher probability of DVCs.

A reference group (locations where no DVCs were known to have occurred) was identified within each county for comparison. The 450 DVC points with the 0.8 km buffer were removed from the landscape. A total of 450 non-DVC points were randomly placed along roadways. The number of randomly selected sample non-DVC points within each county was equal to the number of DVC points (450 points). A buffer of size 0.8 km was built around the 450 non-DVC points. This process ensured that the buffers around non-DVC points did not intersect the buffered sample DVC points and diminished the chance of committing Type II error. Type II error occurs when a false null hypothesis is not rejected (Zar 1984).

Building road attribute information into DVC and Non-DVC Groups

DVC data obtained from SEMCOG had attribute data associated with each crash location. The attributes associated with each crash location were month, day of week, weather condition, number of lanes, speed limit, and road class.

Month, day of week, weather condition, and road class were 100% complete, yet over 80% of all DVC points did not have number of lanes, or the associated speed limit. Road attributes associated with the DVC points missing this information were built through maps and databases provided by SEMCOG. Similarly 24-hour traffic volume counts were obtained for roadways within each study county through SEMCOG and for Washtenaw County through the Washtenaw Area Transportation Center. Traffic volume associated with each DVC point was determined. For all non-DVC locations road attribute information on number of lanes, speed limit, and traffic volume was constructed from the maps and databases provided by SEMCOG.

GIS layer used in landscape analysis

The GIS layer used in the analysis of landscape factors around DVC and non-DVC locations was land cover and follows the Integrated Forest Monitoring Assessment and

Prescription (IFMAP) classification (MDNR–Wildlife Division, MDNR–Land and Mineral Services Division, Resource Mapping and Aerial Photography 2000). IFMAP classification is a hierarchical classification. There are 4 levels; each level is finer in resolution than the preceding level. Levels III and IV have the finest resolution. E.g. the land cover category agricultural represents a Level I classification, Level II would be herbaceous agriculture and non-herbaceous agriculture. Herbaceous agriculture has 2 level III classes (cropland and non-tilled herbaceous agriculture). The level III classification cropland is broken into 4 level IV classes (non-vegetated farmland, row crops, forage crops, and other cropland) whereas non-tilled agriculture is not broken down further. Non-herbaceous agriculture has 2 level III groups (Christmas tree plantations and orchards/vineyards/nursery). These 2 groups are not broken down any further.

Land cover was analyzed by combining groups at Level I, Level II, and Level III classifications. Three Level I categories agricultural, water and upland openland remained the same. The urban Level I category was analyzed at level II; low intensity urban and high intensity urban. The upland forest Level I category was broken into upland deciduous forest whereas upland coniferous forest and upland mixed forest were combined into a miscellaneous category. Wetlands (Level I category) comprised of lowland forests and non-forested wetlands were combined into the miscellaneous category. Bare/sparsely vegetated (Level I classification) was combined into the miscellaneous category. The least available land cover types were grouped into the miscellaneous category. The combined categories are shown in table 3.

A habitat suitability index (HSI) for deer

A habitat suitability index (HSI) was developed from information in the literature and applied to land cover types. The 2000 land cover layer available for analysis in GIS did not have stand age structure data associated with it, which precluded a more accurate HSI. Each land cover type at either level II or level III classification was evaluated based on 3 habitat components for deer: 1) spring and summer foods 2) fall and winter foods, and 3) security cover. Thermal cover was not included as a habitat component because deer in southern Michigan do not appear to need it because of relatively mild winter conditions (Pusateri 2003).

Each habitat components was given an index value of 0 (no suitability), 0.25 (low), 0.50 (average), 0.75 (above average), or 1 (high) based on their suitability to deer. The habitat component with the greatest index value was then assigned as the score for that particular land cover type (Table 4). The greatest habitat component value was assigned to each land cover type based on the assumption that deer are drawn into particular land cover types due to their utmost attraction. Our study evaluated 21 cover types that provided habitat components for deer.

Gardens may provide flowers and shrubs palatable to deer and hence residential areas were assigned an index value of 0.50 based on the spring/summer food potential (Heinrich and Predl 1993). A higher value was not given since some garden plants may be resistant to deer depredation and also because high densities of people may deter deer. The Other Urban category included airports and roads/parking lots and was assigned an index value of 0. There was no evidence in the literature that these areas can provide forage or security cover to deer.

Row crops, typically corn and soybeans in the study area were assigned an index value of 0.75 based on their importance as fall and winter foods for deer (Nixon et al. 1970; Gladfelter 1984). Nixon et al. (1970) showed that waste corn consumed by deer ranked first by weight and eaten during all seasons except summer. Soybeans were not consumed by deer in certain parts of Ohio (Nixon et al. 1970) and given that row crop was the lowest level of classification a suitability index of 1 was not assigned. Research by Braun (1996) identified deer damage on row crops to be much greater than forage crops (e.g. hay). Based on this finding we assigned a lower index value of 0.25 to the forage crop category. Other agricultural areas were assigned an index value of 0.50 because quick fermenting foods like fruits (e.g. apples in orchards, grapes in vineyards) may provide summer foods to deer (Nixon et al. 1970; Kohn and Mooty 1971). A higher index value was not given to the other agricultural category because consumption of fruits is usually less than that of row crops (Nixon et al. 1970).

Openland areas were assigned an index value of 1.0 since herbaceous vegetation comprised of emerging forbs, grasses and new leaves in trees can provide as much as 90% of a deer's spring and summer diet (Pierce 1975; Rogers et al 1981). The upland shrub category may also provide spring and summer foods (Rogers et al. 1981) but because of the higher percentage of woody shrubs it is less suitable compared to openland areas and was thus assigned an index value of 0.50.

Northern hardwood associations were assigned an index value of 1.0 since this cover type can provide security cover due to the diverse horizontal cover because of multiple height strata (Boyd and Cooperrider 1986). Oak association, another common cover type in the study area provides deer with mast, which is a critical component of fall and winter foods to deer (Harlow et al. 1975). Easily digested acorns can comprise as much as 83% of the diet of deer and hence oak association was assigned an index value of 1.0. Aspen, other upland deciduous, and mixed upland deciduous areas were assigned an index value of 0.50 since they only provide fall and winter foods in the form of browse and are typically of lower nutritional quality than acorns (Kohn and Mooty 1971; Felix 2003).

Upland coniferous areas are important bedding areas for deer (Kohn and Mooty 1971) and therefore pine, other upland conifers, and mixed upland conifers were assigned an index value of 1.0. The deciduous component of upland mixed forests can provide summer forage to deer (Kohn and Mooty 1971) but due to the conifer component with lower palatability, nutritional quality these areas were assigned a lower index value of 0.50.

Lowland deciduous forests (Stocker and Gilbert 1977) that have > 60% deciduous tree canopy cover and lowland coniferous (Mackey 1990) forests that have > 60% coniferous tree canopy cover provide vertical structure (Felix 2003) and were assigned an index value of 1.0 since they may provide security cover. Lowland mixed forests were assigned a lower index value of 0.50 because a mixed canopy (40% – 60% deciduous/coniferous cover) provides less vertical structure and hence may provide lower security cover.

Non-forested wetlands were assigned an index value of 0.25 since deer may feed on aquatic vegetation found in these areas during spring and summer (Rogers et al. 1981). Aquatic vegetation may supply sodium (Botkin et al. 1973) and other nutrients important to ungulates (Jordan et al. 1974). Barely vegetated areas comprised of bare soil, sand, and mud flats were assigned an index value of 0 because they do not provide forage or cover for deer. Lakes, ponds, and rivers were assigned an index value of 0.

For each DVC and non-DVC location a final suitability value was calculated by multiplying area of each land cover patch (km^2) within the 800 m buffer by its habitat suitability index value and summing it. The maximum score for any buffered point was the area of the buffer (i.e. 2.01). The final HSI value associated with each DVC and non-DVC point could range from 0 to 1 and was calculated by the formula:

Final HSI value = $\{\sum$ (Patch Area in km^2 * HSI score of land cover category)$\}$ / 2.01 km^2

HSI values were grouped into 4 categories: Very Low (0.00–0.29), Low (0.30–0.49), Medium (0.50–0.69) and, High (0.70–1.00). The final HSI value associated with each DVC and non-DVC location was therefore dimensionless.

Statistical Analysis

A combination of statistical packages was used in the analysis. Descriptive statistics were calculated in SPSS. Chi-square tests of contingency tables were done in Excel. General linear models were built in R.

To study road characteristics of DVCs and non-DVC locations road attribute data were combined into categories. Each DVC and non-DVC location had 4 categories associated with it: 1) Lane Grouping, 2) Speed Grouping, 3) Volume Grouping, and 4) Road Class Grouping.

Number of lanes was divided into 2 categories: roads with 2 or fewer lanes and roads with greater than 2 lanes. Speed limit was divided into 3 categories: low, medium and high. The low speed category consisted of roads with speeds less than or equal to 64 km/hr (40 mph). The medium speed category had speeds between 64 km/hr and 96 km/hr (60 mph) while the high category consisted of roads with speeds greater than or equal to 96 km/hr. Traffic volume was divided into 2 categories: roads with volume of less than or equal to 120 vehicles/hr and roads with volume greater than 120 vehicles/hr. Road class information follows the United States Department of Transportation (USDOT) system known as the National Functional Classification (NFC) System. We used 2 categories within this system for classifying roads: rural versus urban roads. Rural roads are defined as roads located outside urban and urbanized area boundaries. Due to this definition there is no fixed distance from urban areas where urban roads end and rural roads begin. The only difference between the rural roads and urban roads is their proximity to human populations.

A Priori models of DVCs

To model the effect of different road characteristics and landscape characteristics on

DVCs a parsimonious, biologically meaningful set of models were created. Associated with each DVC were 4 road attributes (lane, speed, volume, and road class groupings) and 2 landscape attributes (land cover, HSI). We chose speed, volume, and HSI as the important variables affecting DVCs. Speed (S) was chosen as one of the variables because studies conducted at Yellowstone National Park (Gunther et al. 1998) and Jasper National Park (Bertwistle 1999) concluded that road segments with higher speeds had a greater number of animal-vehicle collisions. From the driver's perspective on faster roads they have less time to respond to a potential threat on the road. From the perspective of deer, high-speed roads imply a need to cross the road faster. Traffic volume (TV) was chosen as another variable because Allen and McCullough (1976) have shown a strong positive relationship between DVCs and traffic volume. Hubbard et al. (2000) have shown a strong positive relationship between number of lanes and DVCs; however, we did not include number of lanes in our model. Number of lanes cannot have a direct effect on the number of collisions. Conceptually number of lanes may be viewed as a multiplicative factor of traffic volume and if modeled would have been a 2nd order interaction. It is a reasonable assumption that number of lanes and traffic volume are highly correlated and ignoring number of lanes made the model more parsimonious. DVC literature has not shown road class classification to be a predictor of DVCs. HSI was chosen because we made the assumption that higher HSI areas are capable of supporting greater numbers of deer and where there are more deer there will be more DVCs. Furthermore, Nielsen et al. (2003) has shown a positive relationship between higher deer-habitat quality and DVCs. Land cover was not chosen as a variable because we wanted to keep the model parsimonious and given that land cover had 6 categories it would have needed 5 parameters to model direct effects.

A 3-way contingency table for the entire study area was built with the rows being traffic volume groups, columns being speed limit groups, and the tiers being HSI categories. The 1350 DVC points for the 3 study area counties were distributed as Poisson cell counts within this 3-way contingency table. When modeling cell counts with 2 or more categorical response variables the model of choice is a Poisson loglinear model, a special case of a Generalized Linear Model (McCullagh and Nelder 1989; Agresti 1996).

After selecting the variables 5 *a priori* models were proposed. The 5 models were:

1. Log (DVC counts) = β_0 + (Effect due to HSI) + (Effect due to TV) + (Effect due to S) = Main Effects Model = HSI, TV, S
2. Sub Model 1 = HSI, TV
3. Sub Model 2 = HSI, S
4. Sub Model 3 = TV, S = Road Attribute Only Model
5. Second Order Interaction Model = HSI, TV, S + TV * S

Model 1 which is the main effects model consisted of 6 model parameters. β_0 is the slope parameter, HSI had 3 parameters (4 categories; very low, low, medium, and high), traffic volume had 1 parameter (2 categories; ≤120 vehicles/hr, >120 vehicles/hr) and, speed had 2 parameters (3 categories; low, medium, and high). Models 2 through 4 were sub models with different 2 way combinations of the 3 main effects. Model 4 which only had road attributes was chosen in order to examine what the effect on DVCs would be if the deer component (i.e. Greater HSI ~ Greater deer numbers) was ignored. Model 5 was the only *a priori* model to have a second order interaction term. Conceptually the probability of a deer successfully crossing a road is going to be a function of an interaction between traffic volume and speed, not simply a function of each individually. The term traffic volume * speed was the only 2nd order interaction term modeled because it was the only one that made conceptual sense. Model 5 had a total of 9 parameters, 7 parameters just like in the main effects model and 2 additional parameters for modeling the interaction between traffic volume and speed.

The 5 models were ranked based on bias corrected Akaike's Information Criterion (AIC_c) and their differences (Δ_i), Akaike weights (w_i) were calculated (Burnham and Anderson 2002). Comparisons between models were made using w_i*'s* and Δ_i's. For the best model odds between the categories for each variable were calculated while keeping the 2 other variables constant.

Contingency tables of DVCs by road attribute combinations

Three 3-dimensional contingency tables were developed with the rows being road class grouping, columns being lane grouping, speed grouping, and volume grouping, and the tiers being study area counties. Two more 3-dimensional contingency tables were generated with the rows being lane grouping, columns being speed grouping, and volume grouping, and the tiers being study area counties. Finally a 3-dimensional contingency table with the rows being traffic grouping, columns being speed grouping, and tiers being study area counties was developed. For non-DVC locations the same 6 contingency tables were also generated. Chi Square tests of mutual independence were performed on all 6, 3-dimensional DVC locations contingency tables ($\alpha = 0.05$). The 6 null hypotheses tested were:

1. Locations of DVCs are mutually independent of road class, number of lanes, and county of occurrence in the population sampled.
2. Locations of DVCs are mutually independent of road class, speed limit, and county of occurrence in the population sampled.

3. Locations of DVCs are mutually independent of road class, traffic volume, and county of occurrence in the population sampled.
4. Locations of DVCs are mutually independent of number of lanes, speed limit, and county of occurrence in the population sampled.
5. Locations of DVCs are mutually independent of number of lanes, traffic volume, and county of occurrence in the population sampled.
6. Locations of DVCs are mutually independent of traffic volume, speed limit, and county of occurrence in the population sampled.

Relative risk and the 95% confidence interval around it were calculated for all tables and compared DVC and non-DVC locations. Relative risk was calculated in order to show specific associations between variables and as a basis for providing management recommendations. Relative risk was defined as the success probabilities between 2 groups.

Relative Risk = π_1 / π_2

Within each county in the study area conditional odds ratios were calculated that compared DVC and non-DVC locations. Two sets of conditional odds ratios were calculated. The 1st set had variables X, Z (county), being constant and at differing levels of Y. The 2nd set had variables Y, Z (county), being constant and at differing levels of X. Odds may be defined as the probability of an event happening divided by the probability of the event not happening.

Odds of an event = P (A) / (1 – P (A))

The odds ratio is the odds of an event for a certain group compared to the odds of the same event for another group.

$$\text{Odds Ratio of an event} = \text{Odds Group 1} / \text{Odds Group 2} = \{P(A \mid \text{group 1}) / (1 - P(A \mid \text{group 1}))\} / \{P(A \mid \text{group 2}) / (1 - P(A \mid \text{group 2}))\}$$

The odds ratio can be a useful measure in comparing 2 sample proportions π_1 and π_2 especially when π_1 and π_2 are small and just the differences in proportion may not convey as much information (Agresti 1996). Even though odds ratios were calculated between all 6 DVC and non-DVC road attribute tables the results examined relative risk only. The reason for this was to avoid repeating the results since relative risk and odds ratios are related concepts. Relative risk and the odds ratio are related and in some cases may take on similar values (i.e. when π_1, and π_2 are close to 0).

$$\text{Odds Ratio} = \text{Relative Risk} * (1 - \pi_2) / (1 - \pi_1)$$

Odds ratios and relative risk that are further away from 1 in any direction represent strong levels of association. If the 95% confidence intervals for odds ratios and relative risk intersect 1 then it may be inferred that either the association is weak or that the sample size is too small.

Contingency tables of DVCs by road attribute data and land cover categories

Contingency tables associating road attribute data (class grouping, lane grouping, speed grouping and volume grouping) with land cover were built. The rows consisted of road attributes, the columns were land cover categories, and the tiers were study area counties. Chi Square tests of mutual independence were performed on 4, 3-dimensional contingency tables ($\alpha = 0.05$). In the chi-square analysis the land cover category water was removed in order to maintain fewer than 20% of the expected cell frequencies below 5. The 4 null hypotheses tested were:

1. Locations of DVCs are mutually independent of road class, land cover, and county of occurrence in the population sampled.
2. Locations of DVCs are mutually independent of number of lanes, land cover, and county of occurrence in the population sampled.
3. Locations of DVCs are mutually independent of speed limit, land cover, and county of occurrence in the population sampled.
4. Locations of DVCs are mutually independent of traffic volume, land cover, and county of occurrence in the population sampled.

For each study area county differences in proportions between DVC and non-DVC locations were examined by calculating relative risk along with the 95% confidence intervals. The main purpose of providing estimates of population relative risk was to provide a basis for making management recommendations and secondarily to point out specific associations. Due to the many different combinations of variable Y (land cover) being possible odds ratios were not calculated for these 4 contingency tables. The most relevant of these hypotheses were 3 and 4 since they directly relate to road attributes established as important in our *a priori* models.

Contingency tables of DVCs by road attribute data and habitat suitability index categories

Contingency tables associating road attribute data (class grouping, lane grouping, speed grouping and volume grouping) with deer habitat suitability index were constructed. The rows consisted of road attributes, the columns were deer habitat suitability index categories (very low, low, medium, and high), and the tiers were study area counties. Chi Square tests of mutual independence were performed on 4, 3-dimensional contingency tables ($\alpha = 0.05$). In the chi-square analysis the category high of the habitat suitability index was dropped in order to maintain fewer than 20% of the expected cell frequencies below 5. The 4 null hypotheses tested were:

1. Locations of DVCs are mutually independent of road class, deer habitat suitability index, and county of occurrence in the population sampled.
2. Locations of DVCs are mutually independent of number of lanes, deer habitat suitability index, and county of occurrence in the population sampled.
3. Locations of DVCs are mutually independent of speed limit, deer habitat suitability index, and county of occurrence in the population sampled.
4. Locations of DVCs are mutually independent of traffic volume, deer habitat suitability index, and county of occurrence in the population sampled.

Comparisons were made of the relative risk and the 95% confidence intervals between DVC and non-DVC locations within each study area county. Relative risk values that had 95% confidence intervals that included 1 were considered to show no association. Estimates of population relative risk between HSI and road attributes serve to provide support to management recommendations and may provide additional support to our *a priori* models. Hypotheses 3 and 4 were the most important due to their relationship with our a priori models.

Contingency table of DVCs by time of week

Allen and McCullough (1976) had shown a relationship between traffic volume and DVCs by day of week. To test if weekday patterns of DVCs existed a chi-square goodness of fit test was performed on the number of DVCs by day of week for the entire study area combined. The null hypothesis DVCs are independent of day of week when they occur was tested at $\alpha = 0.05$.

Contingency table of DVCs by time of year

Months with the greatest number of DVCs are October, November, and December (Allen and McCullough 1976). A chi-square goodness of fit test was conducted on the number of DVCs by month across the entire study area. The null hypothesis DVCs are independent of month of year when they occur was tested at $\alpha = 0.05$.

RESULTS

***A Priori* models of DVCs**

The best model was the 2nd order interaction model (HSI, TV, S + TV * S). In fact, the only model with any support was the 2nd order interaction model (Table 37). There is strong evidence that a traffic volume and speed interaction has an enormous effect on the number of DVCs. The difference Δ_i between the main effects model (HSI, TV, S) and the next best sub-model (HSI, TV) was 166 indicating strongly that there is a speed effect on number of DVCs. Between the (HSI, TV) sub-model and the (HSI, S) sub model the difference Δ_i was 197 which indicates the effect of traffic volume on number of DVCs is much greater than the effect of speed on number of DVCs. The best fit log-linear model was,

Log (Count of DVCs) = 3.53 – 1.18 HSI (Very Low) + 1.31 HSI (Low) + 1.83 HSI (Medium) – 5.95 TV (Low) – 0.45 S (Low) + 0.01 S (Medium) + 4.18 TV (Low) * S (Low) + 5.65 TV (Low) * S (Medium)

Based on the best model the odds of a DVC happening on very low, low, or medium habitat suitability areas versus high suitability areas, keeping traffic volume and speed constant, were 0.31, 3.71, and 6.23 respectively. If habitat suitability and speed are kept constant the odds of a DVC happening on >120 vehicles/hr roads versus ≤120 vehicles/hr roads were 383.75.

When habitat suitability and traffic volume were kept constant the odds of a DVC happening on low (≤ 64 km/hr roads), medium speed roads (> 64 km/hr but < 96 km/hr) compared to high-speed roads (≥ 96 km/hr) was 0.64 and 1.01 respectively. The 2nd order interaction model fits the observed data much better than the main effects model even though there are large residuals in some categories (Table 35).

Contingency tables of DVCs by road attribute combinations

All 6 chi square tests of mutual independence were significant at the $\alpha = 0.05$ level. We accept the alternate hypotheses that:

1. Locations of DVCs are not mutually independent of road class, number of lanes, and county of occurrence in the population sampled (Table 5).
2. Locations of DVCs are not mutually independent of road class, speed limit, and county of occurrence in the population sampled (Table 7).
3. Locations of DVCs are not mutually independent of road class, traffic volume, and county of occurrence in the population sampled (Table 9).
4. Locations of DVCs are not mutually independent of number of lanes, speed limit, and county of occurrence in the population sampled (Table 11).
5. Locations of DVCs are not mutually independent of number of lanes, traffic volume, and county of occurrence in the population sampled (Table 13).
6. Locations of DVCs are not mutually independent of traffic volume, speed limit, and county of occurrence in the population sampled (Table 15).

Relative risk for road class, number of lanes, and study area counties (Table 6)

Rural, ≤2 lane roads in Monroe County had a mean sample relative risk of 0.83 with the 95% confidence interval not intersecting 1. The sample proportion of DVCs happening on rural, ≤2 lane roads in Monroe County was 17% lower compared to non-DVC locations. We can be 95% confident that, the true relative risk (i.e. population relative risk) for DVCs happening on rural, ≤2 lane roads in Monroe County is between 0.73 and 0.90. For the same road type in Washtenaw County the 95% confidence interval for true relative risk intersects 1 and therefore we cannot make an inference regarding a difference between DVC and non-DVC locations. In Oakland County the mean sample relative risk on rural, ≤2 lane roads was 135% greater for DVC than non-DVC locations and the lower 95% confidence interval was 83% higher. The relative risk of DVCs on rural, ≤2 lane roads versus non-DVCs was lowest in Monroe and highest in Oakland. There was a switch in the directionality of relative risk as we move from Monroe, to Washtenaw, to Oakland on rural, ≤2 lane roads. For the study area combined sample relative risk between DVCs and non-DVC locations given that the road is a rural road and has ≤2 lanes was 1.03, however the 95% confidence interval includes 1.

On rural roads, >2 lanes all 3 counties within the study area had relative risk greater than 1 for DVC locations compared to non-DVC locations. The mean sample relative risk on rural roads, >2 lanes were highest in Oakland County but the range of the 95% confidence interval was extremely large (3.10 – 54.45). Washtenaw had the narrowest range (10.64 – 3.69 = 6.95) in the 95% confidence interval and the smallest mean sample relative risk. For the study area combined sample proportion of DVCs happening on rural roads, >2 lanes were 665% higher than non-DVC locations.

On urban roads, ≤2 lanes the mean sample relative risk and the associated 95% confidence intervals were less than 1 for all 3 counties. The sample proportion of DVCs happening on urban roads, ≤2 lanes was 54%, 52%, and 41% lower in Monroe, Washtenaw, and Oakland counties when compared to non-DVC locations. For the total study area the relative risk on urban roads, ≤2 lanes was 47% lower for DVCs than non-DVC locations, and we can be 95% confident that the population relative risk is between 36% and 56% lower.

All 3 study area counties had mean sample relative risk greater than 1 on urban roads, >2 lanes, however the 95% confidence interval for Oakland County intersected 1. In Monroe and Washtenaw counties we can be 95% confident that the population relative risk was at least 38% and 27% higher for DVCs than non-DVC locations on urban roads, >2 lanes.

Relative risk for road class, speed limit, and study area counties (Table 8)

Rural, low speed limit roads in Monroe, Washtenaw, and Oakland counties had the lowest relative risk for DVCs compared to non-DVC locations followed by urban, low speed roads. Overall, on rural and urban, low speed roads the population relative risk for the entire study area was at least 63% and 51% and at most 89% and 68% lower respectively.

Medium speed limit, rural roads in Washtenaw and Oakland counties had an average sample relative risk 46% and 564% greater for DVCs than non-DVC locations. Inferences about the population relative risk for medium speed limit roads in Monroe County could not be made because the 95% confidence intervals for sample relative risk intersected 1. The greatest average sample relative risk for DVCs compared to non-DVC locations was on urban, medium speed roads followed by rural, medium speed roads in Oakland County. The average relative risk on medium speed roads in Oakland County was considerably higher than in Monroe and

Washtenaw counties. For the entire study area urban, medium speed roads had sample relative risk higher than rural, medium speed roads for DVCs compared to non-DVC locations.

High-speed roads had population relative risk greater for DVCs than non-DVC locations except for urban roads in Oakland County, where the 95% confidence interval intersected 1. The greatest average sample relative risk for DVCs compared to non-DVC locations was on rural high-speed roads in Monroe County followed by the same road type in Oakland County. Overall rural, high-speed roads had a greater average sample relative risk than urban, high-speed roads for DVCs compared to non-DVC locations.

Relative risk for road class, traffic volume, and study area counties (Table 10)

The relative risk between DVCs and non-DVC locations across all 3 study area counties was <1 on roads with traffic volume ≤120 vehicles/hr and greater than 1 on roads with traffic volume >120 vehicles/hr. Average sample relative risk on urban roads with traffic volume ≤120 vehicles/hr was lowest in Washtenaw and greatest in Monroe whereas the highest sample relative risk was on urban roads with traffic volume >120 vehicles/hr in Oakland County. None of the 95% confidence intervals for sample relative risk intersected 1.

Relative risk for number of lanes, speed limit, and study area counties (Table 12)

The lowest sample relative risk for DVCs versus non-DVC locations was on ≤2 lane, low speed roads with Monroe County being 75% lower, Oakland County being 68% lower and, Washtenaw County being 60% lower. On >2 lane, low speed roads, the 95% confidence interval around sample relative risk intersected 1 for Monroe and Washtenaw counties but not for Oakland County. We can be 95% confident that the population relative risk between DVCs and non-DVC locations on >2 lane, low speed roads in Oakland County was at least 1% and as much as 64% lower. For the entire study area population relative risk for ≤2 lane, low speed roads was at least 60% lower between DVCs and non-DVC locations. Inferences about population relative risk for >2 lane, low speed roads cannot be made since the 95% confidence interval around sample relative risk intersected 1.

Between DVCs and non-DVC locations ≤2 lane, medium speed roads had sample relative risk greater than 1 for all study area counties but the 95% confidence intervals intersected 1 for Monroe and Washtenaw counties. In Oakland County however, we can be 95% confident that the true relative risk between DVCs and non-DVCs on ≤2 lane, medium speed roads was at least 466% and as much as 1070% higher. The highest average relative risk between DVCs and non-DVCs for Washtenaw and Oakland counties were on >2 lane, medium speed roads.

The highest average relative risk for Monroe County was on >2 lane, high-speed roads. The sample average relative risk for Washtenaw and Oakland counties were 180% and 143% higher on >2 lane, high-speed roads.

Within the entire study area >2 lane, medium and high speeds roads posed the greatest relative risk of a DVC occurring, whereas the lowest relative risk was on ≤2 lane, low speed roads for DVCs.

Relative risk for number of lanes, traffic volume, and study area counties (Table 14)

Across all study area counties the least average relative risk between DVCs and non-DVC locations was on ≤2 lane, ≤120 vehicles/hr roads. Oakland County had the least average sample relative risk on ≤2 lane, ≤120 vehicles/hr roads that were 83% lower, Washtenaw County was 71% lower, and Monroe County was 57% lower. Inferences about population relative risk on >2 lane, >120 vehicles/hr roads could not be made because 95% confidence intervals around sample relative risk intersected 1.

In Monroe and Washtenaw counties the average sample relative risk between DVCs and non-DVC locations was higher on >2 lane, >120 vehicles/hr roads compared to ≤2 lane, ≤120 vehicles/hr roads however; this pattern was reversed in Oakland County. Overall, >120 vehicles/hr roads had sample relative risks much higher than ≤120 vehicles/hr roads.

Relative risk for traffic volume, speed limit, and study area counties (Table 16)

The lowest sample relative risk for DVCs versus non-DVC locations was on ≤120 vehicle/hr, low speed roads with Monroe County being 93% lower, Washtenaw County being 93% lower and, Oakland County being 94% lower. We can be 95% confident that on >120 vehicles/hr, low speed roads the population relative risk between DVCs and non-DVC locations in Monroe, Washtenaw, and Oakland counties were at least 41%, 17%, and 9% higher respectively.

For the entire study area population relative risk for ≤120 vehicles/hr, low speed roads was at least 89% lower between DVCs and non-DVC locations. We can make the inference that population relative risk for >120 vehicles/hr, low speed roads was at least 14% and up to 118% higher.

Between DVCs and non-DVC locations ≤120 vehicles/hr, medium speed roads had sample relative risk less than 1 for Monroe and Washtenaw counties but greater than 1 for Oakland County. In Oakland County we can be 95% confident that the true relative risk between DVCs and non-DVCs on ≤120 vehicles/hr, medium speed roads was at least 14% and as much as

218% higher. The highest average relative risk between DVCs and non-DVCs for Washtenaw and Oakland counties were on >120 vehicles/hr, medium speed roads.

The highest average relative risk in Monroe County was on >120 vehicles/hr, high-speed roads. The sample average relative risk in Washtenaw and Oakland counties were 180% and 143% higher on >120 vehicles/hr high-speed roads.

Within the entire study area >120 vehicles/hr, medium and high roads posed the greatest relative risk while the lowest risk was on ≤120 vehicles/hr, low speed roads for DVCs.

Contingency tables of DVCs by road attribute data and land cover categories

The 4 chi-square tests that examined the relationship between different road attributes and land cover categories were all significant at the $\alpha = 0.05$ level. We accept the alternate hypothesis that:

1. Locations of DVCs are not mutually independent of road class, land cover, and county of occurrence in the population sampled ($X^2 = 898$, $P < 0.001$, $df = 27$).
2. Locations of DVCs are not mutually independent of number of lanes, land cover, and county of occurrence in the population sampled ($X^2 = 535$, $P < 0.001$, $df = 27$).
3. Locations of DVCs are not mutually independent of speed limit, land cover, and county of occurrence in the population sampled ($X^2 = 745$, $P < 0.001$, $df = 44$).
4. Locations of DVCs are not mutually independent of traffic volume, land cover, and county of occurrence in the population sampled ($X^2 = 501$, $P < 0.001$, $df = 27$).

The distribution of random non-DVC points in the different land cover categories differed among the 3 study area counties. Oakland had a total of 202 points in high intensity and low intensity urban categories, while Washtenaw had 128, and Monroe had only 93. In the agricultural category Monroe (319) had the most number of points, Washtenaw (196) was intermediate and Oakland (34) had the least. Upland deciduous, upland openland, and miscellaneous land cover categories had the greatest number of points in Oakland (57, 94, 47), intermediate in Washtenaw (40, 45, 15), and fewest in Monroe (13, 12, 7).

Relative risk for road class, land cover categories, and study area counties (Table 18)

In Monroe County urban roads in high intensity urban areas had the lowest average sample relative risk whereas rural roads in upland deciduous areas had the greatest average relative risk between DVCs and non-DVC locations. We can be 95% confident that on urban roads in high intensity urban areas population relative risk between DVC and non-DVC locations was at least 66% and up to 90% lower. Upland deciduous areas surrounding rural roads had at least 8% greater population relative risk between DVCs and non-DVC locations. All other road class and land cover combinations in Monroe County had 95% confidence intervals for sample relative risk that intersected 1 and hence inferences about population relative risk could not be made.

Rural and urban roads passing through agricultural areas and rural roads passing through high intensity urban areas in Washtenaw County had population relative risk greater than 1. The 95% confidence intervals around agricultural areas had smaller ranges of relative risk compared to rural roads in high intensity urban areas. Urban roads passing through high intensity and low intensity urban areas had the lowest average sample relative risk between DVCs and non-DVC locations. In Washtenaw County we can be 95% confident that population relative risk between DVCs and non-DVC locations in high intensity and low intensity urban areas was at least 38% and 67% lower respectively.

Rural roads in Oakland County that pass through agricultural, upland openland, and miscellaneous areas had sample relative risk greater than 1. For these areas along rural roads we can be 95% confident that the population relative risk between DVCs and non-DVC locations was at least 116%, 53%, and 18% greater. We can be 95% confident that urban roads that pass through areas with dominant land cover in high intensity urban, low intensity urban, water, and miscellaneous categories have population relative risk at least 47%, 45%, 32%, and 27% lower between DVCs and non-DVC locations. Urban roads that passed through agricultural and upland openland areas had population relative risk greater than 1.

Oakland County (9) had the most number of road class and land cover combinations from which inferences about population relative risk could be made, while Monroe County (2) had the fewest. Across the entire study area agricultural areas surrounding both rural and urban roads had population relative risk higher than 1 between DVCs and non-DVC locations. Rural roads passing through upland openland areas also had population relative risk greater than 1. We can be 95% confident that urban roads going through high intensity and low intensity urban areas have population relative risk at least 47% and 44% lower between DVCs and non-DVC locations.

Relative risk for number of lanes, land cover categories, and study area counties (Table 20)

Between DVCs and non-DVC locations in Monroe County we can be 95% confident that the population relative risk was at least 75% and 7% lower on ≤2 lane roads passing through high intensity urban and agricultural areas. On >2 lane roads passing through the same 2 areas population relative risk was at a minimum 78% and 352% higher between DVCs and non-DVC locations. In Monroe County for all other combinations between number of lanes and land cover we cannot be 95% confident that the population relative risk was less than or greater than 1.

In Washtenaw County population relative risk between DVCs and non-DVC locations on ≤2 lane roads was lower than 1 only in high intensity and low intensity urban areas. Inferences about population relative risk on ≤2 lane roads passing through other land cover areas cannot be made since the 95% confidence intervals around sample relative risk intersect 1. On >2 lane roads population relative risk between DVCs and non-DVC locations was at least 83%, 227%, and 18% higher in high intensity urban, agricultural, and upland openland areas.

Roads ≤2 lanes in Oakland County had population relative risk lower in land cover categories high intensity urban, low intensity urban, water, and miscellaneous. We can be 95% confident that the same ≤2 lane roads passing through agricultural and upland openland areas had population relative risk at least 100% and 9% greater between DVCs and non-DVC locations. Agricultural and upland openland were the only 2 areas that had population relative risk greater than 1 on >2 lane roads as well.

Oakland County (8) had the most number of lanes and land cover combinations from which inferences about population relative risk could be made, while Monroe County (4) had the fewest. For the combined study area on ≤2 lane roads we can be 95% confident that the population relative risk was less than 1 for high intensity urban, low intensity urban, upland deciduous, upland openland, and miscellaneous land cover categories. We can be 95% confident that roads >2 lanes had population relative risk greater than 1 for all land cover categories except low intensity urban and water. Sample average relative risk on >2 lane roads were highest in agricultural areas followed by upland deciduous, and upland openland areas.

Relative risk for speed limit, land cover categories, and study area counties (Table 22)

We can be 95% confident that in Monroe County low speed roads passing through high intensity urban and agricultural areas had population relative risk less than 1, while medium speed roads going through upland deciduous areas and high speed roads going through high intensity urban and agricultural areas had population relative risk greater than 1 between DVCs and non-DVC locations. All other speed limit and land cover combinations in Monroe County had 95% confidence intervals for sample relative risk intersect 1 and hence inferences about population relative risk could not be made.

On low speed roads in Washtenaw County population relative risk between DVC and non-DVC locations was lower than 1 in high intensity urban, low intensity urban, upland openland, and miscellaneous land cover categories. Low speed roads in high intensity and low intensity urban areas had the lowest sample average relative risk. We can be 95% confident that medium speed roads passing through agricultural and upland openland areas had population relative risk at least 22% greater between DVCs and non-DVC locations. High-speed roads passing through high intensity urban areas had the highest sample relative risk in Washtenaw County.

In Oakland County we can be 95% confident that population relative risk between DVCs and non-DVC locations was lower than 1 for all low speed roads regardless of the surrounding land cover categories. On medium speed roads all land cover categories had population relative risk greater than 1 except for low intensity urban where the 95% confidence intervals around sample relative risk intersected 1. Upland openland areas was the only land cover category to have population relative risk greater than 1 for high-speed roads.

Oakland County (13) had the most number of speed limit and land cover combinations from which inferences about population relative risk could be made, while Monroe County (5) had the fewest. For the combined study area on low speed roads we can be 95% confident that population relative risk was less than 1 for high intensity urban, low intensity urban, agricultural, and miscellaneous land cover categories. We can be 95% confident that medium speed roads had population relative risk greater than 1 for agricultural, upland deciduous and upland openland areas while high speed roads had population relative risk greater than 1 for high intensity urban and agricultural areas.

Relative risk for traffic volume, land cover categories, and study area counties (Table 24)

Between DVCs and non-DVC locations in Monroe County we can be 95% confident that the population relative risk was at least 85%, 30%, and 40% lower on ≤120 vehicles/hr roads passing through high intensity urban, low intensity urban, and agricultural areas. On >120 vehicles/hr roads passing through high intensity urban and agricultural areas population relative risk was at least 26%, and 464% higher between DVCs and non-DVC locations. In Monroe County for all other combinations between traffic volume and land cover we cannot be 95% confident that the population relative risk was less than or greater than 1.

In Washtenaw County population relative risk between DVCs and non-DVC locations on ≤120 vehicles/hr roads was lower than 1 across all land cover categories. On roads >120 vehicles/hr population relative risk between DVCs and non-DVC locations was at least 187%, 85%, 85%, and 35% higher on agricultural, upland deciduous, upland openland and miscellaneous land cover categories.

Roads ≤120 vehicles/hr in Oakland County had population relative risk lower in land cover categories high intensity urban, upland deciduous, upland openland, and miscellaneous. Agricultural, upland deciduous, upland openland and miscellaneous land cover categories were the only 4 areas that had population relative risk greater than 1 on >120 vehicles/hr roads.

Washtenaw County (10) had the most number of traffic volume and land cover combinations from which inferences about population relative risk could be made, while Monroe County (5) had the fewest. For the combined study area on ≤120 vehicles/hr roads we can be 95% confident that the population relative risk was less than 1 across all land cover categories. We can be 95% confident that roads with traffic volume >120 vehicles/hr had population relative risk greater than 1 for agricultural, upland deciduous, upland openland and miscellaneous land cover categories. Sample average relative risk on >120 vehicles/hr roads were highest in upland deciduous areas followed by agricultural, and upland openland areas.

Contingency tables of DVCs by road attribute data and habitat suitability index categories

The 4 chi-square tests that examined the relationship between different road attributes and habitat suitability categories were all significant at $\alpha = 0.05$ level. We accept the alternate hypothesis that:

1. Locations of DVCs are not mutually independent of road class, deer habitat suitability index, and county of occurrence in the population sampled ($X^2 = 333$, $P < 0.001$, df = 7).
2. Locations of DVCs are not mutually independent of number of lanes, deer habitat suitability index, and county of occurrence in the population sampled ($X^2 = 181$, $P < 0.001$, df = 7).

3. Locations of DVCs are not mutually independent of speed limit, deer habitat suitability index, and county of occurrence in the population sampled (X^2 = 281, P < 0.001, df = 12).
4. Locations of DVCs are not mutually independent of traffic volume, deer habitat suitability index, and county of occurrence in the population sampled (X^2 = 193, P < 0.001, df = 7).

The total number of randomly placed non-DVC points in the different habitat suitability categories differed between the 3 counties. Monroe, Washtenaw, and Oakland counties had 30, 7, and 21 points in the very low suitability category. In the low suitability category Monroe (196) had the most number of points, while Oakland (132) had the least and Washtenaw (183) had in between. In the medium suitability category Washtenaw (232) had the most number of points, while Monroe had the least (199) and Oakland (208) had in between. In high suitability habitats Oakland County had 89 points, while Washtenaw had 28 and Monroe had the fewest with 25.

Relative risk for road class, habitat suitability categories, and study area counties (Table 26)

In Monroe County we can be 95% confident that rural roads passing through high habitat suitability areas and urban roads passing through medium habitat suitability areas had population relative risk at least 30% and 2% lower between DVCs and non-DVC locations. Sample average relative risk on rural roads decreased consistently from being highest in very low habitat suitability areas to lowest in high habitat suitability areas.

We can be 95% confident that rural roads in Washtenaw County going through medium habitat suitability areas had population relative risk at least 15% higher while urban roads in low habitat suitability areas had population relative risk at least 29% lower between DVCs and non-DVC locations. In Washtenaw County there were no consistent observable patterns of sample relative risk for either rural or urban roads across the 4 habitat suitability categories. However, sample average relative risk on rural roads was higher across all habitat suitability categories compared to urban roads.

We can be 95% confident that population relative risk on rural roads passing through low and medium habitat suitability areas in Oakland County was at least 157% and 84% greater between DVCs and non-DVC locations. On urban roads in very low and low habitat suitability areas population relative risk was at least 63% and 67% lower between DVCs and non-DVC locations. Within Oakland County no consistent patterns of sample relative risk for road class by habitat suitability were observable except that sample average relative risk was higher for rural roads than urban roads across the 4 habitat suitability categories.

For the entire study area we can be 95% confident that population relative risk on rural roads passing through very low, low, and medium habitat suitability areas were at least 103%, 6%, and 14% higher between DVCs and non-DVC locations. For the urban road class category only those passing through low habitat suitability areas had population relative risk lower between DVC and non-DVC locations. Sample average relative across all 4-habitat suitability categories were lower on urban roads compared to rural roads.

Relative risk for number of lanes, habitat suitability categories, and study area counties (Table 28)

In Monroe County ≤2 lane roads had sample average relative risk <1 across all 4-habitat suitability categories, however, we can be 95% confident that population relative risk was lower than 1 only in very low, low, and high habitat suitability areas. Roads >2 lanes had population relative risk higher by at least 195% and 149% on low and medium habitat suitability areas between DVCs and non-DVC locations. Average sample relative risk on low and medium >2 lane roads were higher than 1 while the same categories on ≤2 lane roads had average sample relative risk less than 1. On ≤2 lane roads sample average relative risk increased between the very low, low, and medium habitat suitability categories but decreased between the medium and high habitat suitability categories. On >2 lane roads sample average relative risk increased between the low and medium habitat suitability categories.

We can be 95% confident that ≤2 lane roads in Washtenaw County going through low habitat suitability areas had population relative risk at least 34% lower, while roads >2 lanes in low and medium habitat suitability areas had population relative risk at least 102% and 120% higher between DVCs and non-DVC locations. Sample average relative risk on ≤2 lane roads was lower across very low, low, and medium habitat suitability categories compared to >2 lane roads. On ≤2 lane roads sample average relative risk increased between the very low, low, and medium habitat suitability categories but decreased between the medium and high habitat suitability categories. Roads with >2 lanes had increasing sample average relative risk from very low to medium habitat suitability areas.

In Oakland County we can be 95% confident that ≤2 lane roads passing through very low and low habitat suitability areas had population relative risk less than 1 between DVCs and non-DVC locations. Within the >2 lane road category only those passing through medium habitat suitability areas had population relative risk greater than 1 based on 95% confidence intervals. Sample average relative risk for low, medium, and high habitat suitability categories were lower on ≤2 lane compared to >2 lane roads but not for the very low habitat suitability category. On both ≤2 lane and >2 lane roads sample average relative risk increased from the very low to medium habitat suitability categories but fell between the medium and high habitat suitability categories.

For the entire study area we can be 95% confident that population relative risk was less than 1 on ≤2 lane roads passing through very low and low habitat suitability areas, but greater than 1 on >2 lane roads passing through low and medium habitat suitability areas. Across all habitat suitability categories sample average relative risk was higher on >2 lane roads compared to ≤2 lane roads. Within the ≤2 lane category sample average relative risk increased from very low to medium habitat suitability categories but decreased between the medium and high habitat suitability categories. On roads >2 lanes sample average relative risk consistently increased from the very low to the high habitat suitability category.

Relative risk for speed limit, habitat suitability categories, and study area counties (Table 30)

Roads with low speeds had the lowest sample average relative risk in Monroe County while high-speed roads had the greatest sample average relative risk. We can be 95% confident that population relative risk on low speed roads going through very low, low, and medium habitat suitability areas in Monroe County were at least 57%, 57%, and 40% lower while high speed roads going through low and medium habitat suitability areas had population relative risk at least 317% and 145% greater between DVCs and non-DVC locations. Inferences about population relative risk on medium speed roads and habitat suitability categories could not be made since 95% confidence intervals intersected 1.

Low speed roads in Washtenaw County had the lowest sample average relative risk while high-speed roads had the highest sample average risk. We can be 95% confident that population relative risk on low speed roads going through low and medium habitat suitability areas in

Washtenaw County were at least 64% and 22% lower while high speed roads going through low and medium habitat suitability areas had population relative risk at a minimum 54% and 45% greater between DVCs and non-DVC locations. Only on medium speed roads going through medium habitat suitability areas can we be 95% confident that population relative risk was greater than 1. Within the low and medium speed categories sample average relative risk increased from very low to medium habitat suitability categories but decreased between the medium and high habitat suitability categories.

While low speed roads had the lowest sample average relative risk in Oakland County the highest average relative risk was on medium speed roads unlike in Monroe or Washtenaw counties. We can be 95% confident that population relative risk on low speed and medium speed roads going through low, medium, and high habitat suitability areas in Oakland County was at least 81%, 38%, and 43% lower and at least 317%, 442%, and 269% greater between DVCs and non-DVC locations. Population relative risk on high-speed roads was greater than 1 only when passing through medium habitat suitability areas (95% confidence). Just like in Washtenaw County, low speed and high-speed roads in Oakland County had sample average relative risk increase from very low to medium habitat suitability categories but decrease between the medium and high habitat suitability categories. On medium speed roads sample average relative risk decreased continuously from low to medium to high habitat suitability categories.

Low speed roads had the lowest sample average relative risk and high-speed roads had the greatest sample relative risk for the combined study area. Medium speed roads had sample average relative risk that fell between the low and high-speed categories. For the entire study area combined we can be 95% confident that low speed roads had population relative risk lower than 1 across all habitat suitability categories. The sample average relative risk on low speed roads increased from the very low to medium habitat suitability categories but decreased between the medium and high habitat suitability categories. Medium speed roads traversing low, medium, and high habitat suitability categories had population relative risk at least 14%, 45%, and 6% greater between DVCs and non-DVC locations (95% confidence). Sample average relative risk on medium speed roads increased across the very low to high habitat suitability categories. We can be 95% confident that on high-speed roads passing through low and medium habitat suitability areas population relative risk was at least 129% and 78% greater between DVCs and non-DVC locations. Sample average relative risk on high-speed roads decreased across low to medium to high habitat suitability categories.

Relative risk for traffic volume, habitat suitability categories, and study area counties (Table 32)

We can be 95% confident that in Monroe County population relative risk on ≤120 vehicles/hr roads was less than 1 across all habitat suitability categories. On >120 vehicles/hr roads except for the high habitat suitability category estimates of population relative risk were greater than 1 (95% confidence). Sample average relative risk on ≤120 vehicles/hr roads was lower across all habitat suitability categories when compared to >120 vehicles/hr roads. Within both traffic volume categories sample average relative risk increased from the very low to medium habitat suitability categories but decreased between the medium and high habitat suitability categories.

In Washtenaw County except for the very low habitat suitability category all combinations of ≤120 vehicles/hr roads and habitat suitability had population relative risk less than 1 (95% confidence). On >120 vehicles/hr roads going through low, medium, and high habitat suitability areas we can be 95% confident that population relative risk was at least 41%, 196%, and 60% greater between DVCs and non-DVC locations. Across all habitat suitability categories average sample relative risk was lower on ≤120 vehicles/hr roads when compared to >120 vehicles/hr roads. Within ≤120 vehicles/hr roads sample average relative risk increased from the very low to medium habitat suitability categories but decreased between the medium and high habitat suitability categories while on >120 vehicles/hr roads sample average relative risk increased continuously from very low to high habitat suitability categories.

We can be 95% confident that in Oakland County ≤120 vehicles/hr roads had population relative risk less than 1 across all habitat suitability categories except the very low category. On >120 vehicles/hr roads going through low, medium, and high habitat suitability areas population relative risk was greater than 1 between DVCs and non-DVC locations. As in Monroe and Washtenaw counties average sample relative risk in Oakland County across all habitat suitability categories was lower on ≤120 vehicles/hr roads when compared to >120 vehicles/hr roads. Average sample relative risk increased from the very low to high habitat suitability categories on both ≤120 vehicles/hr and >120 vehicles/hr roads.

For the entire study area we can state with 95% confidence that population relative risk on ≤120 vehicles/hr roads passing through very low, low, medium, and high habitat suitability areas were at least 30%, 62%, 51%, and 55% lower between DVCs and non-DVC locations. For >120 vehicles/hr roads passing through low, medium, and high habitat suitability areas population relative risk between DVC and non-DVC locations was at least 83%, 226%, and 158% greater. Sample average relative for all 4-habitat suitability categories were lower on ≤120 vehicles/hr roads compared to >120 vehicles/hr roads. Within ≤120 vehicles/hr roads sample average relative risk increased from the very low to medium habitat suitability categories but decreased between the medium and high habitat suitability categories. Sample average relative risk was greatest on >120 vehicles/hr roads going through high habitat suitability areas followed by the same roads going through medium and low habitat suitability areas.

Contingency table of DVCs by time of week

We rejected the null hypothesis that DVCs are independent of day of week (Table 33). There appeared to be a greater number of DVCs on weekdays than on weekends. DVCs by day of week seemed relatively constant in Monroe County. However in Washtenaw and Oakland counties DVCs on weekends appeared to be lower than on weekdays except for Tuesday.

Contingency table of DVCs by time of year

We rejected the null hypothesis that DVCs are independent of month of year when they occur (Table 34). There appears to be a greater frequency of DVCs in October, November, December, and May compared to other months.

DISCUSSION

A conceptual model of DVCs and relationship to variables in study

In the simplest model, for a DVC to occur within any given landscape 3 conditions must be met: 1) Deer must be present within the landscape. 2) Roads must traverse the landscape, 3) and there have to be drivers who drive vehicles on the roads.

In this study of environmental factors affecting frequency and rates of DVCs our primary interest was on evaluating the impact of conditions 1, 2 and to a lesser extent condition 3 on the number of DVCs. We made no effort to model characteristics of drivers on the road and their effect on DVCs.

Whereas the likelihood of a DVC depends on presence or absence of deer, the number of DVCs depends on both deer numbers and deer behavior. Given that no estimates of deer density were available for Monroe, Washtenaw, or Oakland counties the habitat suitability index is assumed to be an indicator of relative deer abundance (Anderson and Gutzwiller 1996) within each of the 3 study counties. The land cover variable was related to deer behavior since presences of deer in different land cover categories indicated use of those cover types. Number of lanes, speed limit, and traffic volume are road attributes and relate to condition 2 in the conceptual model. Road class relates to condition 3 since proximity to human population centers differentiates rural and urban roads.

A Priori Models of DVCs and the arcade game Frogger

The classic arcade game Frogger depicts an analogous situation to deer crossing roads. The goal of the game is to successfully guide Frogger (a frog) across a road with many lanes and varying speeds/volumes of traffic. The success probability of crossing the road for Frogger and deer depends on traffic volume and speed of the traffic flow. Traffic volume has a direct effect on the probability of a successful road crossing because where there is continuous traffic volume (i.e. bumper to bumper) the probability of a successful crossing approach 0. As traffic volume decreases gaps in flow would increase the probability of a successful crossing. Speed also has a direct effect on the probability of a successful crossing because at slower speeds there is more time for both drivers and deer to respond to a potential threat on the road. There is a 2^{nd} order interaction between traffic volume and speed because joint increases in traffic volume and speed are likely to decrease the success probability of a crossing in a non-linear manner. Roads built to handle greater speeds are most likely to handle greater volumes. The large Δ_i between the 2^{nd}

order interaction model and the main effects model strongly indicated that the interaction between volume and speed has an increasing effect on the number of DVCs.

Habitat suitability for deer is an important factor affecting DVCs (Model 3, Model 4). Exclusion of habitat suitability and retention of only road attributes (model 5) resulted in a model with no support. Finder et al. (1999) and Nielsen et al. (2003) have shown that habitat quality is related to areas around road segments with DVCs. An unexpected result of our model is that low and medium habitat suitability areas are predicted to have greater numbers of DVCs than high suitability habitats. As population density increases, home range size can be expected to decrease (Sanderson 1966). Marchington (1968) indicated that deer population density and home range size might have an inverse relationship. Home ranges of white-tailed deer have substantially increased in size following population reductions (Bridges 1968; Smith 1970). In areas with higher quality habitat in Michigan the distance covered to obtain forage or escape cover is lower (Pusateri 2003). If higher quality habitat is capable of supporting greater deer densities then deer within these areas are likely to have smaller home ranges. Smaller home ranges in deer imply a reduction in the probability of having to cross roads due to decreased movement. DVCs increase up to a certain threshold of habitat suitability (due to increases in deer densities) but beyond this threshold changes in deer movement (smaller home ranges in higher quality habitats) may lead to a reduction in DVCs.

Traffic volume and speed both have an important effect on DVCs, yet the effect of traffic volume was greater than the effect of speed on DVCs. This makes conceptual sense because a road with 1 vehicle/hr traveling at 160 km/hr is less likely to result in a DVC compared to a road with continuous traffic traveling at 16 km/hr. Allen and McCullough (1976) found a strong positive correlation ($R^2 = 0.85$) between traffic volume and number of DVCs. Research in

Yellowstone National Park have shown a significant relationship between vehicle speeds and wildlife collisions (Gunther et al. 1998). Elk-vehicle collisions in Jasper National Park have been shown to have a positive relationship with increasing speeds (Bertwhistle 1999).

Areas of high and low relative risk for DVCs in a mixed landscape

A better understanding of what types of roadways/landscapes is over represented in DVC counts were accomplished by comparing DVCs with non-DVC locations. Implicit in this statement is the assumption that 450 random locations placed on roadways at least 800 meters away from the sample DVC points are enough to capture roadway/landscape characteristics of non-DVC locations within each county. If there was an over representation of DVC counts in certain types of roadways or landscapes the sample relative risk along with the 95% confidence intervals would have to be greater than 1 to make inferences for the entire population within a particular study area county. Similarly under represented DVC counts would have sample relative risk and 95% confidence intervals less than 1. If the 95% confidence intersected 1 we cannot be 95% confident that there was over representation or under representation of DVC counts and, the only way to solve this issue would be to sample the entire population.

We made the assumption that 450 random non-DVC locations were sufficient to capture the distribution of road type and land cover characteristics within each study area county. Monroe County was the most agricultural and Oakland County was the least agricultural. The most urban county was Oakland while the least urban county was Monroe.

When modeling factors affecting DVCs we made an assumption that habitat suitability index is an indicator of deer density. Based on this assumption the distribution of non-DVC points in the 4 different habitat suitability categories across the 3 study area counties would lend support to the notion that deer density may be greatest in Oakland County, intermediate in Washtenaw County and, least in Monroe County.

The chi-square tests of independence indicate statistical relationships between road attributes, land cover categories, habitat suitability index categories, and the study area counties. Given that significant statistical relationships between the independent variables exist, relative risk informs us of which combinations of independent variables pose a greater threat of DVCs to drivers on the road.

Contingency tables of DVCs by road attribute combinations

Relative risk for road class, number of lanes, and study area counties

Rural roads, >2 lanes had greater average sample relative risk than urban roads, >2 lanes because land within an urbanized area may not support deer densities as great as in rural areas. Bashore et al. (1985) and Nielsen et al. (2003) found road segments with DVCs to contain a lower density of buildings. Urbanized areas containing high intensity developments and parking lots are unlikely to provide adequate habitat to support deer. Urban roads, ≤2 lanes had the lowest population relative risk because low traffic volume and high levels of development around roadways do not provide the ideal conditions for DVCs. As mentioned earlier number of lanes is probably highly correlated to traffic volume because roads with greater number of lanes are built specifically to support high volumes of traffic. The switch in directionality of relative risk on rural ≤2 lane roads from Monroe to Oakland may be because Oakland County is most urbanized and traffic volume is likely to be higher across all road classes due to the presence of more drivers.

Relative risk for road class, speed limit, and study area counties

Low speed roads have very low relative risk for DVCs because drivers may have more time to react to deer crossing the road. Bashore et al. (1985) found that shortest visibility was negatively related to DVCs, drivers going at slower speeds are possibly more likely to see deer on roadsides and take suitable steps to avoid a collision. If traffic volume were kept constant, lower speed roads provide larger gaps in time for deer to get through vehicles. Whereas higher speeds represent greater risk in Monroe, and Washtenaw County the pattern observed in Oakland County is different. In Oakland County high speed roads may indicate a greater intensity of human development and such areas would support fewer deer numbers compared to areas with less development, hence relative risk on medium speed roads was higher than on high speed roads. Another possible explanation is that at some point high-speed roads (high speed = high volume in Washtenaw and Oakland) may become a barrier and few deer may attempt to cross such roads (Bashore et al. 1985). Our findings in Oakland County are in agreement with Allen and McCullough (1976), who found DVCs increased up to speeds of 80–95 km/hr after which they declined.

Relative risk for road class, traffic volume, and study area counties

Roads with traffic volumes ≤120 vehicles/hr may not have enough vehicles on them to have an effect on numbers of DVCs regardless of proximity to population centers. Allen and McCullough (1976) indicated a similar strong linear relationship between DVCs and traffic volume in Michigan. Rural areas may support greater deer densities than urban areas and when roads with traffic volume >120 vehicles/hr passes through them an ideal combination for increased DVCs is created.

Relative risk for number of lanes, speed limit, and study area counties

Relative risk on low speed roads typically was less than 1 because driver reaction time to a deer on the road is likely to be higher. Also drivers may be more likely to spot deer on roadsides at lower speeds. High-speed roads with ≤2 lanes do not occur in the study area. The higher average relative risk in Washtenaw and Oakland counties on medium speed, >2 lane roads compared to high speed, > 2 lane roads may be due to a barrier effect. High-speed roads in these 2 counties are also high traffic volume roads. It is possible that a combination of multiple lanes, high traffic volumes, and high speed of vehicles may be more of a deterrent to deer wanting to cross the road when compared to medium speed roads. Deer likely encounter roads on a continual basis in an urban (Oakland) and urban–suburban (Washtenaw) landscape. Over time some deer may develop a sense of where and what types of roads to cross. In Monroe County a barrier effect from roads does not seem to operate. It is likely that deer in Monroe County are less used to roadways and hence their choice of road crossings is more random when compared to deer in Oakland or Washtenaw counties. Given the landscape deer live in, behaviors related to crossing roads may vary. So far, there have been no studies done on the movement behavior of deer crossing roads.

Relative risk for number of lanes, traffic volume, and study area counties

Regardless of the number of lanes, high traffic volume roads have greater risk because the probability of deer successfully making a road crossing decreases with increasing traffic volume.

Relative risk for traffic volume, speed limit, and study area counties

Our *a priori* models suggested that traffic volume is more important in determining number of DVCs than speed limit. The relative risk table between traffic volume, speed limit, and study area counties also supports this conclusion. When traffic volume and speed limit are considered the barrier effect in Washtenaw County is not apparent, but in Oakland County there still seems to be a barrier effect from high speed >120 vehicles/hr roads. Except for the study by Bashore et al. (1985) no studies on DVCs or on white-tailed deer movement detected barrier effects. This lack of evidence in the literature may be due to differences in the scale between our study in Michigan and other DVC studies (Finder et al. 1999; Hubbard et al. 2000; Nielsen et al. 2003). The Bashore et al. (1985) study was done on 4 counties in Pennsylvania, which is close to the number of counties in this study. Studies on other large mammals have shown that high traffic volume roads can act as barriers to crossings. In Banff National Park, Alberta, Canada, the 4-lane, divided Trans-Canada Highway has been shown to be an absolute barrier to the movement of adult female grizzly bears (*Ursus arctos*) and a partial barrier/filter to adult males (Gibeau 2000). Similarly in California, movements of mountain lions (*Puma concolor*) were disrupted after creation of major highways (Dickson et al. 2005).

Contingency tables of DVCs by road attribute data and land cover categories

Relative risk was calculated for each of the 4 road attributes and land cover categories to maintain the consistency of the data presentation. The most important tables in this section, however, were those between speed limit, traffic volume and the land cover categories. The main reason for this is that the variables used in the a priori models were traffic volume and speed. The following discussion thus pertains to these 2 important variables.

Relative risk for speed limit, land cover categories, and study area counties

Drivers may be able to respond better at lower speeds to deer on roadways and therefore sample average relative risk, regardless of land cover or county, remained less than 1. As speed increased relative risk in almost all land cover categories increased, which supports the hypothesis that speed may have a direct effect on DVCs, a notion affirmed by our DVC model.

Deer densities in high intensity urban areas are expected to be much lower than in other more suitable areas, although some high intensity urban areas, such as Chicago with abundant parklands, may support deer populations (Etter et al. 2002). However, just the presence of deer in high intensity urban areas combined with high speeds and low expectancy on the part of drivers to encounter deer on roads may make them high-risk areas.

Monroe County had the highest sample relative risk for DVCs on high-speed roads passing through agricultural areas. Deer in Monroe may depend on agricultural crops (especially corn and soybeans) as a major fall and winter food source (Nixon et al. 1970; Gladfelter 1984). Braun (1996) and Gladfelter (1984) have shown that in some areas deer may develop dependencies on agricultural crops. Washtenaw and Oakland counties showed a similar relationship as Monroe County in agricultural areas except that high-risk roads had medium speeds.

Medium speed roads in Monroe and Oakland counties had high relative risk for DVCs when passing through upland deciduous areas because these areas provide mast for deer (Duvendeck 1964; Harlow et al. 1975) and have high forage availability (Kohn and Mooty 1971). Deer may be attracted to upland deciduous areas due to their high suitability (Felix 2003) and because uplands normally provide security cover (Boyd and Cooperrider 1986). Forest cover provided by deciduous upland forests also makes deer less visible to drivers (Finder et al. 1999), which can be expected to increase the risk of DVCs in these areas.

In Washtenaw and Oakland counties medium speed roads going through upland openland areas had population relative risk greater than 1 because these areas may provide excellent spring and summer foods for deer (McCafferty and Creed 1969; McNeill 1971). Rogers et al. (1981) observed that grasses and shrubs could make up over 90% of a deer's summer diet and these are found in upland openland areas.

The land cover category miscellaneous and medium speed also had high relative risk in Oakland County. Upland mixed forests found within this broad category are extensively foraged by deer (Kohn and Mooty 1971). Upland coniferous forest found within the miscellaneous category can provide deer with woody browse for winter food (Rogers et al. 1981), and depending on species composition, bedding areas (Kohn and Mooty 1971). In Oakland County our results are in agreement with Finder et al. (1999), who found roads traversing wooded vegetation types to have greater number of DVCs.

Medium speed roads in Oakland County had sample relative risk greater than high-speed roads, an indication that a barrier effect may operate in a highly urban landscape.

Relative risk for traffic volume, land cover categories, and study area counties

Low traffic volume roads had sample relative risk less than 1 across almost all land cover categories and counties because gaps in traffic may allow deer to cross roads safely. Percentage of DVCs was very low when traffic volume was low (Allen and McCullough 1976). The reason for higher relative risk in certain land cover categories is related to the quality of these habitats for deer. The section preceding this already discussed how these habitats are important for deer.

Contingency tables of DVCs by road attribute and habitat suitability index categories

Our modeling efforts indicate a positive relationship between the habitat suitability index categories and road attribute characteristics. The observation that sample average relative risk typically decreased between the medium and high habitat suitability index categories may be related to deer home range size in higher quality habitats. The distances covered by deer in high quality habitats may be low (Pusateri 2003) due to easy availability of forage and cover and hence home range size of deer in high quality habitats may be lower. In high habitat suitability areas decreased deer movement may result in lower risk of DVCs.

Contingency table of DVCs by time of week

Allen and McCullough (1976) found that number of DVCs were highest on weekends and attributed this to greater traffic volume. Our research found an opposite pattern, with DVCs being most frequent on weekdays and least frequent on weekends. Traffic patterns as related to work schedules might have shifted in the last 30 years. In urban and suburban-urban counties people have to commute to work during weekdays while weekends might be days of leisure and less travel. Traffic volume is probably associated with day of week in Washtenaw and Oakland counties and lower numbers of DVCs on weekends may reflect lower traffic volumes. In a rural community (Monroe County) where traffic volume is less likely to be governed by 0900 to 1800 hr office schedules we found DVCs to be more evenly spread out across the days of the week.

Contingency table of DVCs by time of year

Late October and early November have been shown to be the time of year when the rut peaks in Michigan (Allen and McCullough 1976). Movement of deer increases dramatically during the rut (Hirth 1977). Such an increase in movement increases the likelihood of deer crossing roads, which would result in greater numbers of DVCs. Allen and McCullough (1976) found little correlation between traffic volume and month of year lending further support to the notion that higher DVCs in October, November, and December are a result of deer movement patterns. The slight increase in DVCs during May was also noted by Allen and McCullough (1976) and attributed to higher traffic volume associated with Memorial Day (May 30). Spring dispersal of deer and pre-fawning movements are likely additional factors causing the small peak in DVCs seen in May (Puglisi et al. 1974). Pusateri (2003) estimated peak fawning date (2001–2002) in southwest Michigan was May 23rd. Yearling deer disperse during April and May (Nixon et al. 1991).

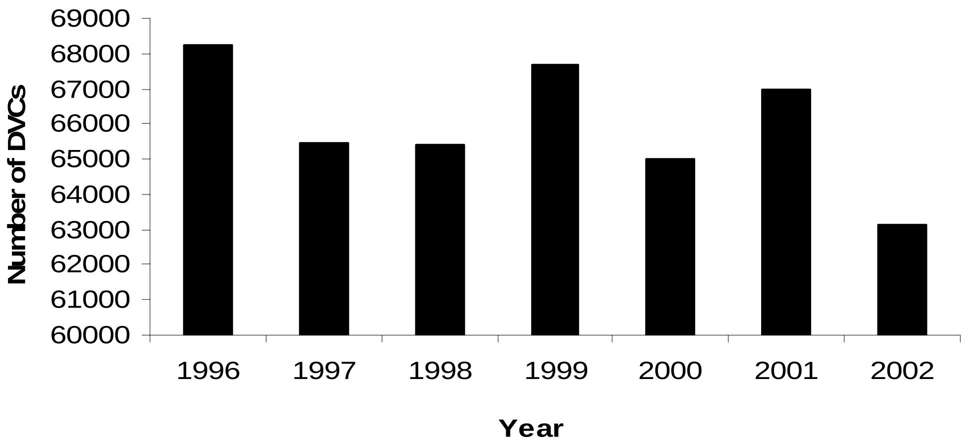

Figure 1. Recent trend in annual number of deer-vehicle crashes in Michigan, 1996–2002 (Michigan Crash Data, Office of Highway Safety Planning).

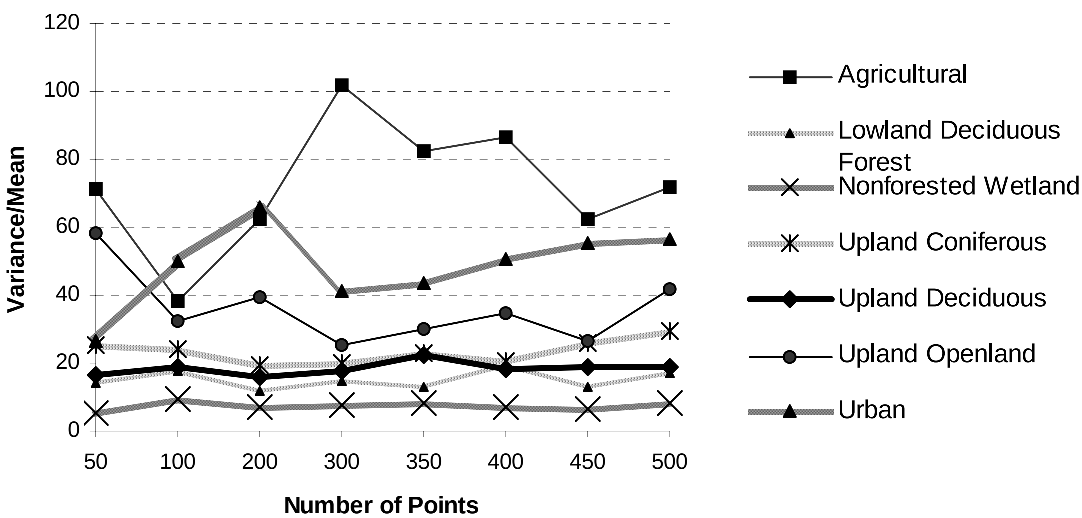

Figure 2. Variance divided by mean area of different land cover classes as a function of increasing number of points for Oakland County.

Table 1. Annual number of deer vehicle-crashes and deer-vehicle crashes as a percentage of total crashes for study area, 1999–2001 (Michigan Crash Data, Office of Highway Safety Planning).

	Monroe		Washtenaw		Oakland	
YEAR	DVCs	%	DVCs	%	DVCs	%
1999	299	6.62	1,759	3.59	1,319	9.99
2000	282	5.72	1,638	3.29	1,244	9.22
2001	312	6.84	1,633	3.57	1,395	10.95

Table 2. Number of polygons present in land use and land cover layers for study area counties.

	Monroe		Washtenaw		Oakland	
	Land Use	Land Cover	Land Use	Land Cover	Land Use	Land Cover
Number of Polygons	8417	214630	16438	503702	18305	713755

Table 3. IFMAP land cover classification combined for use in data analysis.

Level I	Level II	Category Group
Urban	Low Intensity Urban	Low Intensity Urban
	High Intensity Urban	High Intensity Urban
Agricultural	Herbaceous Agriculture	Agricultural
	Non-Herbaceous Agriculture	
Upland Openland	Herbaceous Openland	Upland Openland
	Upland Shrub	
	Low Density Trees	
	Parks/Golf Courses	
Upland Forest	Upland Deciduous Forest	Upland Deciduous Forest
	Upland Coniferous Forest	Miscellaneous
	Upland Mixed Forest	
Water		Water
Wetlands	Lowland Forest	Miscellaneous
	Nonforested Wetlands	Miscellaneous
Bare/Sparsely Vegetated		Miscellaneous

Table 4. Highest habitat suitability index (HSI) scores for different levels of land cover categories based on literature.

LAND COVER LEVEL I	LAND COVER LEVEL II, III, AND IV	CODE	HSI GROUP	HSI SCORE
Urban	Low Intensity Urban (II)	1	RESIDENTIAL	0.50
Urban	High Intensity Urban (III)	2		
Urban	Airports (III)	3	OTHER URBAN	0.00
Urban	Road/Parking Lot (III)	4		
Agricultural	Row Crops (IV)	6	ROW CROPS	0.75
Agricultural	Forage Crops (IV)	7	FORAGE CROPS	0.25
Agricultural	X-mas Tree Plantation (III)	8	OTHER AGRICULTURAL	0.50
Agricultural	Orchards/Vineyards/ Nursery (III)	9		
Agricultural	Non-vegetated Farmland (IV)	5	OPENLAND	1.00
Upland Openland	Herbaceous Openland (II)	10		
Upland Openland	Upland Shrub (II)	11	UPLAND SHRUB	0.50
Upland Openland	Low Density Trees (II)	12		
Upland Openland	Parks/Golf Courses (II)	13		
Upland Forest	Northern Hardwood Association (III)	14	NORTHERN HARDWOOD	1.00
Upland Forest	Oak Association (III)	15	OAK ASSOCIATION	1.00
Upland Forest	Aspen Association (III)	16	ASPEN ASSOCIATION	0.50
Upland Forest	Other Upland Deciduous (III)	17	OTHER UPLAND DECIDUOUS	0.50
Upland Forest	Mixed Upland Deciduous (III)	18	OTHER UPLAND DECIDUOUS	0.50
Upland Forest	Pines (II)	19	PINES	1.00

Upland Forest	Other Upland Conifers (II)	20	OTHER UPLAND CONIFERS	1.00
Upland Forest	Mixed Upland Conifers (II)	21		
Upland Forest	Upland Mixed Forest (II)	22	UPLAND MIXED FOREST	0.50
Water	Water	23	WATER	0.00
Wetlands	Lowland Deciduous Forest (III)	24	LOWLAND DECIDUOUS FOREST	1.00
Wetlands	Lowland Coniferous Forest (III)	25	LOWLAND CONIFEROUS FOREST	1.00
Wetlands	Lowland Mixed Forest (III)	26	LOWLAND MIXED FOREST	0.50
Wetlands	Floating Aquatic (III)	27	NON-FORESTED WETLAND	0.25
Wetlands	Lowland Shrub (III)	28		
Wetlands	Emergent Wetland (III)	29		
Wetlands	Mixed Non-Forest Wetland (III)	30		
Barely vegetated	Sand, Soil (II)	31	BARELY VEGETATED	0.00
Barely vegetated	Exposed Rock (II)	32		
Barely vegetated	Non-stocked Forest (II)	33		
Barely vegetated	Mud Flats (II)	34		
Barely vegetated	Other Bare/Sparsely Vegetated (II)	35		

Table 5. Road class by number of lanes between DVCs and non-DVC locations in Monroe, Washtenaw, and Oakland counties, Michigan, 1999–2001.

LOCATION	COUNTY	ROAD CLASS	NUMBER OF LANES ≤ 2 Lanes	NUMBER OF LANES > 2 Lanes	CHI SQUARE (P,df)
DVCs	MONROE	RURAL	249 (0.55)	117 (0.26)	
		URBAN	54 (0.12)	30 (0.07)	
	WASHTENAW	RURAL	211 (0.47)	94 (0.21)	
		URBAN	87 (0.19)	58 (0.13)	185 (<0.001,7)
	OAKLAND	RURAL	160 (0.36)	26 (0.06)	
		URBAN	192 (0.43)	72 (0.16)	
	TOTAL	RURAL	620 (0.46)	237 (0.18)	
		URBAN	333 (0.25)	160 (0.12)	
NON-DVCs	MONROE	RURAL	308 (0.68)	14 (0.03)	
		URBAN	117 (0.26)	11 (0.02)	
	WASHTENAW	RURAL	225 (0.50)	15 (0.03)	
		URBAN	180 (0.40)	30 (0.07)	
	OAKLAND	RURAL	68 (0.15)	2 (0.00)	
		URBAN	328 (0.73)	52 (0.12)	
	TOTAL	RURAL	601 (0.45)	31 (0.02)	
		URBAN	625 (0.46)	93 (0.07)	

Table 6. Relative risk and 95% confidence intervals for road class by number of lanes between DVCs and non-DVC locations in Monroe, Washtenaw, and Oakland counties, Michigan, 1999–2001.

COUNTY	ROAD CLASS	NUMBER OF LANES ≤ 2 Lanes	NUMBER OF LANES > 2 Lanes
MONROE	RURAL	0.81 (0.73–0.90) *	8.36 (4.88–14.32) *
	URBAN	0.46 (0.34–0.62) *	2.73 (1.38–5.37) *
WASHTENAW	RURAL	0.94 (0.82–1.07)	6.27 (3.69–10.64) *
	URBAN	0.48 (0.39–0.60) *	1.93 (1.27–2.95) *
OAKLAND	RURAL	2.35 (1.83–3.03) *	13.00 (3.10–54.45) *
	URBAN	0.59 (0.52–0.66) *	1.38 (0.99–1.93)
TOTAL	RURAL	1.03 (0.89–1.19)	7.65 (4.05–14.43) *
	URBAN	0.53 (0.44–0.64) *	1.72 (1.13–2.63) *

Table 7. Road class by speed limit between DVCs and non-DVC locations in Monroe, Washtenaw, and Oakland counties, Michigan, 1999–2001.

LOCATION	COUNTY	ROAD CLASS	SPEED LIMIT			CHI SQUARE (P,df)
			Low	Medium	High	
DVCs	MONROE	RURAL	6 (0.01)	251 (0.56)	109 (0.24)	610 (<0.001,12)
		URBAN	43 (0.10)	28 (0.06)	13 (0.03)	
	WASHTENAW	RURAL	24 (0.05)	243 (0.54)	38 (0.08)	
		URBAN	77 (0.17)	36 (0.08)	32 (0.07)	
	OAKLAND	RURAL	4 (0.01)	166 (0.37)	16 (0.04)	
		URBAN	134 (0.30)	112 (0.25)	18 (0.04)	
	TOTAL	RURAL	34 (0.03)	660 (0.49)	163 (0.12)	
		URBAN	254 (0.19)	176 (0.13)	63 (0.05)	
NON-DVCs	MONROE	RURAL	71 (0.16)	241 (0.54)	10 (0.02)	
		URBAN	105 (0.23)	19 (0.04)	4 (0.01)	
	WASHTENAW	RURAL	58 (0.13)	167 (0.37)	15 (0.03)	
		URBAN	174 (0.39)	26 (0.06)	10 (0.02)	
	OAKLAND	RURAL	43 (0.10)	25 (0.06)	2 (0.00)	
		URBAN	361 (0.80)	7 (0.02)	12 (0.03)	
	TOTAL	RURAL	172 (0.13)	433 (0.32)	27 (0.02)	
		URBAN	640 (0.47)	52 (0.04)	26 (0.02)	

Table 8. Relative risk and 95% confidence intervals for road class by speed limit between DVCs and non-DVC locations in Monroe, Washtenaw, and Oakland counties, Michigan, 1999–2001.

COUNTY	ROAD CLASS	SPEED LIMIT		
		Low	Medium	High
MONROE	RURAL	0.08 (0.04–0.19) *	1.04 (0.92–1.17)	10.90 (5.78–20.55) *
	URBAN	0.41 (0.29–0.57) *	1.47 (0.84–2.60)	3.25 (1.07–9.89) *
WASHTENAW	RURAL	0.41 (0.26–0.65) *	1.46 (1.26–1.69) *	2.53 (1.41–4.54) *
	URBAN	0.44 (0.35–0.56) *	1.38 (0.85–2.25)	3.20 (1.59–6.43) *
OAKLAND	RURAL	0.09 (0.03–0.26) *	6.64 (4.45–9.90) *	8.00 (1.85–34.59) *
	URBAN	0.37 (0.32–0.43) *	16.00 (7.54–33.95) *	1.50 (0.73–3.08)
TOTAL	RURAL	0.20 (0.11–0.37) *	1.52 (1.29–1.80) *	6.04 (3.02–12.07) *
	URBAN	0.40 (0.32–0.49) *	3.38 (2.01–5.69) *	2.42 (1.11–5.29) *

Table 9. Road class by traffic volume between DVCs and non-DVC locations in Monroe, Washtenaw, and Oakland counties, Michigan, 1999–2001.

LOCATION	COUNTY	ROAD CLASS	TRAFFIC VOLUME ≤ 120 vehicles/hr	TRAFFIC VOLUME > 120 vehicles/hr	CHI SQUARE (P,df)
DVCs	MONROE	RURAL	161 (0.36)	205 (0.46)	345 (<0.001,7)
		URBAN	15 (0.03)	69 (0.15)	
	WASHTENAW	RURAL	89 (0.20)	216 (0.48)	
		URBAN	7 (0.02)	138 (0.31)	
	OAKLAND	RURAL	35 (0.08)	151 (0.34)	
		URBAN	24 (0.05)	240 (0.53)	
	TOTAL	RURAL	285 (0.21)	572 (0.42)	
		URBAN	46 (0.03)	447 (0.33)	
NON-DVCs	MONROE	RURAL	296 (0.66)	26 (0.06)	
		URBAN	103 (0.23)	25 (0.06)	
	WASHTENAW	RURAL	182 (0.40)	58 (0.13)	
		URBAN	139 (0.31)	71 (0.16)	
	OAKLAND	RURAL	60 (0.13)	10 (0.02)	
		URBAN	280 (0.62)	100 (0.22)	
	TOTAL	RURAL	538 (0.40)	94 (0.07)	
		URBAN	522 (0.39)	196 (0.15)	

Table 10. Relative risk and 95% confidence intervals for road class by traffic volume between DVCs and non-DVC locations in Monroe, Washtenaw, and Oakland counties, Michigan, 1999–2001.

COUNTY	ROAD CLASS	TRAFFIC VOLUME ≤ 120 vehicles/hr	TRAFFIC VOLUME > 120 vehicles/hr
MONROE	RURAL	0.54 (0.47–0.63) *	7.88 (5.36–11.61) *
	URBAN	0.15 (0.09–0.25) *	2.76 (1.78–4.28) *
WASHTENAW	RURAL	0.49 (0.39–0.61) *	3.72 (2.88–4.82) *
	URBAN	0.05 (0.02–0.11) *	1.94 (1.51–2.51) *
OAKLAND	RURAL	0.58 (0.39–0.87) *	15.10 (8.07–28.25) *
	URBAN	0.09 (0.06–0.13) *	2.40 (1.98–2.91) *
TOTAL	RURAL	0.53 (0.43–0.65) *	6.09 (4.27–8.67) *
	URBAN	0.09 (0.05–0.15) *	2.28 (1.76–2.96) *

Table 11. Number of lanes by speed limit between DVCs and non-DVC locations in Monroe, Washtenaw, and Oakland counties, Michigan, 1999–2001.

LOCATION	COUNTY	NUMBER OF LANES	SPEED LIMIT Low	Medium	High	CHI SQUARE (P,df)
DVCs	MONROE	≤ 2 Lanes	42 (0.09)	261 (0.58)	0 (0.00)	
		> 2 Lanes	7 (0.02)	18 (0.04)	122 (0.27)	
	WASHTENAW	≤ 2 Lanes	86 (0.19)	212 (0.47)	0 (0.00)	
		> 2 Lanes	15 (0.03)	67 (0.15)	70 (0.16)	894
	OAKLAND	≤ 2 Lanes	116 (0.26)	236 (0.52)	0 (0.00)	(<0.001,12)
		> 2 Lanes	22 (0.05)	42 (0.09)	34 (0.08)	
	TOTAL	≤ 2 Lanes	244 (0.18)	709 (0.53)	0 (0.00)	
		> 2 Lanes	44 (0.03)	127 (0.09)	226 (0.17)	
NON-DVCs	MONROE	≤ 2 Lanes	171 (0.38)	254 (0.56)	0 (0.00)	
		> 2 Lanes	5 (0.01)	6 (0.01)	14 (0.03)	
	WASHTENAW	≤ 2 Lanes	214 (0.48)	191 (0.42)	0 (0.00)	
		> 2 Lanes	18 (0.04)	2 (0.00)	25 (0.06)	
	OAKLAND	≤ 2 Lanes	367 (0.82)	29 (0.06)	0 (0.00)	
		> 2 Lanes	37 (0.08)	3 (0.01)	14 (0.03)	
	TOTAL	≤ 2 Lanes	752 (0.56)	474 (0.35)	0 (0.00)	
		> 2 Lanes	60 (0.04)	11 (0.01)	53 (0.04)	

Table 12. Relative risk and 95% confidence intervals for number of lanes by speed limit between DVCs and non-DVC locations in Monroe, Washtenaw, and Oakland counties, Michigan, 1999–2001.

COUNTY	NUMBER OF LANES	SPEED LIMIT Low	Medium	High
MONROE	≤ 2 Lanes	0.25 (0.18–0.34) *	1.03 (0.92–1.15)	NA
	> 2 Lanes	1.40 (0.45–4.38)	3.00 (1.20–7.49) *	8.71 (5.09–14.92) *
WASHTENAW	≤ 2 Lanes	0.40 (0.32–0.50) *	1.11 (0.96–1.28)	NA
	> 2 Lanes	0.83 (0.43–1.63)	33.50 (8.26–135.90) *	2.80 (1.81–4.34) *
OAKLAND	≤ 2 Lanes	0.32 (0.27–0.37) *	8.14 (5.60–11.70) *	NA
	> 2 Lanes	0.59 (0.36–0.99)	14.00 (4.37–44.84) *	2.43 (1.32–4.46) *
TOTAL	≤ 2 Lanes	0.32 (0.26–0.40) *	1.50 (1.28–1.74) *	NA
	> 2 Lanes	0.73 (0.38–1.42)	11.55 (4.00–33.29) *	4.26 (2.58–7.04) *

Table 13. Number of lanes by traffic volume between DVCs and non-DVC locations in Monroe, Washtenaw, and Oakland counties, Michigan, 1999–2001.

LOCATION	COUNTY	NUMBER OF LANES	TRAFFIC VOLUME ≤ 120 vehicles/hr	TRAFFIC VOLUME > 120 vehicles/hr	CHI SQUARE (P,df)
DVCs	MONROE	≤ 2 Lanes	172 (0.38)	131 (0.29)	312 (<0.001,7)
		> 2 Lanes	4 (0.01)	143 (0.32)	
	WASHTENAW	≤ 2 Lanes	93 (0.21)	205 (0.46)	
		> 2 Lanes	3 (0.01)	149 (0.33)	
	OAKLAND	≤ 2 Lanes	56 (0.12)	296 (0.66)	
		> 2 Lanes	3 (0.01)	95 (0.21)	
	TOTAL	≤ 2 Lanes	321 (0.24)	632 (0.47)	
		> 2 Lanes	10 (0.01)	387 (0.29)	
NON-DVCs	MONROE	≤ 2 Lanes	396 (0.88)	29 (0.06)	
		> 2 Lanes	3 (0.01)	22 (0.05)	
	WASHTENAW	≤ 2 Lanes	319 (0.71)	86 (0.19)	
		> 2 Lanes	2 (0.00)	43 (0.10)	
	OAKLAND	≤ 2 Lanes	335 (0.74)	61 (0.14)	
		> 2 Lanes	5 (0.01)	49 (0.11)	
	TOTAL	≤ 2 Lanes	1050 (0.78)	176 (0.13)	
		> 2 Lanes	10 (0.01)	114 (0.08)	

Table 14. Relative risk and 95% confidence intervals for number of lanes by traffic volume between DVCs and non-DVC locations in Monroe, Washtenaw, and Oakland counties, Michigan, 1999–2001.

COUNTY	NUMBER OF LANES	TRAFFIC VOLUME ≤ 120 vehicles/hr	TRAFFIC VOLUME > 120 vehicles/hr
MONROE	≤ 2 Lanes	0.43 (0.38–0.49) *	4.52 (3.09–6.61) *
	> 2 Lanes	1.33 (0.30–5.92)	6.50 (4.23–9.99) *
WASHTENAW	≤ 2 Lanes	0.29 (0.24–0.35) *	2.38 (1.92–2.96) *
	> 2 Lanes	1.50 (0.25–8.93)	3.47 (2.53–4.74) *
OAKLAND	≤ 2 Lanes	0.17 (0.13–0.21) *	4.85 (3.81–6.19) *
	> 2 Lanes	0.60 (0.14–2.50)	1.94 (1.41–2.67) *
TOTAL	≤ 2 Lanes	0.31 (0.26–0.36) *	3.59 (2.77–4.65) *
	> 2 Lanes	1.00 (0.22–4.54)	3.39 (2.42–4.76) *

Table 15. Traffic volume by speed limit between DVCs and non-DVC locations in Monroe, Washtenaw, and Oakland counties, Michigan, 1999–2001.

LOCATION	COUNTY	TRAFFIC VOLUME	SPEED LIMIT			CHI SQUARE (P,df)
			Low	Medium	High	
DVCs	MONROE	≤ 120 vehicles/hr	11 (0.02)	164 (0.36)	1 (0.00)	399 (<0.001,12)
		> 120 vehicles/hr	38 (0.08)	115 (0.26)	121 (0.27)	
	WASHTENAW	≤ 120 vehicles/hr	12 (0.03)	84 (0.19)	0 (0.00)	
		> 120 vehicles/hr	89 (0.20)	195 (0.43)	70 (0.16)	
	OAKLAND	≤ 120 vehicles/hr	19 (0.04)	40 (0.09)	0 (0.00)	
		> 120 vehicles/hr	119 (0.26)	238 (0.53)	34 (0.08)	
	TOTAL	≤ 120 vehicles/hr	42 (0.03)	288 (0.21)	1 (0.00)	
		> 120 vehicles/hr	246 (0.18)	548 (0.41)	225 (0.17)	
NON-DVCs	MONROE	≤ 120 vehicles/hr	161 (0.36)	237 (0.53)	1 (0.00)	
		> 120 vehicles/hr	15 (0.03)	23 (0.05)	13 (0.03)	
	WASHTENAW	≤ 120 vehicles/hr	176 (0.39)	145 (0.32)	0 (0.00)	
		> 120 vehicles/hr	56 (0.12)	48 (0.11)	25 (0.06)	
	OAKLAND	≤ 120 vehicles/hr	319 (0.71)	21 (0.05)	0 (0.00)	
		> 120 vehicles/hr	85 (0.19)	11 (0.02)	14 (0.03)	
	TOTAL	≤ 120 vehicles/hr	656 (0.49)	403 (0.30)	1 (0.00)	
		> 120 vehicles/hr	156 (0.12)	82 (0.06)	52 (0.04)	

Table 16. Relative risk and 95% confidence intervals for traffic volume by speed limit between DVCs and non-DVC locations in Monroe, Washtenaw, and Oakland counties, Michigan, 1999–2001.

COUNTY	TRAFFIC VOLUME	SPEED LIMIT		
		Low	Medium	High
MONROE	≤ 120 vehicles/hr	0.07 (0.04–0.12) *	0.69 (0.60–0.80) *	1.00 (0.06–15.94)
	> 120 vehicles/hr	2.53 (1.41–4.54) *	5.00 (3.26–7.67) *	9.31 (5.33–16.24) *
WASHTENAW	≤ 120 vehicles/hr	0.07 (0.04–0.12) *	0.58 (0.46–0.73) *	NA
	> 120 vehicles/hr	1.59 (1.17–2.16) *	4.06 (3.05–5.42) *	2.80 (1.81–4.34) *
OAKLAND	≤ 120 vehicles/hr	0.06 (0.04–0.09) *	1.90 (1.14–3.18) *	NA
	> 120 vehicles/hr	1.40 (1.09–1.79) *	21.64 (11.99–39.04) *	2.43 (1.32–4.46) *
TOTAL	≤ 120 vehicles/hr	0.06 (0.04–0.11) *	0.71 (0.57–0.90) *	1.00 (0.01–121.40)
	> 120 vehicles/hr	1.58 (1.14–2.18) *	6.68 (4.57–9.77) *	4.33 (2.61–7.17) *

Table 17. Road class by land cover categories between DVCs and non-DVC locations in Monroe, Washtenaw, and Oakland counties, Michigan, 1999–2001.

LOCATION	COUNTY	ROAD CLASS	High Intensity Urban	Low Intensity Urban	Agricultural	Upland Deciduous	Upland Openland	Miscellaneous
DVCs	MONROE	RURAL	31 (0.07)	1 (0.00)	305 (0.68)	18 (0.04)	6 (0.01)	4 (0.01)
		URBAN	11 (0.02)	5 (0.01)	56 (0.12)	4 (0.01)	6 (0.01)	2 (0.00)
	WASHTENAW	RURAL	16 (0.04)	1 (0.00)	218 (0.48)	24 (0.05)	32 (0.07)	14 (0.03)
		URBAN	37 (0.08)	4 (0.01)	49 (0.11)	15 (0.03)	29 (0.06)	7 (0.02)
	OAKLAND	RURAL	6 (0.01)	0 (0.00)	98 (0.22)	23 (0.05)	39 (0.09)	16 (0.04)
		URBAN	63 (0.14)	15 (0.03)	11 (0.02)	48 (0.11)	107 (0.24)	18 (0.04)
	TOTAL	RURAL	53 (0.04)	2 (0.00)	621 (0.46)	65 (0.05)	77 (0.05)	34 (0.03)
		URBAN	111 (0.08)	24 (0.02)	116 (0.09)	67 (0.05)	142 (0.11)	27 (0.02)
NON-DVCs	MONROE	RURAL	20 (0.04)	2 (0.00)	280 (0.62)	7 (0.02)	7 (0.02)	3 (0.01)
		URBAN	60 (0.13)	11 (0.02)	39 (0.09)	6 (0.01)	5 (0.01)	4 (0.01)
	WASHTENAW	RURAL	6 (0.01)	2 (0.00)	168 (0.37)	28 (0.06)	19 (0.04)	13 (0.03)
		URBAN	86 (0.19)	34 (0.08)	28 (0.06)	12 (0.03)	36 (0.08)	12 (0.03)
	OAKLAND	RURAL	0 (0.00)	0 (0.00)	31 (0.07)	17 (0.04)	14 (0.03)	5 (0.01)
		URBAN	154 (0.34)	48 (0.11)	3 (0.01)	40 (0.09)	80 (0.18)	42 (0.09)
	TOTAL	RURAL	26 (0.02)	4 (0.00)	479 (0.35)	52 (0.04)	40 (0.03)	21 (0.02)
		URBAN	300 (0.22)	93 (0.07)	70 (0.05)	58 (0.04)	121 (0.09)	58 (0.04)

Table 18. Relative risk and 95% confidence intervals for road class by land cover categories between DVCs and non-DVC locations in Monroe, Washtenaw, and Oakland counties, Michigan, 1999–2001.

COUNTY	ROAD CLASS	High Intensity Urban	Low Intensity Urban	Agricultural	Upland Deciduous	Upland Openland	Miscellaneous
MONROE	RURAL	1.55 (0.90–2.68)	0.50 (0.05–5.49)	1.08 (0.99–1.20)	2.57 (1.08–6.10) *	0.86 (0.29–2.53)	1.33 (0.30–5.92)
	URBAN	0.18 (0.10–0.34) *	0.45 (0.16–1.30)	1.44 (0.97–2.12)	0.67 (0.19–2.35)	1.20 (0.37–3.90)	0.50 (0.09–2.72)
WASHTENAW	RURAL	2.66 (1.05–6.75) *	0.50 (0.05–6.75)	1.29 (1.11–1.51) *	0.86 (0.50–1.46)	1.68 (0.97–2.93)	1.08 (0.51–2.27)
	URBAN	0.43 (0.30–0.62) *	0.11 (0.04–0.33) *	1.75 (1.12–2.73) *	1.25 (0.59–2.64)	0.81 (0.50–1.29)	0.58 (0.23–1.47)
OAKLAND	RURAL	NA	NA	3.16 (2.16–4.63) *	1.35 (0.73–2.50)	2.79 (1.53–5.06) *	3.20 (1.18–8.66) *
	URBAN	0.40 (0.31–0.53) *	0.31 (0.18–0.55) *	3.67 (1.03–13.06) *	1.20 (0.81–1.79)	1.34 (1.03–1.73) *	0.43 (0.25–0.73) *
TOTAL	RURAL	2.03 (0.91–4.55)	0.5 (0.03–9.43)	1.30 (1.10–1.52) *	1.25 (0.67–2.32)	1.93 (1.01–3.68) *	1.62 (0.64–4.12)
	URBAN	0.37 (0.26–0.53) *	0.25 (0.12–0.56) *	1.66 (1.01–2.72) *	1.16 (0.64–2.09)	1.17 (0.79–1.75)	0.47 (0.21–1.02)

Table 19. Number of lanes by land cover categories between DVCs and non-DVC locations in Monroe, Washtenaw, and Oakland counties, Michigan, 1999–2001.

LOCATION	COUNTY	NUMBER OF LANES	High Intensity Urban	Low Intensity Urban	Agricultural	Upland Deciduous	Upland Openland	Miscellaneous
DVCs	MONROE	≤ 2 Lanes	9 (0.02)	5 (0.01)	258 (0.57)	19 (0.04)	11 (0.02)	1 (0.00)
		> 2 Lanes	33 (0.07)	1 (0.00)	103 (0.23)	3 (0.01)	1 (0.00)	5 (0.01)
	WASHTENAW	≤ 2 Lanes	7 (0.02)	4 (0.01)	204 (0.45)	30 (0.07)	35 (0.08)	16 (0.04)
		> 2 Lanes	46 (0.10)	1 (0.00)	63 (0.14)	9 (0.02)	26 (0.06)	5 (0.01)
	OAKLAND	≤ 2 Lanes	28 (0.06)	12 (0.03)	98 (0.22)	62 (0.14)	118 (0.26)	28 (0.06)
		> 2 Lanes	41 (0.09)	3 (0.01)	11 (0.02)	9 (0.02)	28 (0.06)	6 (0.01)
	TOTAL	≤ 2 Lanes	57 (0.04)	12 (0.01)	473 (0.35)	58 (0.04)	74 (0.05)	23 (0.02)
		> 2 Lanes	107 (0.08)	14 (0.01)	264 (0.20)	74 (0.05)	145 (0.11)	38 (0.03)
NON-DVCs	MONROE	≤ 2 Lanes	71 (0.16)	12 (0.03)	306 (0.68)	11 (0.02)	12 (0.03)	0 (0.00)
		> 2 Lanes	9 (0.02)	1 (0.00)	13 (0.03)	2 (0.00)	0 (0.00)	7 (0.02)
	WASHTENAW	≤ 2 Lanes	78 (0.17)	32 (0.07)	186 (0.41)	35 (0.08)	44 (0.10)	25 (0.06)
		> 2 Lanes	14 (0.03)	4 (0.01)	10 (0.02)	5 (0.01)	11 (0.02)	0 (0.00)
	OAKLAND	≤ 2 Lanes	117 (0.26)	42 (0.09)	34 (0.08)	56 (0.12)	85 (0.19)	46 (0.10)
		> 2 Lanes	37 (0.08)	6 (0.01)	0 (0.00)	1 (0.00)	9 (0.02)	1 (0.00)
	TOTAL	≤ 2 Lanes	266 (0.20)	86 (0.06)	526 (0.39)	102 (0.08)	141 (0.10)	71 (0.05)
		> 2 Lanes	60 (0.04)	11 (0.01)	23 (0.02)	8 (0.01)	20 (0.01)	8 (0.01)

Table 20. Relative risk and 95% confidence intervals for number of lanes by land cover categories between DVCs and non-DVC locations in Monroe, Washtenaw, and Oakland counties, Michigan, 1999–2001.

COUNTY	LANES	High Intensity Urban	Low Intensity Urban	Agricultural	Upland Deciduous	Upland Openland	Miscellaneous
MONROE	≤ 2 Lanes	0.13 (0.06–0.25) *	0.42 (0.15–1.17)	0.84 (0.76–0.93) *	1.73 (0.83–3.59)	0.92 (0.41–2.06)	NA
	> 2 Lanes	3.67 (1.78–7.57) *	1.00 (0.06–15.94)	7.92 (4.52–13.90) *	1.50 (0.25–8.93)	NA	0.71 (0.23–2.23)
WASHTENAW	≤ 2 Lanes	0.09 (0.04–0.19) *	0.13 (0.04–0.35) *	1.10 (0.94–1.27)	0.86 (0.54–1.37)	0.80 (0.52–1.22)	0.64 (0.35–1.18)
	> 2 Lanes	3.29 (1.83–5.89) *	0.25 (0.03–2.23)	6.30 (3.27–12.12) *	1.80 (0.61–5.33)	2.36 (1.18–4.73) *	NA
OAKLAND	≤ 2 Lanes	0.24 (0.16–0.35) *	0.29 (0.15–0.54) *	2.88 (2.00–4.16) *	1.11 (0.79–1.55)	1.39 (1.09–1.78) *	0.61 (0.39–0.96) *
	> 2 Lanes	1.11 (0.72–1.69)	0.50 (0.13–1.99)	NA	9.00 (1.14–70.75) *	3.11 (1.48–6.52) *	6.00 (0.73–49.64)
TOTAL	≤ 2 Lanes	0.21 (0.13–0.35) *	0.14 (0.05–0.39) *	0.90 (0.76–1.07)	0.57 (0.33–0.98) *	0.52 (0.33–0.84) *	0.32 (0.14–0.72) *
	> 2 Lanes	1.78 (1.05–3.03) *	1.27 (0.33–4.97)	11.48 (5.55–23.73) *	9.25 (3.26–32.50) *	7.25 (3.26–16.12) *	4.75 (1.28–17.68) *

Table 21. Speed limit by land cover categories between DVCs and non-DVC locations in Monroe, Washtenaw, and Oakland counties, Michigan, 1999–2001.

LOCATION	COUNTY	SPEED LIMIT	High Intensity Urban	Low Intensity Urban	Agricultural	Upland Deciduous	Upland Openland	Miscellaneous
DVCs	MONROE	Low	7 (0.02)	4 (0.01)	30 (0.07)	3 (0.01)	5 (0.01)	0 (0.00)
		Medium	6 (0.01)	1 (0.00)	246 (0.55)	17 (0.04)	7 (0.02)	2 (0.00)
		High	29 (0.06)	1 (0.00)	85 (0.19)	2 (0.00)	0 (0.00)	4 (0.01)
	WASHTENAW	Low	9 (0.02)	5 (0.01)	48 (0.11)	15 (0.03)	19 (0.04)	3 (0.01)
		Medium	11 (0.02)	0 (0.00)	202 (0.45)	22 (0.05)	30 (0.07)	14 (0.03)
		High	33 (0.07)	0 (0.00)	17 (0.04)	2 (0.00)	12 (0.03)	4 (0.01)
	OAKLAND	Low	25 (0.06)	9 (0.02)	7 (0.02)	24 (0.05)	62 (0.14)	9 (0.02)
		Medium	32 (0.07)	6 (0.01)	97 (0.22)	45 (0.10)	73 (0.16)	21 (0.05)
		High	12 (0.03)	0 (0.00)	5 (0.01)	2 (0.00)	11 (0.02)	4 (0.01)
	TOTAL	Low	41 (0.03)	18 (0.01)	85 (0.06)	42 (0.03)	86 (0.06)	12 (0.01)
		Medium	49 (0.04)	7 (0.01)	545 (0.40)	84 (0.06)	110 (0.08)	37 (0.03)
		High	74 (0.05)	1 (0.00)	107 (0.08)	6 (0.00)	23 (0.02)	12 (0.01)
NON-DVCs	MONROE	Low	68 (0.15)	9 (0.02)	76 (0.17)	7 (0.02)	7 (0.02)	4 (0.01)
		Medium	10 (0.02)	4 (0.01)	233 (0.52)	4 (0.01)	5 (0.01)	3 (0.01)
		High	2 (0.00)	0 (0.00)	10 (0.02)	2 (0.00)	0 (0.00)	0 (0.00)
	WASHTENAW	Low	75 (0.17)	36 (0.08)	46 (0.10)	20 (0.04)	36 (0.08)	15 (0.03)
		Medium	13 (0.03)	0 (0.00)	140 (0.31)	15 (0.03)	13 (0.03)	10 (0.02)
		High	4 (0.01)	0 (0.00)	10 (0.02)	5 (0.01)	6 (0.01)	0 (0.00)
	OAKLAND	Low	141 (0.31)	46 (0.10)	21 (0.05)	49 (0.11)	86 (0.19)	45 (0.10)
		Medium	3 (0.01)	2 (0.00)	13 (0.03)	7 (0.02)	5 (0.01)	2 (0.00)
		High	10 (0.02)	0 (0.00)	0 (0.00)	1 (0.00)	3 (0.01)	0 (0.00)
	TOTAL	Low	284 (0.21)	91 (0.07)	143 (0.11)	76 (0.06)	129 (0.09)	64 (0.05)
		Medium	26 (0.02)	6 (0.00)	386 (0.29)	26 (0.02)	23 (0.01)	15 (0.01)
		High	16 (0.01)	0 (0.00)	20 (0.01)	8 (0.01)	9 (0.01)	0 (0.00)

Table 22. Relative risk and 95% confidence intervals for speed limit by land cover categories between DVCs and non-DVC locations in Monroe, Washtenaw, and Oakland counties, Michigan, 1999–2001.

COUNTY	SPEED LIMIT	High Intensity Urban	Low Intensity Urban	Agricultural	Upland Deciduous	Upland Openland	Miscellaneous
MONROE	Low	0.10 (0.05–0.22) *	0.44 (0.14–1.43)	0.39 (0.26–0.59) *	0.43 (0.11–1.65)	0.71 (0.23–2.23)	0.00 (NA)
	Medium	0.60 (0.22–1.64)	0.25 (0.03–2.23)	1.06 (0.93–1.19)	4.25 (1.44–12.53) *	1.40 (0.45–4.38)	0.67 (0.11–3.97)
	High	14.50 (3.48–60.41) *	NA	8.50 (4.47–16.15) *	1.00 (0.14–7.07)	NA	NA
WASHTENAW	Low	0.12 (0.06–0.24) *	0.14 (0.06–0.35) *	1.04 (0.71–1.53)	0.75 (0.39–1.45)	0.53 (0.31–0.91) *	0.20 (0.06–0.69) *
	Medium	0.85 (0.38–1.87)	NA	1.44 (1.22–1.71) *	1.47 (0.77–2.79)	2.31 (1.22–4.37) *	1.40 (0.63–3.12)
	High	8.25 (2.95–23.10) *	NA	1.70 (0.79–3.67)	0.40 (0.08–2.05)	2.00 (0.76–5.28)	NA
OAKLAND	Low	0.18 (0.12–0.27) *	0.20 (0.10–0.39) *	0.33 (0.14–0.78) *	0.49 (0.31–0.78) *	0.72 (0.53–0.97) *	0.20 (0.10–0.40) *
	Medium	10.67 (3.29–34.58) *	3.00 (0.61–14.78)	7.46 (4.25–13.11) *	6.43 (2.93–14.10) *	14.60 (5.96–35.79) *	10.50 (2.48–44.52) *
	High	1.20 (0.52–2.75)	NA	NA	2.00 (0.18–21.98)	3.67 (1.03–13.06) *	NA
TOTAL	Low	0.14 (0.08–0.25) *	0.20 (0.08–0.47) *	0.59 (0.38–0.93) *	0.55 (0.29–1.05)	0.67 (0.42–1.05)	0.19 (0.06–0.54) *
	Medium	1.88 (0.84–4.25)	1.17 (0.18–7.68)	1.41 (1.17–1.70) *	3.23 (1.53–6.84) *	4.78 (2.22–10.30) *	2.47 (0.88–6.92)
	High	4.63 (1.83–11.68) *	NA	5.35 (2.36–12.11) *	0.75 (0.12–4.67)	2.56 (0.68–9.65)	NA

Table 23. Traffic volume by land cover categories between DVCs and non-DVC locations in Monroe, Washtenaw, and Oakland counties, Michigan, 1999–2001.

LOCATION	COUNTY	TRAFFIC VOLUME	High Intensity Urban	Low Intensity Urban	Agricultural	Upland Deciduous	Upland Openland	Miscellaneous
DVCs	MONROE	≤ 120 vehicles/hr	3 (0.01)	1 (0.00)	152 (0.34)	13 (0.03)	5 (0.01)	2 (0.00)
		> 120 vehicles/hr	39 (0.09)	5 (0.01)	209 (0.46)	9 (0.02)	7 (0.02)	4 (0.01)
	WASHTENAW	≤ 120 vehicles/hr	2 (0.00)	1 (0.00)	70 (0.16)	6 (0.01)	10 (0.02)	7 (0.02)
		> 120 vehicles/hr	51 (0.11)	4 (0.01)	197 (0.44)	33 (0.07)	51 (0.11)	14 (0.03)
	OAKLAND	≤ 120 vehicles/hr	4 (0.01)	0 (0.00)	23 (0.05)	6 (0.01)	18 (0.06)	8 (0.02)
		> 120 vehicles/hr	65 (0.14)	15 (0.03)	86 (0.19)	65 (0.14)	128 (0.28)	26 (0.06)
	TOTAL	≤ 120 vehicles/hr	9 (0.01)	2 (0.00)	245 (0.18)	25 (0.02)	33 (0.02)	17 (0.01)
		> 120 vehicles/hr	155 (0.11)	24 (0.02)	492 (0.36)	107 (0.08)	186 (0.14)	44 (0.03)
NON-DVCs	MONROE	≤ 120 vehicles/hr	62 (0.14)	11 (0.03)	294 (0.65)	10 (0.02)	10 (0.02)	6 (0.01)
		> 120 vehicles/hr	18 (0.04)	2 (0.00)	25 (0.06)	3 (0.01)	2 (0.00)	1 (0.00)
	WASHTENAW	≤ 120 vehicles/hr	49 (0.11)	29 (0.06)	144 (0.32)	34 (0.07)	39 (0.09)	22 (0.05)
		> 120 vehicles/hr	43 (0.10)	7 (0.02)	52 (0.12)	6 (0.01)	16 (0.04)	3 (0.01)
	OAKLAND	≤ 120 vehicles/hr	97 (0.22)	41 (0.09)	29 (0.06)	51 (0.11)	68 (0.15)	38 (0.08)
		> 120 vehicles/hr	57 (0.13)	7 (0.02)	5 (0.01)	6 (0.01)	26 (0.06)	9 (0.02)
	TOTAL	≤ 120 vehicles/hr	208 (0.15)	81 (0.06)	467 (0.35)	95 (0.07)	117 (0.09)	66 (0.05)
		> 120 vehicles/hr	118 (0.09)	16 (0.01)	82 (0.06)	15 (0.01)	44 (0.03)	13 (0.01)

Table 24. Relative risk and 95% confidence intervals for traffic volume by land cover categories between DVCs and non-DVC locations in Monroe, Washtenaw, and Oakland counties, Michigan, 1999–2001.

COUNTY	TRAFFIC VOLUME	High Intensity Urban	Low Intensity Urban	Agricultural	Upland Deciduous	Upland Openland	Miscellaneous
MONROE	≤ 120 vehicles/hr	0.05 (0.02–0.15) *	0.09 (0.01–0.70)	0.52 (0.45–0.60) *	1.30 (0.58–2.93)	0.50 (0.17–1.45)	0.33 (0.07–1.64)
	> 120 vehicles/hr	2.17 (1.26–3.73) *	2.50 (0.49–12.82)	8.36 (5.64–12.39) *	3.00 (0.82–11.01)	3.50 (0.73–16.76)	4.00 (0.45–35.65)
WASHTENAW	≤ 120 vehicles/hr	0.04 (0.01–0.17) *	0.03 (0.00–0.25) *	0.49 (0.38–0.63) *	0.18 (0.13–0.42) *	0.26 (0.13–0.51) *	0.32 (0.14–0.74) *
	> 120 vehicles/hr	1.19 (0.81–1.74)	0.57 (0.17–1.94)	3.79 (2.87–4.99) *	5.50 (1.85–13.00) *	3.19 (1.85–5.50) *	4.67 (1.35–16.13) *
OAKLAND	≤ 120 vehicles/hr	0.04 (0.02–0.11) *	0.00 (NA)	0.79 (0.47–1.35)	0.12 (0.16–0.27) *	0.26 (0.16–0.44) *	0.21 (0.10–0.45) *
	> 120 vehicles/hr	1.14 (0.82–1.59)	2.14 (0.88–5.21)	17.20 (7.05–41.97) *	10.83 (3.30–24.75) *	4.92 (3.30–7.35) *	2.89 (1.37–6.10) *
TOTAL	≤ 120 vehicles/hr	0.04 (0.01–0.14) *	0.02 (0.00–0.28) *	0.52 (0.42–0.66) *	0.26 (0.12–0.56) *	0.28 (0.15–0.54) *	0.26 (0.10–0.64) *
	> 120 vehicles/hr	1.31 (0.89–1.95)	1.50 (0.51–4.45)	6.00 (4.09–8.80) *	7.13 (2.82–18.02) *	4.23 (2.43–7.36) *	3.38 (1.17–9.81) *

Table 25. Road class by habitat suitability index categories between DVCs and non-DVC locations in Monroe, Washtenaw, and Oakland counties, Michigan, 1999–2001.

LOCATION	COUNTY	ROAD CLASS	HABITAT SUITABILITY INDEX			
			Very Low	Low	Medium	High
DVCS	MONROE	RURAL	26 (0.06)	152 (0.34)	181 (0.40)	7 (0.02)
		URBAN	6 (0.01)	52 (0.11)	24 (0.05)	2 (0.00)
	WASHTENAW	RURAL	1 (0.00)	105 (0.23)	187 (0.42)	12 (0.03)
		URBAN	1 (0.00)	48 (0.11)	88 (0.20)	8 (0.02)
	OAKLAND	RURAL	2 (0.00)	60 (0.13)	97 (0.22)	27 (0.06)
		URBAN	1 (0.00)	26 (0.06)	173 (0.38)	64 (0.14)
	TOTAL	RURAL	29 (0.02)	317 (0.23)	465 (0.34)	46 (0.03)
		URBAN	8 (0.01)	126 (0.09)	285 (0.21)	74 (0.05)
NON-DVCs	MONROE	RURAL	14 (0.03)	126 (0.28)	159 (0.35)	23 (0.05)
		URBAN	16 (0.04)	70 (0.16)	40 (0.09)	2 (0.00)
	WASHTENAW	RURAL	3 (0.01)	90 (0.20)	136 (0.30)	11 (0.02)
		URBAN	4 (0.01)	93 (0.21)	96 (0.21)	17 (0.04)
	OAKLAND	RURAL	1 (0.00)	13 (0.03)	37 (0.08)	19 (0.04)
		URBAN	20 (0.04)	119 (0.26)	171 (0.38)	70 (0.16)
	TOTAL	RURAL	18 (0.01)	229 (0.17)	332 (0.25)	53 (0.04)
		URBAN	40 (0.03)	282 (0.21)	307 (0.23)	89 (0.07)

Table 26. Relative risk and 95% confidence intervals for road class by habitat suitability index categories between DVCs and non-DVC locations in Monroe, Washtenaw, and Oakland counties, Michigan, 1999–2001.

COUNTY	ROAD CLASS	HABITAT SUITABILITY INDEX			
		Very Low	Low	Medium	High
MONROE	RURAL	1.86 (0.98–3.51)	1.21 (0.99–1.47)	1.14 (0.96–1.35)	0.30 (0.13–0.70) *
	URBAN	0.38 (0.15–1.95)	0.74 (0.53–1.04)	0.60 (0.37–0.98) *	1.00 (0.14–7.07)
WASHTENAW	RURAL	0.33 (0.03–3.19)	1.17 (0.91–1.50)	1.38 (1.15–1.64) *	1.09 (0.49–2.45)
	URBAN	0.25 (0.03–2.23)	0.52 (0.37–0.71) *	0.92 (0.71–1.19)	0.47 (0.21–1.08)
OAKLAND	RURAL	2.00 (0.18–21.98)	4.62 (2.57–8.29) *	2.62 (1.84–3.74) *	1.42 (0.80–2.52)
	URBAN	0.05 (0.01–0.37) *	0.22 (0.15–0.33) *	1.01 (0.86–1.19)	0.91 (0.67–1.25)
TOTAL	RURAL	4.83 (2.03–11.53) *	1.38 (1.06–1.80) *	1.40 (1.14–1.72) *	0.87 (0.44–1.70)
	URBAN	0.60 (0.25–1.43)	0.45 (0.32–0.63) *	0.93 (0.73–1.19)	0.83 (0.50–1.40)

Table 27. Number of lanes by habitat suitability index categories between DVCs and non-DVC locations in Monroe, Washtenaw, and Oakland counties, Michigan, 1999–2001.

LOCATION	COUNTY	NUMBER OF LANES	HABITAT SUITABILITY INDEX			
			Very Low	Low	Medium	High
DVCS	MONROE	≤ 2 Lanes	10 (0.02)	121 (0.27)	163 (0.36)	9 (0.02)
		> 2 Lanes	22 (0.05)	83 (0.18)	42 (0.09)	0 (0.00)
	WASHTENAW	≤ 2 Lanes	1 (0.00)	85 (0.19)	196 (0.44)	16 (0.04)
		> 2 Lanes	1 (0.00)	68 (0.15)	79 (0.18)	4 (0.01)
	OAKLAND	≤ 2 Lanes	2 (0.00)	61 (0.14)	207 (0.46)	82 (0.18)
		> 2 Lanes	1 (0.00)	25 (0.06)	63 (0.14)	9 (0.02)
	TOTAL	≤ 2 Lanes	13 (0.01)	267 (0.20)	566 (0.42)	107 (0.08)
		> 2 Lanes	24 (0.02)	176 (0.13)	184 (0.14)	13 (0.01)
NON-DVCs	MONROE	≤ 2 Lanes	30 (0.07)	179 (0.40)	191 (0.42)	25 (0.06)
		> 2 Lanes	0 (0.00)	17 (0.04)	8 (0.02)	0 (0.00)
	WASHTENAW	≤ 2 Lanes	6 (0.01)	162 (0.36)	209 (0.46)	28 (0.06)
		> 2 Lanes	1 (0.00)	21 (0.05)	23 (0.05)	0 (0.00)
	OAKLAND	≤ 2 Lanes	13 (0.03)	107 (0.24)	190 (0.42)	86 (0.19)
		> 2 Lanes	8 (0.02)	25 (0.06)	18 (0.04)	3 (0.01)
	TOTAL	≤ 2 Lanes	49 (0.04)	448 (0.33)	590 (0.44)	139 (0.10)
		> 2 Lanes	9 (0.01)	63 (0.05)	49 (0.04)	3 (0.00)

Table 28. Relative risk and 95% confidence intervals for number of lanes by habitat suitability index categories between DVCs and non-DVC locations in Monroe, Washtenaw, and Oakland counties, Michigan, 1999–2001.

COUNTY	NUMBER OF LANES	HABITAT SUITABILITY INDEX			
		Very Low	Low	Medium	High
MONROE	≤ 2 Lanes	0.33 (0.16–0.67) *	0.68 (0.56–0.82) *	0.85 (0.72–1.00)	0.36 (0.17–0.76) *
	> 2 Lanes	NA	4.88 (2.95–8.09) *	5.25 (2.49–11.06) *	NA
WASHTENAW	≤ 2 Lanes	0.17 (0.02–1.38)	0.52 (0.42–0.66) *	0.94 (0.81–1.08)	0.57 (0.31–1.04)
	> 2 Lanes	1.00 (0.06–15.94)	3.24 (2.02–5.19) *	3.43 (2.20–5.36) *	NA
OAKLAND	≤ 2 Lanes	0.15 (0.03–0.68) *	0.57 (0.43–0.76) *	1.09 (0.94–1.26)	0.95 (0.73–1.25)
	> 2 Lanes	0.13 (0.02–1.00)	1.00 (0.58–1.71)	3.50 (2.11–5.81) *	3.00 (0.82–11.01)
TOTAL	≤ 2 Lanes	0.27 (0.09–0.76) *	0.60 (0.47–0.75) *	0.96 (0.82–1.12)	0.77 (0.51–1.17)
	> 2 Lanes	2.67 (0.71–9.99)	2.79 (1.73–4.52) *	3.76 (2.21–6.38) *	4.33 (0.49–37.97)

Table 29. Speed limit by habitat suitability index categories between DVCs and non-DVC locations in Monroe, Washtenaw, and Oakland counties, Michigan, 1999–2001.

LOCATION	COUNTY	SPEED LIMIT	HABITAT SUITABILITY INDEX			
			Very Low	Low	Medium	High
DVCs	MONROE	Low	3 (0.01)	26 (0.06)	20 (0.04)	0 (0.00)
		Medium	8 (0.02)	115 (0.26)	147 (0.33)	9 (0.02)
		High	21 (0.05)	63 (0.14)	38 (0.08)	0 (0.00)
	WASHTENAW	Low	1 (0.00)	22 (0.05)	68 (0.15)	10 (0.02)
		Medium	1 (0.00)	100 (0.22)	168 (0.37)	10 (0.02)
		High	0 (0.00)	31 (0.07)	39 (0.09)	0 (0.00)
	OAKLAND	Low	0 (0.00)	13 (0.03)	94 (0.21)	31 (0.07)
		Medium	3 (0.01)	63 (0.14)	156 (0.35)	56 (0.12)
		High	0 (0.00)	10 (0.02)	20 (0.04)	4 (0.01)
	TOTAL	Low	4 (0.00)	61 (0.05)	182 (0.13)	41 (0.03)
		Medium	12 (0.01)	278 (0.21)	471 (0.35)	75 (0.06)
		High	21 (0.02)	104 (0.08)	97 (0.07)	4 (0.00)
NON-DVCs	MONROE	Low	23 (0.05)	91 (0.20)	55 (0.12)	7 (0.02)
		Medium	7 (0.02)	98 (0.22)	137 (0.30)	18 (0.04)
		High	0 (0.00)	7 (0.02)	7 (0.02)	0 (0.00)
	WASHTENAW	Low	5 (0.01)	96 (0.21)	114 (0.25)	17 (0.04)
		Medium	2 (0.00)	77 (0.17)	103 (0.23)	11 (0.02)
		High	0 (0.00)	10 (0.02)	15 (0.03)	0 (0.00)
	OAKLAND	Low	16 (0.04)	122 (0.27)	186 (0.41)	80 (0.18)
		Medium	0 (0.00)	7 (0.02)	18 (0.04)	7 (0.02)
		High	5 (0.01)	3 (0.01)	4 (0.01)	2 (0.00)
	TOTAL	Low	44 (0.03)	309 (0.23)	355 (0.26)	104 (0.08)
		Medium	9 (0.01)	182 (0.13)	258 (0.19)	36 (0.03)
		High	5 (0.00)	20 (0.01)	26 (0.02)	2 (0.00)

Table 30. Relative risk and 95% confidence intervals for speed limit by habitat suitability index categories between DVCs and non-DVC locations in Monroe, Washtenaw, and Oakland counties, Michigan, 1999–2001.

COUNTY	SPEED LIMIT	HABITAT SUITABILITY INDEX			
		Very Low	Low	Medium	High
MONROE	Low	0.13 (0.04–0.43) *	0.29 (0.19–0.43) *	0.36 (0.22–0.60) *	0.00 (NA)
	Medium	1.14 (0.42–3.13)	1.17 (0.93–1.49)	1.07 (0.89–1.30)	0.50 (0.23–1.10)
	High	NA	9.00 (4.17–19.44) *	5.43 (2.45–12.03) *	NA
WASHTENAW	Low	0.20 (0.02–1.71)	0.23 (0.15–0.36) *	0.60 (0.46–0.78) *	0.59 (0.27–1.27)
	Medium	0.5 (0.05–5.49)	1.30 (0.99–1.70)	1.63 (1.33–2.01) *	0.91 (0.39–2.12)
	High	NA	3.10 (1.54–6.25) *	2.60 (1.45–4.65) *	NA
OAKLAND	Low	0.00 (NA)	0.11 (0.06–0.19) *	0.51 (0.41–0.62) *	0.39 (0.26–0.57) *
	Medium	NA	9.00 (4.17–19.44) *	8.67 (5.42–13.87) *	8.00 (3.69–17.36) *
	High	0.00 (NA)	3.33 (0.92–12.03)	5.00 (1.72–14.51) *	2.00 (0.37–10.86)
TOTAL	Low	0.09 (0.02–0.53) *	0.20 (0.12–0.31) *	0.51 (0.39–0.68) *	0.39 (0.21–0.73) *
	Medium	1.33 (0.30–5.92)	1.53 (1.14–2.05) *	1.83 (1.45–2.29) *	2.08 (1.06–4.10) *
	High	4.20 (0.78–22.63)	5.20 (2.29–11.79) *	3.73 (1.78–7.81) *	2.00 (0.11–37.72)

Table 31. Traffic volume by habitat suitability index categories between DVCs and non-DVC locations in Monroe, Washtenaw, and Oakland counties, Michigan, 1999–2001.

LOCATION	COUNTY	TRAFFIC VOLUME	HABITAT SUITABILITY INDEX			
			Very Low	Low	Medium	High
DVCS	MONROE	≤ 120 vehicles/hr	7 (0.02)	69 (0.15)	95 (0.21)	5 (0.01)
		> 120 vehicles/hr	25 (0.06)	135 (0.30)	110 (0.24)	4 (0.01)
	WASHTENAW	≤ 120 vehicles/hr	1 (0.00)	23 (0.05)	66 (0.15)	6 (0.01)
		> 120 vehicles/hr	1 (0.00)	130 (0.29)	209 (0.46)	14 (0.03)
	OAKLAND	≤ 120 vehicles/hr	0 (0.00)	8 (0.02)	33 (0.07)	18 (0.04)
		> 120 vehicles/hr	3 (0.01)	78 (0.17)	237 (0.53)	73 (0.16)
	TOTAL	≤ 120 vehicles/hr	8 (0.01)	100 (0.07)	194 (0.14)	29 (0.02)
		> 120 vehicles/hr	29 (0.02)	343 (0.25)	556 (0.41)	91 (0.07)
NON-DVCs	MONROE	≤ 120 vehicles/hr	25 (0.06)	170 (0.38)	180 (0.40)	24 (0.05)
		> 120 vehicles/hr	5 (0.01)	26 (0.06)	19 (0.04)	1 (0.00)
	WASHTENAW	≤ 120 vehicles/hr	5 (0.01)	112 (0.25)	178 (0.40)	26 (0.06)
		> 120 vehicles/hr	2 (0.00)	71 (0.16)	54 (0.12)	2 (0.00)
	OAKLAND	≤ 120 vehicles/hr	12 (0.03)	93 (0.21)	156 (0.35)	79 (0.18)
		> 120 vehicles/hr	9 (0.02)	39 (0.09)	52 (0.12)	10 (0.02)
	TOTAL	≤ 120 vehicles/hr	42 (0.03)	375 (0.28)	514 (0.38)	129 (0.10)
		> 120 vehicles/hr	16 (0.01)	136 (0.10)	125 (0.09)	13 (0.01)

Table 32. Relative risk and 95% confidence intervals for speed limit by habitat suitability index categories between DVCs and non-DVC locations in Monroe, Washtenaw, and Oakland counties, Michigan, 1999–2001.

COUNTY	TRAFFIC VOLUME	HABITAT SUITABILITY INDEX			
		Very Low	Low	Medium	High
MONROE	≤ 120 vehicles/hr	0.28 (0.12–0.64) *	0.41 (0.32–0.52) *	0.53 (0.43–0.65) *	0.21 (0.08–0.54) *
	> 120 vehicles/hr	5.00 (1.93–12.94) *	5.19 (3.48–7.74) *	5.79 (3.62–9.25) *	4.00 (0.45–35.65)
WASHTENAW	≤ 120 vehicles/hr	0.20 (0.02–1.71)	0.21 (0.13–0.32) *	0.37 (0.29–0.48) *	0.23 (0.10–0.56) *
	> 120 vehicles/hr	0.50 (0.05–5.49)	1.83 (1.41–2.37) *	3.87 (2.96–5.07) *	7.00 (1.60–30.62) *
OAKLAND	≤ 120 vehicles/hr	0.00 (NA)	0.09 (0.04–0.18) *	0.21 (0.15–0.30) *	0.23 (0.14–0.37) *
	> 120 vehicles/hr	0.33 (0.09–1.22)	2.00 (1.39–2.87) *	4.56 (3.48–5.97) *	7.30 (3.82–13.95) *
TOTAL	≤ 120 vehicles/hr	0.19 (0.05–0.70) *	0.27 (0.19–0.38) *	0.38 (0.29–0.49) *	0.22 (0.11–0.45) *
	> 120 vehicles/hr	1.81 (0.63–5.17)	2.52 (1.83–3.47) *	4.45 (3.26–6.06) *	7.00 (2.58–18.99) *

Table 33. Deer-vehicle crashes by day of week in Monroe, Washtenaw, and Oakland counties, Michigan, 1999–2001.

	STUDY AREA			CHI SQUARE (P,df)
DAY OF WEEK	MONROE	WASHTENAW	OAKLAND	
MONDAY	56	67	77	
TUESDAY	61	53	58	
WEDNESDAY	68	73	62	
THURSDAY	69	81	63	420 (< 0.001, 6)
FRIDAY	66	69	77	
SATURDAY	66	49	54	
SUNDAY	64	58	59	
TOTAL	450	450	450	

Table 34. Deer-vehicle crashes by month in Monroe, Washtenaw, and Oakland counties, Michigan, 1999–2001.

TIME OF YEAR	STUDY AREA			CHI SQUARE (P,df)
MONTH	MONROE	WASHTENAW	OAKLAND	
JANUARY	19	38	35	
FEBRUARY	19	36	23	
MARCH	24	25	26	
APRIL	26	27	20	
MAY	47	34	25	
JUNE	26	27	25	
JULY	20	14	17	668 (< 0.001, 11)
AUGUST	11	14	16	
SEPTEMBER	19	24	27	
OCTOBER	85	69	85	
NOVEMBER	108	101	109	
DECEMBER	46	41	42	
TOTAL	450	450	450	

Table 35. Observed deer-vehicle crash counts and log linear model fit of deer-vehicle crash counts for the best 2 models in Monroe, Washtenaw, and Oakland counties combined, Michigan, 1999–2001.

HABITAT SUITABILITY INDEX	TRAFFIC VOLUME GROUPS	SPEED LIMIT GROUPS	OBSERVED COUNT	BEST MODEL ($HSI + V + S + V^{*}S$) FITTED COUNT	MODEL ($HSI + V + S$) FITTED COUNT
Very Low	≤120 vehicles/hr	Low	0	1	2
		Medium	7	8	5
		High	1	0	3
	>120 vehicles/hr	Low	4	7	6
		Medium	5	11	14
		High	20	11	8
Low	≤120 vehicles/hr	Low	10	14	23
		Medium	90	95	54
		High	0	0	31
	>120 vehicles/hr	Low	51	81	71
		Medium	140	128	168
		High	152	126	95
Medium	≤120 vehicles/hr	Low	21	23	39
		Medium	173	160	92
		High	0	1	52
	>120 vehicles/hr	Low	161	137	121
		Medium	187	216	284
		High	208	213	161
High	≤120 vehicles/hr	Low	11	4	6
		Medium	18	26	15
		High	0	0	8
	>120 vehicles/hr	Low	30	22	19
		Medium	57	35	45
		High	4	34	26

Table 36. Log values of observed deer-vehicle crash counts and log linear model fit of deer-vehicle crash counts for the best 2 models in Monroe, Washtenaw, and Oakland counties combined, Michigan, 1999–2001.

HABITAT SUITABILITY INDEX	TRAFFIC VOLUME GROUPS	SPEED LIMIT GROUPS	OBSERVED LOG COUNT	BEST MODEL (HIS + V + S + V*S) PREDICTED LOG SCORE	MODEL (HSI + V + S) PREDICTED LOG SCORE
Very Low	≤120 vehicles/hr	Low	NA	0.14	0.66
		Medium	1.95	2.07	1.51
		High	0.00	-3.60	0.95
	>120 vehicles/hr	Low	1.39	1.91	1.78
		Medium	1.61	2.37	2.64
		High	3.00	2.35	2.08
Low	≤120 vehicles/hr	Low	2.30	2.62	3.14
		Medium	4.50	4.55	4.00
		High	NA	-1.11	3.43
	>120 vehicles/hr	Low	3.93	4.39	4.27
		Medium	4.94	4.85	5.12
		High	5.02	4.84	4.56
Medium	≤120 vehicles/hr	Low	3.04	3.15	3.67
		Medium	5.15	5.08	4.52
		High	NA	-0.59	3.96
	>120 vehicles/hr	Low	5.08	4.92	4.79
		Medium	5.23	5.38	5.65
		High	5.34	5.36	5.08
High	≤120 vehicles/hr	Low	2.40	1.32	1.84
		Medium	2.89	3.24	2.69
		High	NA	-2.42	2.13
	>120 vehicles/hr	Low	3.40	3.08	2.96
		Medium	4.04	3.54	3.82
		High	1.39	3.53	3.25

Table 37. Summary of *a priori* models of deer-vehicle crash data showing differences (Δ_i), Akaike weights (w_i), and number of parameters (K) in Monroe, Washtenaw, and Oakland counties combined, Michigan, 1999–2001.

MODEL	Log Likelihood	AIC_c	Δ_i	w_i	K
HSI + Volume + Speed + Volume * Speed	-112	265	0	1	11
HSI + Volume + Speed	-276	579	314	0	9
HSI + Volume	-364	745	480	0	7
HSI + Speed	-460	942	677	0	8
Volume + Speed	-789	1592	1327	0	6

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CHAPTER 2

RELATIONSHIP OF FALL HUNTING SEASON TO THE FREQUENCY OF DEER-VEHICLE COLLISIONS IN MICHIGAN

INTRODUCTION

Deer-vehicle collisions (DVCs) in the US annually cause an estimated 29,000 human injuries, 200 human fatalities (Conover et al. 1995), and >$1 billion in property damage (Conover 1997). Total social costs of DVCs likely are greater due to human injury, trauma, absence from work, and additional costs of highway safety officers (Hansen 1983). More than 65,000 DVCs are currently reported annually in Michigan (Michigan Traffic Crash Facts 2003), which is a 230% increase since 1982. The actual number of DVCs may be greater than reported due to suspected under-reporting of DVCs (Decker et al. 1990, Conover et al. 1995).

Deer-vehicle collisions involving white-tailed deer (*Odocoileus virginianus)* in northern latitudes occur most frequently during autumn (Puglisi et al. 1974, Allen and McCullough 1976). Hunting has been implicated as a contributing factor to the autumn peak in DVCs because it increases movement of white-tailed deer (Etter et al. 2002). If hunting actually contributes to increased frequency of DVCs wildlife managers could be subjected to political pressure to alter hunting seasons or deer populations. A need to understand relationships between hunting and DVCs is necessary to evaluate harvest policies or in efforts to reduce DVCs.

OBJECTIVES

Our objectives were:

1. Examine temporal patterns of DVCs in Michigan.

2. Determine possible interactions between firearm-hunting season and frequency of DVCs.

STUDY AREA

Michigan was divided into 3 eco-regions: the Southern Lower Peninsula (SLP), Northern Lower Peninsula (NLP), and Upper Peninsula (UP). The SLP contains 38 counties and an area of 38,720 km^2, with a human population of 8.8 million individuals (Michigan Information Center 2001). Thirty counties in the NLP cover an area of 25,896 km^2 with a human population of 749,768 individuals, while 15 counties in the UP comprise an area 26,270 km^2 with a human population of 317,616 individuals. The landscape varies among the 3 eco-regions (Albert 1995) and transitions from urban-suburban environments in the SLP to a more rural environment in the NLP and UP. The climax vegetation types found in the SLP are white oak (*Quercus alba*)-black oak (*Q. velutina*) savannas and forests, and beech (*Fagus grandifolia*)-sugar maple (*Acer saccharum*) forests. Land use has greatly altered southern Michigan and currently a mix of agricultural fields, housing developments, and woodlots dominate the landscape. Northern hardwood forests, jack pine (*Pinus banksiana*) barrens, white pine (*P. strobes*)-red pine (*P. resinosa*) forests, conifer swamps and bogs are the most common climax vegetation types in the NLP and UP. Human densities, human developments, and agricultural areas generally decrease south-to-north and east-to-west across Michigan.

METHODS

Michigan DVC data were analyzed for years 1997–2001. These data were obtained from accident reports of the Michigan State Police via the Michigan Office of Highway Safety

Planning. The firearm-hunting season occurred 15-30 November each year in all regions. Three (28 days, 14 days, 7days) 2-sample *t* tests were used to test the null hypothesis that mean daily DVCs were equal for the pre-hunting and the hunting season periods ($\alpha = 0.05$). To determine prolonged, intermediate, and short term effects of hunting on DVCs, mean daily reported DVCs across all years were determined for 28 days, 14 days, and 7 days before and after the start of the hunting season.

A best-fit regression line was determined for all 56 data points, 18 October (28 days prior to 15 November) to 12 December (28 days after 15 November) for the entire state. The forms tested included linear, logarithmic, quadratic, exponential, and logistic.

An interrupted time series (Manly 1992) was performed on the statewide data and for each of the SLP, NLP, and UP eco-regions. The 28 data points before and after hunting season started were fitted with a linear regression. An assumption was made that

A paired *t*-test was used to test the hypothesis that DVCs occurring at night (2100–0600 hrs) 2 weeks before opening day of the firearm hunting season was different than the frequency of DVCs at night 2 weeks after opening day. The hypothesis that DVCs occurring for the period at daylight (0900–1800 hrs) 2 weeks before hunting season was different than the frequency of DVCs 2 weeks after hunting started was also tested using a paired *t*-test ($\alpha = 0.05$). We hypothesized that to avoid hunters once firearm hunting season started deer would shift their movement pattern to being more nocturnal, and this behavioral shift would be reflected by a corresponding shift in temporal patterns of DVCs. Each DVC was assigned to the hourly increment in which it was reported to occur for 2 weeks before and 2 weeks after the start of hunting season. To avoid opening day effects 15 November was excluded from this part of the analysis. Total DVCs that occurred between 2100–0600 and 0900–1800 hrs were calculated for the 2 periods (before and after the opening day of hunting season). We excluded 0600–0900 and 1800–2100 hr periods because deer activity during these dawn and dusk periods has been shown to be relatively constant (McCaffery 1973).

RESULTS

Mean number of daily DVCs 28 and 14 days after the start of hunting was lower than the mean number of daily DVCs 28 and 14 days before the start of hunting season ($P < 0.001$, Table 2.1). The difference in mean number of daily DVCs 7 days before and after the start of hunting season was not different ($P = 0.285$). Mean number of daily DVCs before hunting increased between the 28-day period (432 ± 8) and the 14-day period (485 ± 10), but decreased slightly between the 14-day period (485 ± 10) and the 7-day period (484 ± 13). Mean daily DVCs decreased by over 25 % from the opening day mean during the first week of hunting season, and continued to decrease through the end of hunting season.

Statewide, the best-fit line for the entire autumn time period (18 October to 12 December) was quadratic ($R^2 = 0.51$). The equation for the best-fit line was

$$\text{Number of DVCs} = 320.06 + 12.62\ \text{Days} - 0.28\ \text{Days}^2.$$

The quadratic equation describing DVCs began a downward trend on 15 November. The R^2 value of the quadratic equation was higher than that of the linear ($R^2 = 0.20$), logarithmic ($R^2 = 0.04$), exponential ($R^2 = 0.23$), and logistic ($R^2 = 0.23$) equations.

Numbers of DVCs statewide and DVCs within the 3 eco-regions increased linearly from 18 October to 14 November (Figure 2.1). In each region, the greatest number of DVCs occurred on 15 November, opening day of firearm hunting season. From 15 November to 12 December number of DVCs declined at a faster daily rate than their increase earlier in autumn. The linear trend line predicted statewide, SLP, and NLP DVCs well, but poorly predicted UP DVCs. Except for NLP DVCs, R^2 values for the trend lines after the start of hunting were greater than for the trends prior to the start of hunting. The slope of the regression for the NLP (1.61/day) was intermediate between the UP (0.14/day) and the SLP (4.93/day). Mean daily DVCs peaked in the first week of November statewide and for the SLP. This peak was not as apparent for the NLP and UP.

We accept the alternate hypothesis that between 2100 and 0600 hrs frequency of DVCs 2 weeks before hunting season was different than the frequency of DVCs 2 weeks after hunting season started (t = 5.91, $P < 0.001$). We also accept the alternate hypothesis that between 0900 and 1800 hrs the frequency of DVCs 2 weeks before hunting season began was different than the frequency of DVCs 2 weeks after hunting season started ($t = -4.18$, $P < 0.005$). Frequency of DVCs throughout a 24-hour period has a bimodal distribution (Figure 2.2). The mode during morning hours (0500-1000) was smaller compared to the mode during evening hours (1600-2200). Between 1800 and 0900 hrs frequency of hourly statewide DVCs appeared greater for the 2 week period prior to hunting (1-14 November) than for after hunting (16 -30 November). This pattern, however, did not continue between 0900 and 1800 hrs.

DISCUSSION

Hunting activity by humans causes an increase in daily movement activities and changes in home range for white-tailed deer (Sparrowe and Springer 1970, Root et al. 1988, Naugle et al. 1997). Etter et al. (2002) suggested behavioral response of deer to hunting might contribute to the fall peak in DVC numbers. This assertion was supported by McCaffrey (1973), who found numbers of deer carcasses along roadways to be highly correlated with numbers of bucks killed during the firearm hunting season in Wisconsin. If disturbance from hunting contributes to an increase in DVCs in Michigan, it is apparent only on opening day of hunting season. It is unclear beyond opening day whether hunting contributes or ameliorates the frequency of DVCs.

The coincidental timing between peak of the rut and peak of DVCs suggests deer movement associated with the rut is the predominant cause for the fall peak in DVCs. In Michigan the sex ratio of deer involved in fall DVCs is disproportionately male compared to other seasons when sex ratios are approximately equal (Allen and McCullough 1976). Chasing behavior of bucks, which increases movement of females, increases through late October and crests in Michigan during the first 2 weeks of November (Hirth 1977). That most of the breeding is occurring just prior to the firearm hunting season in Michigan is supported by data on conception dates. McCullough (1979) reported that conception in yearling and adult does occurs in late October and early November in Michigan. Mean breeding dates calculated from lengths of deer embryos in accidentally killed adult does was 6 November in the SLP, 15 November in the NLP, and 20 November in the UP (Friedrich and Schmitt 1988). In the SLP and NLP the mean breeding dates correspond with daily DVCs. In most of Michigan by the time firearm hunting season starts, deer movement due to the rut is likely on a decline and hence DVCs also begin to decline.

There is a rapid decline in DVCs past opening day and this pattern is observed across all 3 eco-regions in Michigan. There are 4 plausible explanations for this pattern of rapid decline. First, at least 250,000 deer may be killed in the first week of firearm hunting season (B. Rudolph, Michigan Department of Natural Resources, Wildlife Division, pers. communication). The removal of approximately 10-15 % of the deer population during the first week of hunting may contribute to the 25% decrease in DVCs during this week, as there are fewer deer available to be hit by vehicles. Second, by 15 November the rut in Michigan may be ebbing (Jenkins and Bartlett 1959), leading to decreased deer movement and fewer deer crossing roads. Mean DVCs for the 14-day period before hunting is slightly greater than the mean DVCs 7 days before hunting season indicating that the rut may have peaked in the first week of November. Third, deer may have changed their behavior to being more nocturnal to avoid hunters and this may have resulted in fewer DVCs. Our analyses, however, did not support this third possible explanation. Lastly, we could not exclude the possibility that VMT after the start of hunting season declined substantially as to make an impact on frequency of DVCs. Even though this may be unlikely there was no way to validate our assumption that VMT remained constant between the pre-hunting and hunting season periods.

Deer increase crepuscular activity dramatically during hunting season while maintaining high diurnal activity (Naugle et al. 1997). Based on this assumption we predicted *a priori* that once hunting started DVCs would increase during nighttime hours and decrease during daylight hours. We reasoned that during daylight hours deer would hide from hunters and move less, whereas at night deer would be less affected by hunting pressure and move more. We assumed increased movement to be positively correlated to DVCs. Our data supported the opposite prediction. A possible explanation for the lower number of DVCs at night after the start of hunting is that the rut is declining and fewer deer are moving. Increased numbers of daytime DVCs after the start of hunting supports the notion that hunters are disturbing deer enough to increase their vulnerability to DVCs.

MANAGEMENT IMPLICATIONS

Motorists should be informed about an increased probability of encountering deer on roadways during the first 2 weeks of November due to movements associated with rutting behavior, and on opening day of deer hunting season. Information and education about the increased risk of DVCs during autumn, particularly on the first 15 days of November and during daylight hours of deer hunting season, may help reduce the impact of DVCs. Any changes to the opening date of deer hunting season that would make it correspond closer to the peak of the rut can be expected to increase number of DVCs. Our data are from only 1 Midwestern state. Examination of the relationship between rutting behavior, hunting season, and frequency of DVCs elsewhere would help better determine effects on DVCs of policy changes to hunting seasons.

Table 2.1. Mean number of deer-vehicle crashes per day 28, 14, and 7 days before and after the start of the hunting season in Michigan (1997 –2001).

Time Period	Mean	SE	*n*	*t*	Significance
28 Days Before	432	8	140	6.96	< 0.001
28 Days After	332	9	140		
14 Days Before	485	10	70	5.03	< 0.001
14 Days After	404	12	70		
7 Days Before	484	13	35	1.09	> 0.10
7 Days After	462	18	35		

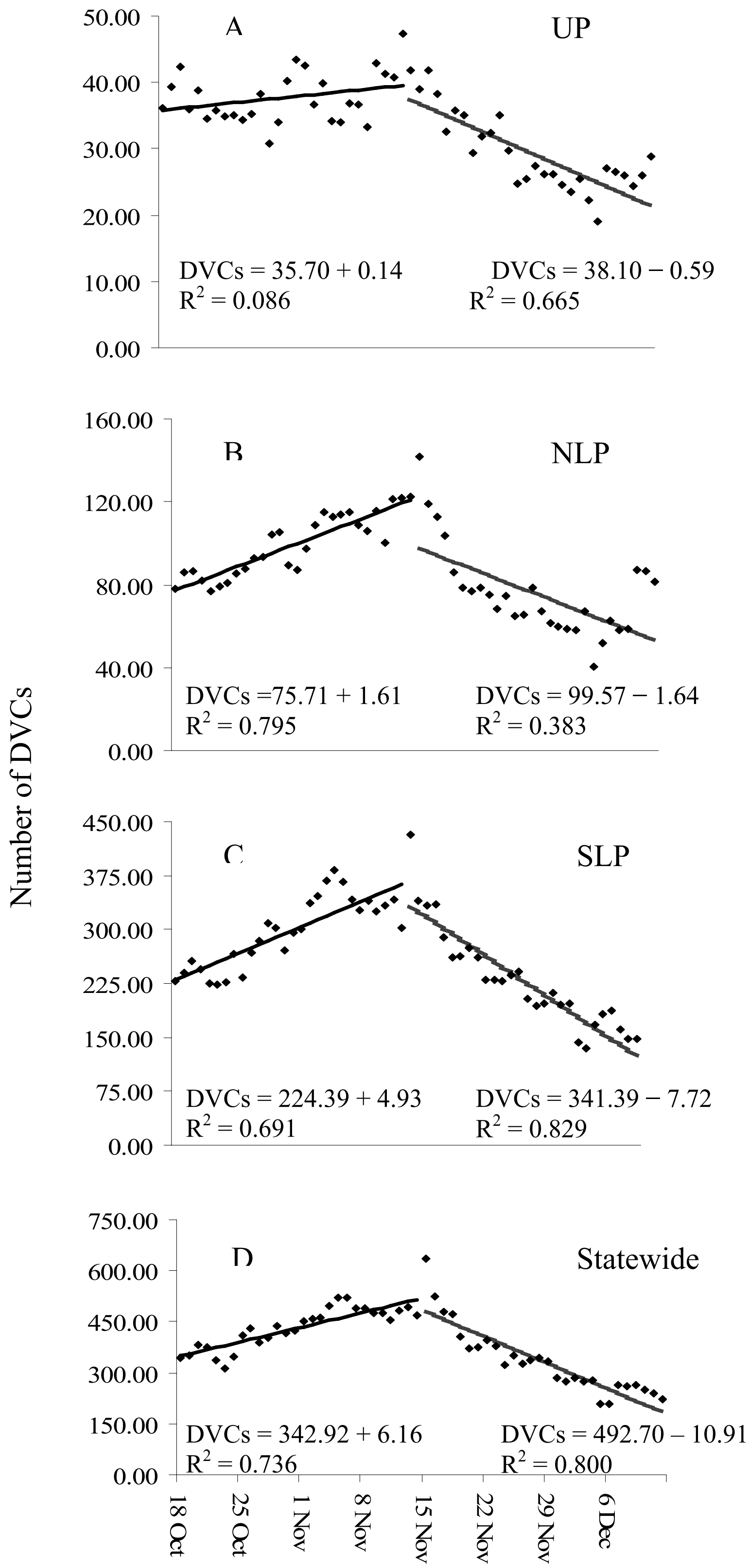

Figure 2.1. Mean number of daily deer-vehicle collisions (1997–2001) in
(A) Upper Peninsula,
(B) Northern Lower Peninsula,
(C) Southern Lower Peninsula and,
(D) Statewide
28 days before and after opening day of deer hunting season.

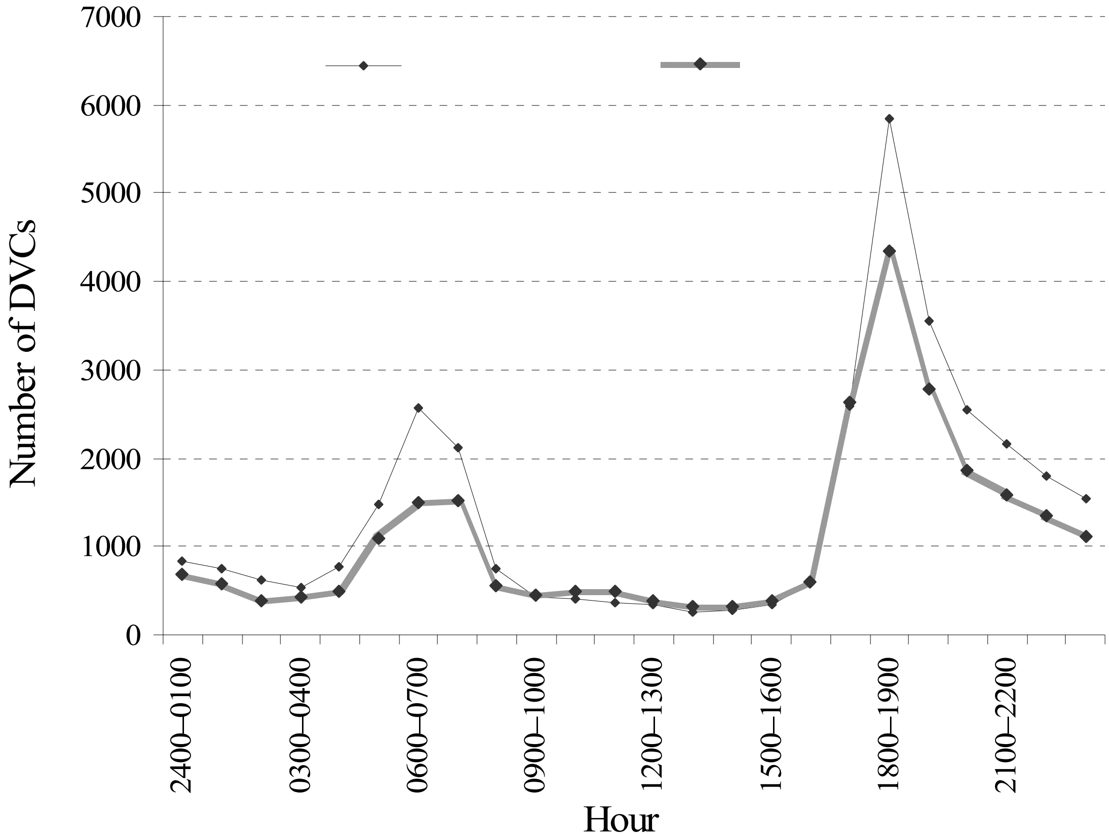

Figure 2.2. Statewide deer-vehicle collisions (1997–2001) by time of day 14 days prior and 14 days after the start of hunting season in Michigan.

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CHAPTER 3

DEER-VEHICLE CRASH PATTERNS ACROSS ECOREGIONS IN MICHIGAN

ABSTRACT

Deer-vehicle collisions (DVCs) impact the economic and social well being of humans. We examined large-scale patterns behind DVCs across 3 ecoregions: Southern Lower Peninsula (SLP), Northern Lower Peninsula (NLP), and Upper Peninsula (UP) in Michigan. A 3 component conceptual model of DVCs with drivers, deer, and a landscape was the framework of analysis. The conceptual model was parameterized into a parsimonious mathematical model. The dependent variable was DVCs by county by ecoregion and the independent variables were percent forest cover, percent crop cover, mean annual vehicle miles traveled (VMT), and mean deer density index (DDI) by county. A discriminant function analysis of the 4 independent variables by counties by ecoregion indicated low misclassification, and provided support to the groupings by ecoregions. The global model and all sub-models were run for the 3 ecoregions and evaluated using information-theoretic approaches. Adjusted R^2 values for the global model increased substantially from the SLP (0.21) to the NLP (0.54) to the UP (0.72). VMT and DDI were important variables across all 3 ecoregions. Percent crop cover played an important role in DVCs in the SLP and UP. The scales at which causal factors of DVCs operate appear to be finer in southern Michigan than in northern Michigan. Reduction of DVCs will likely occur only through a reduction in deer density, a reduction in traffic volume, or in modification of site-specific factors, such as driver behavior, sight distance, highway features, or speed limits.

INTRODUCTION

Deer-vehicle collisions (DVCs) involving white-tailed deer (*Odocoileus virginianus)* create numerous impacts to society throughout the species range. An estimated minimum of 29,000 human injuries and 200 human fatalities are caused by DVCs annually in the US (Conover et al. 1995). DVCs result in property damage that costs society over $1 billion (Conover 1997). Hansen (1983) postulated total social costs are likely much greater due to missed work, physical and mental trauma, and added costs of highway safety officers. Michigan currently leads the nation in number of reported DVCs, with more than 65,000 annually and approximately $150 million in vehicle damage (Richard Miller, Public Safety Officer, AAA Michigan, pers. communication).

The goal of this study was to understand large-scale environmental patterns that provide insight into factors causing DVCs on the Michigan landscape. We started with a conceptual model of DVCs and built a parsimonious mathematical model. Our simple conceptual model of DVCs consists of 3 components: deer, drivers, and a landscape of deer habitat traversed by a network of roads, features perceived by wildlife and transportation managers as most affecting the distribution and abundance of DVCs (Sullivan and Messmer 2003). The interaction between these 3 components was expected to determine the distribution and frequency of DVCs. The full mathematical model and its sub-models were evaluated across 3 broad ecoregions in Michigan using the corrected Akaike's Information Criteria (AIC_c) to better understand patterns of DVCs. A Michigan county DVC model does not exist, though Finder (1997), and Iverson and Iverson (1999) have developed such models to predict the number of DVCs within counties in Illinois and Ohio respectively. The models for Illinois and Ohio are not parsimonious nor did the authors resolve the covariance between independent variables.

STUDY AREA

The 83 counties in Michigan were grouped into 3 broad ecoregions: the Southern Lower Peninsula (SLP) (38 counties), Northern Lower Peninsula (NLP)(30 counties), and Upper Peninsula (UP)(15 counties) (Figure 3.1). These ecoregions generally matched the landscape sections of Michigan characterized by Albert (1995) according to similar soils, vegetation, climate, geology, and physiography, except the UP ecoregion combined 2 sections. Human densities and proportion of the landscape in agricultural food crops decrease along a gradient from south to north (Sudharsan et al. In Press). We examined DVCs by county grouped into ecoregions because it provided a simple way to understand DVCs in relation to changes in the landscape. Furthermore, management decisions made by transportation and natural resource agencies often are made along the ecoregion administrative boundaries. For example, Wildlife Division administrative units may be grouped into areas that closely match these ecoregions (Figure 3.1).

METHODS

The conceptual model may be presented in the form

$$\text{Annual Number of DVCs} = \int (\text{deer, drivers, landscape})$$

We used data on 4 independent variables available at the county level to parameterize this model: deer density index (DDI), annual vehicle miles traveled (VMT), percent forest cover, and percent crop cover. We believed these 4 variables parsimoniously captured the 3 components in our conceptual model well. Michigan crash data (Office of Highway Safety Planning, Michigan, unpublished data) was used to determine annual number of DVCs by county for years 1999-2003.

Absolute estimates of deer density by county in Michigan currently do not exist. We calculated an index of deer density for each county as a surrogate by dividing total firearm effort (days hunted) in the given county by the number of bucks killed within that county. The unit of DDI therefore was number of days taken to kill 1 buck. Our assumption was it took more days to kill a buck in counties with a lower deer density. Annual estimates of deer hunting participation and harvest in Michigan are generated using a mail survey of randomly selected deer license buyers following completion of the hunting season (Frawley 2000, 2001, 2002, 2003, 2004). The mean DDI, by county, was calculated for years 1999-2003.

Vehicle miles traveled by county were obtained for the years 1999 to 2003 (Office of Highway Safety Planning, Michigan, unpublished data) and the average over these 5 years was used in the analysis.

Percent forest and percent crop for each county was obtained (Michigan Agricultural Statistics Department 2005) and used to characterize landscape components important to deer. Forests provide food and cover for deer (Blouch 1984). Agricultural crops (e.g. soybeans, corn) may play an important supplemental role in meeting nutritional needs of deer (Nixon et al. 1970). We expected percent forest cover and percent crop cover to co-vary with each other, but they maybe differentially important to deer across Michigan depending on their composition and juxtaposition on the landscape. We also recognized that these deer habitat quality is comprised of a complex assortment of variables (Felix et al. 2004) and the crop-forest measurements are only a coarse representation of deer habitat, but these data are readily available to most land use planners. All correlations between independent variables were calculated to examine inter-relatedness.

Prior to running the global model and the sub-models for the 3 ecoregions a discriminant function analysis was performed on the 4 independent variables based on ecoregion groupings. The purpose of the discriminant function analysis was to ascertain whether the ecoregions provide a suitable basis on which to group counties. If a large number of counties were misclassified then it would not make sense to run the models by ecoregions.

The next step in the analysis was to run the global model and all possible sub-models for the 3 ecoregions (15 total models). Our global model was

$$\text{Annual Number of DVCs} = \int (\%\text{Forest} + \%\text{Crop} + \text{DDI} + \text{VMT}),$$

where %forest = percent of landscape covered by forests, and so on…

We assumed that DVCs would be linearly related to the independent variables within the ecoregions. Within each ecoregion the models were evaluated using corrected Akaike Information Criterion scores (AIC_c) and weights (w_i; Burnham and Anderson 2002). Only competing models within 3 AIC_c points of the best approximating model were considered.

Finally DVCs by county by ecoregion were plotted against each of the 4 independent variables. The signs of the slope coefficients within ecoregions were compared. The relationship between DVCs and each of the independent variables was visually examined to cross check our *a priori* hypothesis of a linear relationship.

RESULTS

Discriminant function analysis differentiated Michigan counties into the 3 ecoregions (Figure 3.2). Along canonical variate 1 the separation among ecoregions was by percent forest cover, DDI, and percent crop cover (Table 3.1). Along canonical variate 1 SLP counties have negative values while the NLP and UP counties have positive values. Typically UP counties have higher values along variate 1 than NLP counties. The canonical variate 2 separated ecoregions by DDI, percent crop cover, and percent forest cover. Canonical variate 1 and variate 2 explained 98% and 1.6% of the variation between ecoregions respectively. A total of 7 counties were misclassified into the wrong ecoregion. Six of 7 misclassified counties occurred on the boundary between ecoregions (Figure 3.1). Midland and Muskegon are counties in the SLP that are along the boundary with the NLP. Chippewa, Luce, Mackinac, and Schoolcraft are counties in the UP adjacent to the NLP. Marquette in the UP was the only misclassified non-boundary county.

The equations for the global model for the 3 ecoregions were

SLP DVCs = 3345.62 – 11.90 %Forest – 20.19 %Crop – 0.61 VMT – 31.97 DDI

NLP DVCs = 976.15 + 0.81 %Forest + 3.50 %Crop + 7.52 VMT – 23.75 DDI

UP DVCs = 599.32 – 1.60 %Forest + 84.42 %Crop + 11.02 VMT – 15.78 DDI

Four patterns are visible in the equations for the global models. First, the intercept value for the global models decrease in magnitude from the SLP to the UP (3345.62, 976.15, 599.32). Second, the sign and magnitude of the slope coefficient for %crop changed from negative and relatively high in the SLP (–20.19) to positive and small in the NLP (3.50) to positive and high in the UP (84.42). A 1% increase in percent crop cover by county leads to DVCs increasing by 84 in the UP. Thirdly, a similar change in sign but gradual increase in magnitude of the slope coefficient is seen from the SLP to UP for VMT (–0.61, 7.52, 11.02). Lastly, the magnitude of DDI decreases from the SLP to the UP (–31.97, –23.75, –15.78). In the UP percent crop cover was low and unequally distributed (mean crop area by county = 2.52 % and sd = 2.54 %) compared to percent forest cover (mean forest area by county = 81.22 % and sd = 5.86 %). In the NLP percent crop cover (mean forest area by county = 10.92 % and sd = 7.37 %) and percent forest cover (mean forest area by county = 65.19 % and sd = 11.36 %) were variable but the greatest landscape variability was in the SLP (mean crop area by county = 42.76 % and sd = 17.06 %; mean forest area by county = 21.72 % and sd = 8.94 %).

Slope coefficients for all 4 independent variables from the SLP were negative. For the NLP, percent forest cover, percent crop cover, and VMT had positive slope coefficients, while DDI had a negative slope coefficient. Yet, the slope value for percent forest cover was close to 0 (0.81). For the UP, percent crop cover and VMT had positive slope coefficients while DDI and percent forest cover had negative slope coefficients. It should be noted that the adjusted R^2 value for the global models increase from the SLP to the NLP to the UP (0.21, 0.51, and 0.73).

In the SLP there were 3 models within 3 AIC_c points of the best approximating model (Table 3.2). The SLP is the only ecoregion where the global model is present among the best models. The best approximating model in the SLP had percent crop cover and DDI as variables. In the SLP the Akaike weight for the best model was close to the weight for the next 2 models. The evidence ratios for the 2nd and 3rd best models were 1.24 (0.31/0.25) and 2.58 (0.31/0.12). The variables percent crop cover and DDI were present in all 3 top models for the SLP. In the SLP we excluded the 4th model as being competitive because its log likelihood was very close to the best model and it had 1 extra parameter.

The variables in the best approximating model for the NLP were VMT and DDI. There were 2 models within 3 AIC_c points of the best approximating model in the NLP. However, models 2 and 3 were not supported; the log likelihood of models 2 and 3 were identical to that of the best approximating model and they had 1 extra parameter. Neither percent forest cover nor percent crop cover were factors affecting DVCs in the NLP.

Three models were within 3 AIC_c points of the best approximating model for the UP. The evidence ratios for the 2nd and 3rd best models were 1.48 (0.40/0.27) and 2.50 (0.40/0.16). The UP was the only region where a 3-parameter model (%crop, intercept, residual variance) figured in the top models. The variable percent crop cover appeared in all 3 top models for the UP. Again, model 4 had little support since its log likelihood was very close to that of the best approximating model and it had 1 extra parameter.

The adjusted R^2 value for the best model in the 3 ecoregions increased in value from the SLP (0.19), to the NLP (0.54), and was highest in the UP (0.72). Percent of the landscape in forest and crop cover were most highly correlated across all ecoregions except in the SLP where percent crop cover and VMT had the highest correlation (Table 3.3). Counties with high percent forest cover had low percent crop cover (especially in the NLP). In the NLP percent forest cover and percent crop cover were more highly correlated to DDI than in the SLP and UP. Correlations between the independent variables were generally weak across all 3 ecoregions. Percent crop cover and VMT were negatively correlated to each other in the SLP but positively correlated in the NLP and UP. Percent forest cover and DDI were negatively correlated with each other in the UP but positively correlated in the SLP and NLP.

DISCUSSION

The discriminant function analysis indicated the ecoregions identified *a priori* provide a logical basis for grouping counties. Scale of analyses should be matched with the scale of decisions. Most decisions in wildlife or transportation planning do not occur at scales much smaller than counties. Trying to understand and manage all possible factors affecting the distribution and abundance of DVCs is overwhelming and probably not necessary. Managers may benefit from a simple classification system, such as the one used in the current analysis, which provides a framework to make decisions on larger scales.

At the county level, Finder (1998) found traffic volume and deer density to be important predictors of DVCs in Illinois. The presence of VMT and DDI in the set of best models across all 3 ecoregions indicates that regardless of the distribution of percent forest cover and percent crop cover 2 variables that consistently affect DVCs most are traffic volume (VMT) and deer density (DDI).

The first 3 models in the UP are all potentially useful. Percent crop cover is present in all 3 models and appears to be a primary landscape factor affecting DVCs in that ecoregion. Fall and winter foods may be especially important to deer in the UP because a continuous diet of woody browse can result in malnutrition (Mautz 1978). A significant portion of a deer's fall and winter food can be agricultural crops (Nixon et al. 1970). In a landscape, where percent crop cover is very low and unequally distributed compared to percent forest cover, we might expect areas with available agricultural crops to be especially attractive to deer. A higher percent crop cover in the UP appears to lead to greater deer density in a given area. At a county-level scale the combination of relatively higher percent crop cover combined with high traffic volume appears to lead to greater numbers of DVCs in the UP.

There also were 3 likely models of DVCs in the SLP. The presence of the global model among the best models suggests all 4 independent variables may be important as factors contributing to DVCs. In highly variable landscapes local factors such as visibility of deer to drivers, speed limit, or presence of riparian corridors, may have a greater effect on distribution and frequency of DVCs. The county-level scale may be too coarse to evaluate all factors affecting DVCs in the SLP.

A non-linear relationship between percent forest cover and deer density exists throughout Michigan. Mean forest cover increases from the SLP to the NLP to the UP whereas the correlation between percent forest cover and DDI changes from the SLP (positive, weak, $R = 0.01$) to the NLP (positive, strong, $R = 0.61$) to the UP (negative, intermediate, $R = -0.33$). As percent forest cover increases in the SLP and NLP deer density decreases. In the UP, however, there is an increase in deer density (i.e., higher DDI equates to lower deer density) as percent forest increases.

The inverse relationship between percent crop cover and VMT in the SLP may be because an increase in VMT is an indication of increasing urbanization and associated increases in traffic volume in a given landscape. As percent urban land cover increases we would expect a decrease in percent crop cover. Percent crop cover and VMT are positively correlated in the NLP and UP. Agricultural areas in the NLP and UP may have a more level terrain better and soil types suited for roads, hence the positive correlations.

The inverse relationship between DVCs and both VMT and percent forest cover in the SLP was mostly due to the presence of outliers. The 3 outlier counties represented in the graph of VMT and DVCs were Macomb, Oakland, and Wayne. The 2 outliers for the SLP in the graph of percent forest cover and DVCs were Midland and Muskegon. These outliers had the effect of turning a positive relationship between DVCs and the respective independent variables into a negative relationship for the SLP.

For simplicity we assumed a linear relationship between the independent variables and DVCs within the ecoregions. This assumption may be sufficient at the ecoregion level, but is inadequate at the state level. The variables VMT, percent forest cover, and percent crop cover seems to be non-linearly associated with DVCs at the statewide level. The abundance of DVCs increases with increases in these variables up to a certain threshold after which it begins to decrease. This issue of non-linearity raises 2 important aspects for modelers to consider. First, *a priori* consideration about the nature of relationships between independent variables and the dependent variable is needed. Second, in heterogeneous landscapes the size of the geographical units modeled should be explicitly considered since it may determine the nature of these relationships. Non-linear relationships with thresholds provide important information to transportation and wildlife planners. Notably efforts should be concentrated on areas where the return on mitigation is going to be maximized.

MANAGEMENT IMPLICATIONS

Our analyses point to several management implications. Different strategies to reduce DVCs are needed depending on landscape characteristics within the region of interest. Two variables considered, percent forest cover and percent crop cover, typically are outside the realm of control for most wildlife or transportation agencies. Reduction of DVCs will then occur only through a reduction in deer density, a reduction in traffic volume, or in modification of factors such as driver behavior sight distance, highway features, or speed limits (Marcoux et al. 2005). Yet, ability of managers to control white-tailed deer populations through public hunting is becoming limited, especially in areas with small tracts of private lands (Brown et al. 2000). Additional research is needed to evaluate mechanisms for adjusting driver behavior, and to achieve a better understanding of how finer scale characteristics of the landscape affect the distribution and abundance of DVCs.

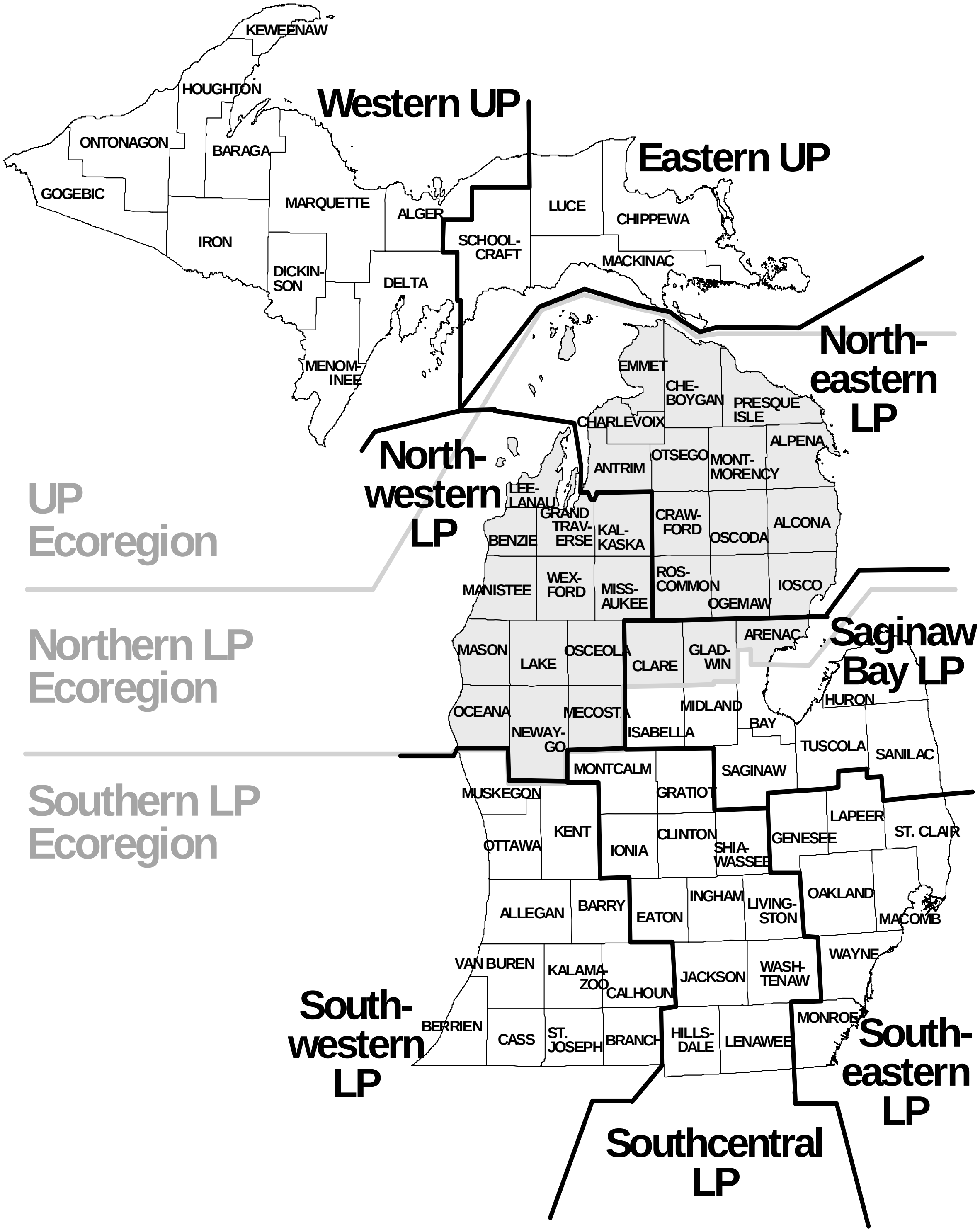

Figure 3.1. Counties (outlined by light black lines), Wildlife Division administrative units (outlined by heavy black lines), and ecoregions (outlined by heavy gray lines) of Michigan, USA.

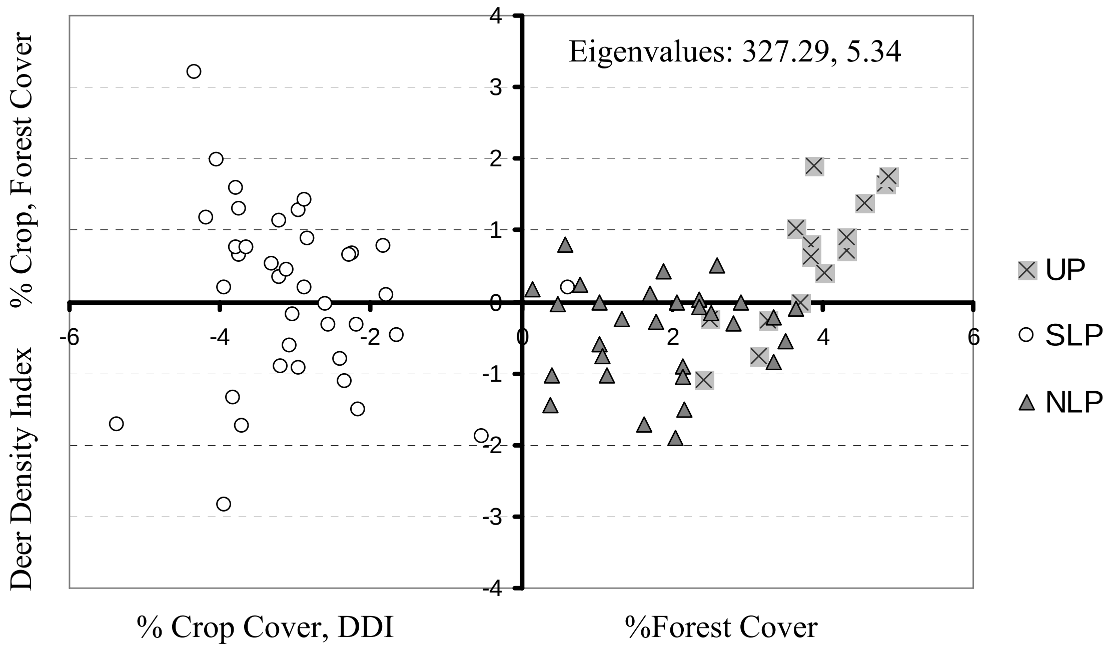

Figure 3.2. Discriminant function analysis of Michigan counties by ecoregions showing scores along linear discriminant axis 1 and linear discriminant axis 2.

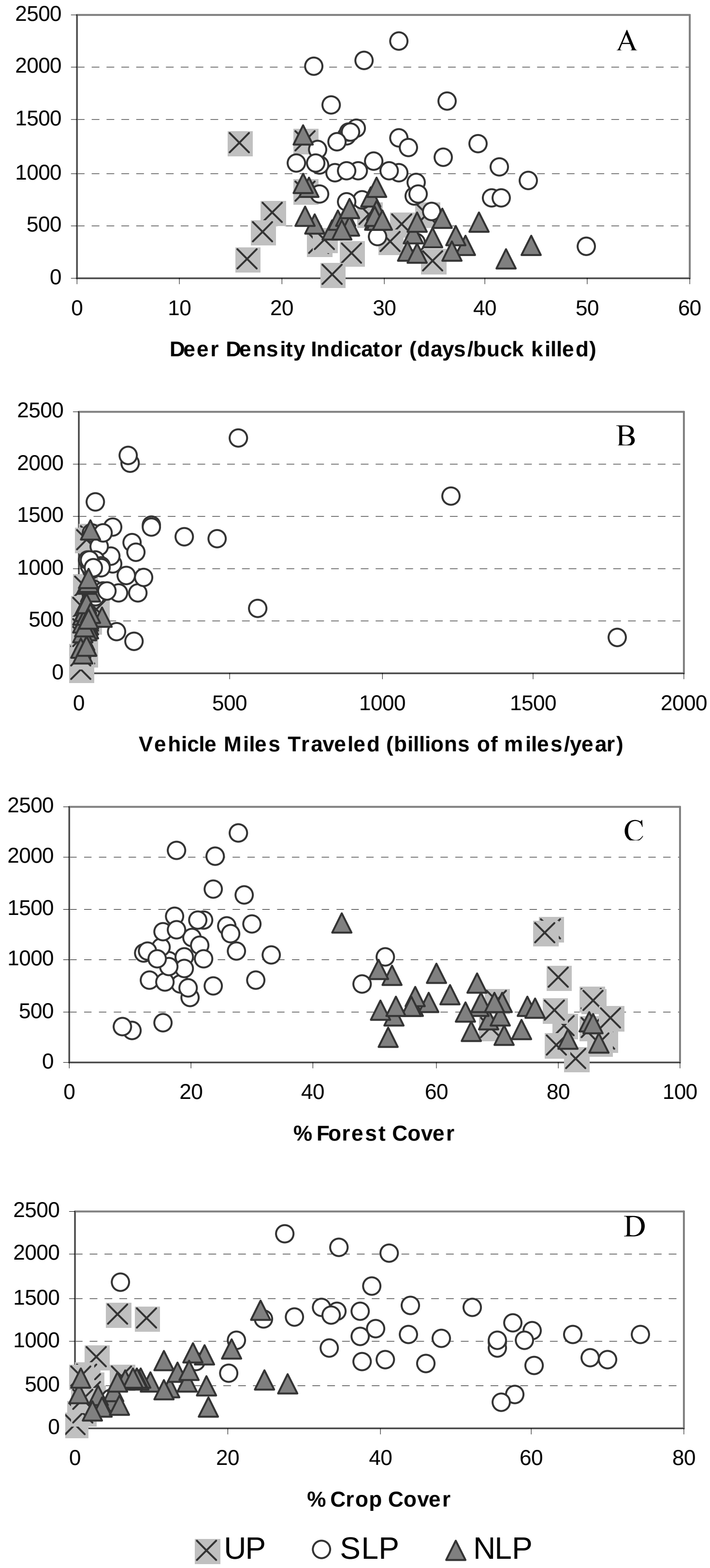

Figure 3.3. Deer vehicle collisions (1999–2003) by ecoregions as a function of
(A) Deer Density Indicator,
(B) Vehicle Miles Traveled,
(C) Percent Forest Cover and,
(D) Percent Crop Cover.

Table 3.1. Discriminant analysis of the 4 independent variables showing standardized canonical coefficients and eigen values for the first two canonical variates.

Discriminant variable	Canonical variate 1	Canonical variate 2
Percent Forest Cover	0.09	0.08
Percent Crop Cover	–0.02	0.09
Deer Density Index	–0.06	–0.10
Vehicle Miles Traveled	0.00	0.00
Eigen Values	327.29	5.34

Table 3.2. Models within 3 AIC_c points of the best approximating model of factors influencing deer-vehicle collisions by ecoregions, Michigan, USA.

Region	Model	Log Likelihood	AIC_c[a]	Δ_i	W_i[b]	K[c]	Adjusted R^2
SLP	%Crop + DDI	-279.35	567.42	0.00	0.31	4	0.19
	%Crop + VMT + DDI	-278.32	567.85	0.44	0.25	5	0.21
	%Forest + %Crop + VMT + DDI	-277.75	569.39	1.97	0.12	6	0.21
	%Forest + %Crop + DDI	-279.30	569.80	2.39	0.09	5	0.17
NLP	VMT + DDI	-193.83	396.58	0.00	0.56	4	0.54
	%Crop + VMT + DDI	-193.70	399.01	2.43	0.17	5	0.52
	%Forest + VMT + DDI	-193.80	399.20	2.62	0.15	5	0.52
UP	%Crop + VMT	-98.87	207.92	0.00	0.40	4	0.72
	%Crop + VMT + DDI	-97.36	208.73	0.81	0.27	5	0.75
	%Crop	-101.36	209.73	1.81	0.16	3	0.64
	%Forest + %Crop + VMT	-98.23	210.85	2.93	0.09	5	0.72

[a] AIC corrected for small sample size; [b] Akaike weight; [c] K parameters

Table 3.3. Coefficient of determination (R^2) and correlation coefficient (R) values between the independent variables across 3 ecoregions, Michigan, USA.

Variables	SLP	NLP	UP
% Forest and DDI	0.00 (0.01)	0.37 (0.61)	0.11 (–0.33)
% Crop and DDI	0.12 (–0.34)	0.39 (–0.63)	0.11 (–0.33)
% Forest and % Crop	0.20 (–0.45)	0.71 (–0.84)	0.20 (–0.45)
% Forest and VMT	0.04 (–0.20)	0.20 (–0.45)	0.03 (–0.17)
% Crop and VMT	0.42 (–0.65)	0.07 (0.27)	0.12 (0.34)
VMT and DDI	0.06 (0.25)	0.00 (0.01)	0.07 (0.26)

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CHAPTER 4

MANAGEMENT IMPLICATIONS

To meet their physiological and behavioral needs deer regularly cross roads that traverse through their habitats. The probability of drivers hitting deer increases with the number of deer crossing roads, traffic volume and speed. Roads traversing landscapes comprised of moderate quality deer habitat have more DVCs than very low or high quality habitats. Those areas with high traffic volume, medium or high speeds, or a combination of high traffic volume and medium or high speed have the greatest frequency of DVCs. An exception to this finding is when traffic volumes reach a high enough level because of human development that quality of deer habitat decreases.

DVCs are not random events on the landscape. Our data indicate that there are patterns as to where DVCs occur and that context, or location, matters. Specific factors that make DVCs more likely are different across the rural, urban, or mixed rural-urban landscape. Deer habitat suitability index (a measure of habitat quality) was the most important causal factor of DVCs. Traffic volume and speed limit combined contribute less to DVCs than deer habitat suitability index. Based on the best fit log-linear model a reduction in traffic volume on all roads ≥ 120 vehicles/hr would result in the greatest reduction in number of DVCs, however, this is an impractical solution. A more practical solution, however, may be to implement vegetation management strategies that would improve sight distances for drivers, and make roadsides less attractive to deer.

An important finding of our research is a process for identifying conditions and road types along which management strategies could be prioritized. Three characteristics of road types where management strategies likely will have the greatest impact are:

1. Roads in rural rather than urban-suburban areas.
2. Roads > 2 lane rather than ≤ 2 lane.
3. Roads with > 120 vehicles/hr rather than ≤ 120 vehicles/hr.

In Monroe County, management along high speed roads (≥ 96 km/hr) rather than on medium speed roads (64 < 96 km/hr) or low speed roads (≤ 64 km/hr) is more likely to reduce DVCs than in Washtenaw and Oakland counties. In Washtenaw and Oakland Counties, management strategies should focus along medium speed roads rather than on high speed roads or low speed roads. High traffic volume, high speed roads in urban landscapes may become a barrier to deer crossings, and management in those areas likely will have little effect on rates of DVCs.

Driver education campaigns to reduce DVC numbers should warn them about increased risk of encountering deer on roadways during the months of October, November, and December. This is the time of year when deer movement, associated with breeding behavior, increases and likely increases the frequency of deer crossing roads. The mid-October to December time period is when dusk and dawn, daily times of greatest deer movement, coincides with commuting traffic.

APPENDICES

EXAMPLE INTERPRETATION OF ODDS RATIOS

Odds ratios for road class, number of lanes, and study area counties (Appendix Table 1)

On rural roads in Monroe County the odds of a DVC happening on roads >2 lanes compared to roads ≤2 lanes was 0.47 (117/249) while the same odds for a non-DVC location was 0.045 (14/308). In Monroe county the odds ratio between DVC and non-DVC locations given rural roads and >2 lanes is 10.35 (0.47/0.045) meaning that the conditional odds of a DVC happening on a rural road >2 lanes compared to ≤2 lanes is 10.35 times higher than for a non-DVC location. Similarly the conditional odds of a DVC happening on an urban road >2 lanes compared to ≤2 lanes is 5.91, 4.00, and 2.37 times higher than for a non-DVC location in Monroe, Washtenaw, and Oakland counties. The sample mean odds ratio given rural roads, >2 lanes versus ≤2 lanes is higher when compared to urban roads, >2 lanes versus ≤2 lanes across all 3 study area counties. The same was also true for relative risk given rural roads and >2 lanes compared to ≤2 lanes. From this observation we notice the relationship between the odds ratio and relative risk.

I.e.

Odds ratio DVC vs. non-DVC for [Monroe | Rural (>2 lanes vs. ≤2 lanes)] = Relative Risk (Monroe | Rural | >2 lanes) / Relative Risk (Monroe | Rural | ≤2 lanes)

Appendix Table 1. Odds ratios and 95% confidence intervals between DVC and non-DVC locations given road class and number of lanes in Monroe, Washtenaw, and Oakland counties, Michigan, 1999–2001.

COUNTY	CONSTANT	GROUP	ODDS RATIO	95% CI	
				LOWER	UPPER
MONROE	RURAL	>2 Lanes vs. ≤2 Lanes	10.34	5.79	18.44
	URBAN		5.91	2.76	12.67
WASHTENAW	RURAL		6.68	3.75	11.89
	URBAN		4.00	2.40	6.66
OAKLAND	RURAL		5.53	1.28	23.93
	URBAN		2.37	1.59	3.52
MONROE	≤2 Lanes	RURAL vs. URBAN	1.75	1.22	2.52
	>2 Lanes		3.06	1.26	7.43
WASHTENAW	≤2 Lanes		1.94	1.33	2.82
	>2 Lanes		3.24	1.61	6.53
OAKLAND	≤2 Lanes		4.02	2.88	5.62
	>2 Lanes		9.39	2.13	41.32

Appendix Table 2. Odds ratios and 95% confidence intervals between DVC and non-DVC locations given road class and speed limit in Monroe, Washtenaw, and Oakland counties, Michigan, 1999–2001.

COUNTY	CONSTANT	GROUP	ODDS RATIO	95% CI LOWER	95% CI UPPER
MONROE	RURAL	Medium vs. Low	12.32	5.26	28.89
		High vs. Low	128.98	44.90	370.57
		High vs. Medium	10.47	5.35	20.48
	URBAN	Medium vs. Low	3.60	1.82	7.12
		High vs. Low	7.94	2.45	25.71
		High vs. Medium	2.21	0.62	7.14
WASHTENAW	RURAL	Medium vs. Low	3.52	2.10	5.88
		High vs. Low	6.12	2.85	13.14
		High vs. Medium	1.74	0.93	3.27
	URBAN	Medium vs. Low	3.13	1.77	5.54
		High vs. Low	7.23	3.38	15.45
		High vs. Medium	2.31	0.97	5.52
OAKLAND	RURAL	Medium vs. Low	71.38	23.58	216.05
		High vs. Low	86.00	14.33	516.03
		High vs. Medium	1.20	0.26	5.56
	URBAN	Medium vs. Low	43.10	19.58	94.87
		High vs. Low	4.04	1.90	8.61
		High vs. Medium	0.09	0.03	0.27
MONROE	Low	URBAN vs. RURAL	4.85	1.96	11.99
	Medium	URBAN vs. RURAL	1.41	0.77	2.60
	High	URBAN vs. RURAL	0.30	0.08	1.09
WASHTENAW	Low	URBAN vs. RURAL	1.07	0.62	1.85
	Medium	URBAN vs. RURAL	0.95	0.55	1.64
	High	URBAN vs. RURAL	1.26	0.50	3.20
OAKLAND	Low	URBAN vs. RURAL	3.99	1.41	11.33
	Medium	URBAN vs. RURAL	2.41	1.01	5.76
	High	URBAN vs. RURAL	0.19	0.04	0.97

Appendix Table 3. Odds ratios and 95% confidence intervals between DVC and non-DVC locations given road class and traffic volume in Monroe, Washtenaw, and Oakland counties, Michigan, 1999–2001.

COUNTY	CONSTANT	GROUP	ODDS RATIO	95% CI	
				LOWER	UPPER
MONROE	RURAL	>120 vs. ≤120 vehicles/hr	14.50	9.23	22.76
	URBAN		18.95	9.33	38.51
WASHTENAW	RURAL		7.62	5.18	11.19
	URBAN		38.60	17.15	86.88
OAKLAND	RURAL		25.89	12.06	55.56
	URBAN		28.00	17.37	45.15
MONROE	≤120 vehicles/hr	RURAL vs. URBAN	3.73	2.10	6.64
	>120 vehicles/hr		2.86	1.55	5.27
WASHTENAW	≤120 vehicles/hr		9.71	4.36	21.62
	>120 vehicles/hr		1.92	1.27	2.88
OAKLAND	≤120 vehicles/hr		6.81	3.77	12.27
	>120 vehicles/hr		6.29	3.18	12.43

Appendix Table 4. Odds ratios and 95% confidence intervals between DVC and non-DVC locations given number of lanes and speed limit in Monroe, Washtenaw, and Oakland counties, Michigan, 1999–2001.

COUNTY	CONSTANT	GROUP	ODDS RATIO	95% CI	
				LOWER	UPPER
MONROE	≤2 Lanes	Medium vs. Low	4.18	2.86	6.11
		High vs. Low	NA	NA	NA
		High vs. Medium	NA	NA	NA
	>2 Lanes	Medium vs. Low	2.14	0.49	9.35
		High vs. Low	6.22	1.74	22.25
		High vs. Medium	2.90	0.99	8.53
WASHTENAW	≤2 Lanes	Medium vs. Low	2.76	2.01	3.79
		High vs. Low	NA	NA	NA
		High vs. Medium	NA	NA	NA
	>2 Lanes	Medium vs. Low	40.20	8.41	192.17
		High vs. Low	3.36	1.79	9.31
		High vs. Medium	0.08	0.04	0.76
OAKLAND	≤2 Lanes	Medium vs. Low	6.22	4.01	9.64
		High vs. Low	NA	NA	NA
		High vs. Medium	NA	NA	NA
	>2 Lanes	Medium vs. Low	23.55	6.52	85.08
		High vs. Low	4.08	1.81	9.24
		High vs. Medium	0.17	0.05	0.65
MONROE	Low	>2 Lanes vs. ≤2 Lanes	5.70	1.72	18.85
	Medium		2.92	1.14	7.47
	High		NA	NA	NA
WASHTENAW	Low		2.07	1.00	4.30
	Medium		30.18	7.30	124.86
	High		NA	NA	NA
OAKLAND	Low		1.88	1.07	3.34
	Medium		1.72	0.50	5.90
	High		NA	NA	NA

Appendix Table 5. Odds ratios and 95% confidence intervals between DVC and non-DVC locations given number of lanes and traffic volume in Monroe, Washtenaw, and Oakland counties, Michigan, 1999–2001.

COUNTY	CONSTANT	GROUP	ODDS RATIO	95% CI LOWER	95% CI UPPER
MONROE	≤2 Lanes	>120 vs. ≤120 vehicles/hr	10.40	6.70	16.15
	>2 Lanes		4.88	1.02	23.26
WASHTENAW	≤2 Lanes		8.18	5.81	11.51
	>2 Lanes		2.31	0.37	14.27
OAKLAND	≤2 Lanes		29.03	19.56	43.09
	>2 Lanes		3.23	0.74	14.09
MONROE	≤120 vehicles/hr	>2 Lanes vs. ≤2 Lanes	3.07	0.68	13.86
	>120 vehicles/hr		1.44	0.79	2.63
WASHTENAW	≤120 vehicles/hr		5.15	0.85	31.25
	>120 vehicles/hr		1.45	0.95	2.22
OAKLAND	≤120 vehicles/hr		3.59	0.83	15.44
	>120 vehicles/hr		0.40	0.26	0.62

Appendix Table 6. Odds ratios and 95% confidence intervals between DVC and non-DVC locations given traffic volume and speed limit in Monroe, Washtenaw, and Oakland counties, Michigan, 1999–2001.

COUNTY	CONSTANT	GROUP	ODDS RATIO	95% CI LOWER	95% CI UPPER
MONROE	≤120 vehicles/hr	Medium vs. Low	10.13	5.33	19.25
		High vs. Low	14.64	0.86	250.10
		High vs. Medium	1.45	0.09	23.27
	>120 vehicles/hr	Medium vs. Low	1.97	0.94	4.16
		High vs. Low	3.67	1.61	8.40
		High vs. Medium	1.86	0.90	3.85
WASHTENAW	≤120 vehicles/hr	Medium vs. Low	8.50	4.46	16.17
		High vs. Low	NA	NA	NA
		High vs. Medium	NA	NA	NA
	>120 vehicles/hr	Medium vs. Low	2.56	1.61	4.05
		High vs. Low	1.76	1.00	3.10
		High vs. Medium	0.69	0.40	1.20
OAKLAND	≤120 vehicles/hr	Medium vs. Low	31.98	15.84	64.55
		High vs. Low	NA	NA	NA
		High vs. Medium	NA	NA	NA
	>120 vehicles/hr	Medium vs. Low	15.45	7.94	30.07
		High vs. Low	1.73	0.88	3.43
		High vs. Medium	0.11	0.05	0.27
MONROE	Low	>120 vs. ≤120 vehicles/hr	37.08	15.78	87.15
	Medium		7.23	4.43	11.79
	High		9.31	0.55	157.77
WASHTENAW	Low		23.31	11.88	45.72
	Medium		7.01	4.63	10.62
	High		NA	NA	NA
OAKLAND	Low		23.51	13.70	40.34
	Medium		11.36	5.09	25.35
	High		NA	NA	NA

LITERATURE REVIEW

Deer movement related to deer-vehicle collisions

Deer movement that results in crossing roads may be divided into 3 major types. They are 1) seasonal movement, 2) daily activity rhythms, and 3) movements outside the home range. Seasonal movements comprise dispersal (emigration and immigration) and migration to and from winter range. Daily activity rhythms may be defined as the everyday cycle followed by deer within their home range. Wiles et al. (1992) described movement outside a home range as falling into 3 categories: 1) exploratory trips, 2) temporary flights from disturbances, and 3) permanent dispersals. Exploratory trips were defined as voluntary excursions outside home range from a few hours to many days. Temporary flights of deer may be caused by disturbances such as hunters entering the home range. Flights from home ranges occurred during the shotgun season but not during the archery season. The proposed reasons given for this difference were availability of escape cover and hunter density. Free ranging domestic dogs also may cause deer to temporarily flee their home range (Wiles et al., 1992). Permanent dispersals are categorized as occasional seasonal movement and should be classified as thus rather than as movement outside the home range.

Deer often feed in right-of-ways (ROWs) (Feldhamer et al. 1986; Waring et al. 1991) and to cross the highway/road requires risk-taking behavior. Waring (1991) found that deer typically walk to the highway and stop at the edge of the pavement before crossing. Crossing behaviors were described as being relaxed and cautious in the case of adult does, less cautious and following adult does in the case of fawns, and with excitement in the case of adult and yearling males.

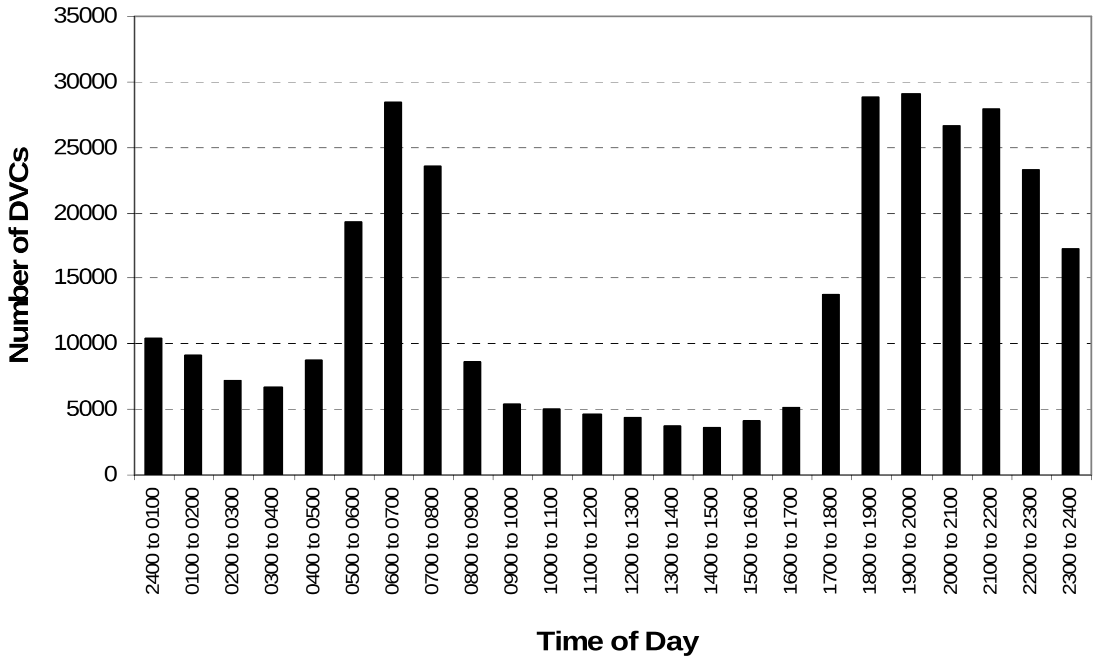
The probability of deer survival may depend on whether crossing highways or roads is due to seasonal movement, part of its daily activity rhythm, or movement outside their home range (exploratory, temporary flight). One can think of the daily activity rhythm as being a daily probability (of successfully crossing a road) versus seasonal movement, and movement outside the home range which are less frequent probabilities. The survival probability of a deer crossing a highway or road as part of its daily activity rhythm may be likely lower than the survival probability of a deer involved in highway or road crossing as part of its seasonal movement pattern.

Daily Activity Rhythms of Deer

Studies have shown that deer are most active during dusk and dawn (Montgomerey 1963; Zagata et al. 1974; Carbaugh et al. 1975; Wiles et al. 1986; Waring et al. 1991). Montgomery (1963) found that deer in Pennsylvania spent the daytime in wooded areas and moved into open fields for grazing 1 or more hours before sunset in the winter and during sunset in the summer. Deer typically grazed for 4 hours after sunset in the winter and for 7-8 hours after sunset in the summer before bedding for the night. Montgomery observed that deer typically moved back into wooded areas just before dawn. Zagata et al. (1974), studying the observability of Iowa deer, concluded that a significant relationship existed between the number of deer sighted and the time of sunrise as well as the time of sunset. The relationship between observability and time of sunrise had a negative slope indicating that lower numbers of deer were observed the further one was away from sunrise. The relationship between observability and time of sunset however had a positive slope indicating that more deer were observed after sunset while light permitted. The findings by Zagata in Iowa deer are consistent with Montogomery's observations with

Pennsylvania deer. Carbaugh et al. (1975) found deer at two study sites in Pennsylvania to follow the pattern of feeding in right-of-ways at dusk for a few hours and moving back into woods during the day. Wiles et al. (1986), studying use patterns of Indiana deer visiting natural licks, found peak activity to be 1-2 hours after sunset and occasionally a second peak was observed 3-4 hours after sunset. Waring et al. (1991) observed that deer roadside activity was most pronounced between 17:00 and 07:00 h and that deer feed on the grassy right-of-ways.

Allen and McCullough (1976) observed that in ten counties in southern Michigan most DVCs occurred between 16:00 and 02:00 hours; however there were 2 spikes in DVCs during a 24 hour period: at sunrise and 1 to 2 hours after sunset. They found that traffic volume was not correlated to DVCs for all hours of the day due to changing deer activity but traffic volume was highly correlated to DVCs during 18:00 and 07:00 h ($R^2 = 0.854$). It is significant that traffic volume explained 85% of the variation in DVCs when deer activity had settled down to approximately a constant (hours of dusk). Analysis of DVC data for the years 1997 to 2001 in Michigan shows the two peaks in DVCs occurring between 05:00 and 08:00 h in the morning and between 18:00 and 24:00 h in the evenings (Appendix Figure 1). This bimodal daily pattern is a common feature of DVCs in Michigan even today. Given the dawn and dusk activity pattern of deer it is reasonable to expect DVCs to be correlated with this pattern.



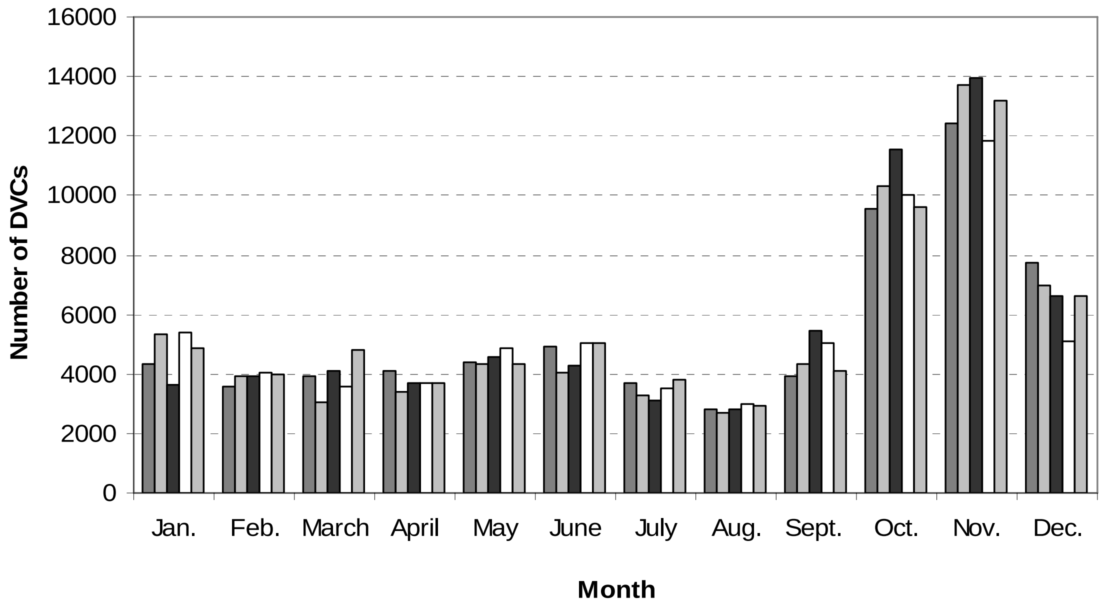
Appendix Figure 1. Deer-vehicle crashes by Time of Day in Michigan, 1997−2001 (Michigan Crash Data, Office of Highway Safety Planning).

Seasonal Movement in Deer

The time of year when DVCs are most prevalent is early winter (October through December) and spring (May through June) (Bellis et al. 1971; Puglisi et al. 1974; Carbaugh et al. 1975; Allen and McCullough 1976; Etter et al. 2002). The major peak in DVCs, which happens in the early winter months, has been attributed to increased deer movement during the rut (Allen and McCullough 1976). Movement during this time also may be influenced by hunting (Sparrowe et al. 1970; Allen et al. 1976). Naugle et al. (1997) found deer home range size was greater during the hunting season than before and was a result of increased deer movement into escape cover. Analysis of the sex ratio of deer killed during early winter was skewed towards males and this supports the hypothesis that DVCs in early winter is mainly a result of the rut (Allen and McCullough 1976; Etter et al. 2002). Another reason for the early winter peak in

DVCs may be due to fall migration in deer. Fall migration is common among northern deer and coincides in places such as Michigan with the hunting season (Van Deelen et al. 1998). Fourteen out of nineteen yearling deer studied by Nelson (1998) in northeastern Minnesota migrated in early November and early December. Fall migration largely has been ignored as a factor in DVCs and may be an important factor in northern deer. In northern deer migratory behavior is a result of both genetic and adaptive behavior (Nelson 1998); however in southern deer it is not known whether they have the genetic capacity to migrate (Marchington et al. 1991).

The cause of the minor peak in DVCs during May and June has been linked to spring dispersal movement of deer (Puglisi et al. 1974), however Allen and McCullough (1976) linked it to antler development in male deer (sex ratio of deer killed in DVCs was skewed towards males), which causes restlessness and hence increased movement. The sex ratio observed in DVCs during May and June differed between Michigan (more male than female) (Allen and McCullough 1976) and Pennsylvania (more females than males) (Puglisi et al. 1974). Current knowledge seems to suggest spring dispersal is the cause of the smaller spike in DVCs. In the Piatt County, Illinois, 51% of male fawns (less than 12 month old deer), 50% of female fawns, and 21% of yearling (12-24 month old deer) dispersed during the months of April through June (Nixon et al., 1991). Between March and May, 20% of resident winter does (older than 24 months) also migrated away from the study area. These dispersal times coincide with the timing of the smaller peak in DVCs. During early spring the use of mineral licks by deer also increases (Wiles et al. 1986). In a suburban environment like Chicago the risk to fawn survival due to DVCs increases during spring (Etter et al. 2002). Typical road crossings by matriarchal groups were lead by adult does that timed their crossing run with a break in traffic (Etter et al. 2002). Etter et al. (2002) suggest the high DVCs involving yearling and fawns during spring may be due to absence of adult does to lead the crossings. In Bloomington, Minnesota urban deer with very large home range sizes during spring were exposed to roadways regularly and often died in DVCs (Grund et al. 2002).



Appendix Figure 2. Deer-vehicle crashes by month in Michigan, 1997−2001 (Michigan Crash Data, Office of Highway Safety Planning).

DVC data for Michigan (1997 to 2001) follows a similar bi-modal distribution even though the spring peak (May and June) is less pronounced (Appendix Figure 2). The early winter months (October through December) account for 45.16% of all DVCs (Figure 2). It is important to note that the increase in DVCs starts in October while hunting season in Michigan begins on November 15th each year. It is possible that the early winter spike is predominantly a factor of the rut and not hunting activities, which is supported by Allen and McCullough (1976).

Michigan has varied land use patterns throughout the state and deer present in different regions have different behavior patterns. Northern deer found in upper Michigan have different behavior patterns compared to southern deer found in the lower half of the state. For example, migratory behavior is well documented in deer in the upper Michigan (Verme 1973; Van Deelen et al. 1998) but such behavior has not been reported in southern deer (Pusateri, 2003). Deer in the suburbs of Detroit may exhibit behavior similar to deer adapted to living in other urban areas. Depending on the region where a DVC occurred the reasons deer cross roads may differ. Examining state wide DVCs does not address this problem of scale. This research project focuses on deer in southern Michigan and its external validity may be most relevant with regards to southern deer.

Past Research on DVC Site Characteristics

There have been few studies that have rigorously examined DVC site characteristics. The few studies conducted on the effects of habitat on DVCs often show conflicting results making broad conclusions region/landscape specific. For example; results of studies conducted in Pennsylvania (Bellis and Graves 1971; Bashore et al. 1985) differ from those in Michigan (Allen and McCullough 1976), Illinois (Finder et al. 1999), and Iowa (Hubbard et al. 2000). This is not surprising given the different landscapes and the different statistical techniques used in the studies, but also because the DVCs studied were along different road types - interstate highways (Interstate 80) (Bellis and Graves 1971; Puglisi et al. 1974), two-lane highways (Bashore et al. 1985), state highways (U.S. 127, M-24, M-46) (Allen and McCullough 1976), and all roads (Finder et al. 1999, Hubbard et al. 2000). There are some common findings between studies but generalizations made across landscapes based on any one or some of these studies should be done with caution.

Bellis and Graves (1971) attempted to correlate various vegetation and physiographic characteristics of ROWs (where observed deer numbers were high) with the number of total deer killed on the traffic lanes within these segments in Pennsylvania. The correlation between percent of grass, vetch, clover, and forbs and the number of deer killed within these segments were so low as to have no predictive value. Similar low R^2 values were obtained for slope of ROWs, area of ROWs, and presence or absence of fences and guardrails (most were less than 63 inches high). However an analysis of combined highway features indicated that deer mortality was higher in a) road sections present in troughs with steep banks and inclines on ROWs on the other side; b) road sections were troughs were prevented by lowering the elevation of median strips; and c) road sections were both sides of the road along with the median strip were relatively flat and offered feeding opportunities. Puglisi et al. (1974) studying the effects of fences on highway mortality of deer in Pennsylvania found that in areas with no fences the mean deer killed per mile was significantly high where one side of the road was wooded and the other side was a field.

DVC collision sites were however reported to be randomly distributed with regards to adjoining habitat type in Michigan except where deer trails might be present (Allen and McCullough, 1976).

Bashore et al. (1985) modeling DVC sites on two-lane highways in Pennsylvania found that the probability of a DVC decreased when there was an increase in residences, commercial buildings, other buildings, shortest visibility, speed limit, distance to woodland, and fencing next to the highway. Buildings and residences, which contribute to higher human activity, loss of habitat, and act as barriers to movement were all hypothesized as potential reasons for the negative relationship. With regards to shortest visibility, drivers who see deer early are less likely to be in a DVC. The negative relationship between speed limit and DVC sites may be because a) as speed limit increases deer are less likely to want to cross the road (a barrier effect) or b) more likely is that actual vehicle speeds do not match the prescribed speed limit. The negative relationship of distance to woodland may be explained by deer behavior where they tend to stay close to wooded habitat when feeding or while moving. The two variables that increased the probability of a DVC were in-line visibility (distance where an observer 1m from the highway center line could not view an optical density board 2m high placed 10m away from the highway edge) and amount of non-wooded area next to the highway. Bashore et al. (1985) suggest that in areas where the highway is relatively clear drivers travel at high speed and often miss deer crossing from a blind spot.

Finder et al. (1999) established that the most important predictor of high DVC sites in Illinois was distance to forest cover. The greater the distance to forest cover the lower the probability of a road segment being a high DVC area. This is in agreement with results from Bashore et al. (1985). Other factors that increased the probability of a road segment being a high DVC area included occurrence of nearby gullies, riparian travel corridors traversing the road, and public recreational land within a 0.8 km radius. DVC ‘hotspots’ had significantly greater number of residences directly contradicting Bashore et al. (1985). The logic behind this finding is that residential areas and public recreational areas act as refuges from hunting, frequently provide wooded habitat or food plots, and may have higher deer densities. The finding that riparian travel corridors are areas of higher DVC incidence support Allen and McCullough (1976). Gullies next to road segments decrease the visibility of deer and motorists to each other until a crash is inevitable. The importance of topography reported by Bellis and Graves (1971) is further substantiated by this finding. A landscape matrix model used by Finder et al. (1999) indicates that areas with abundant forest patches and uniformly dispersed habitat types (results in high deer densities) when combined with high traffic flows provides the right combination for increased DVC levels.

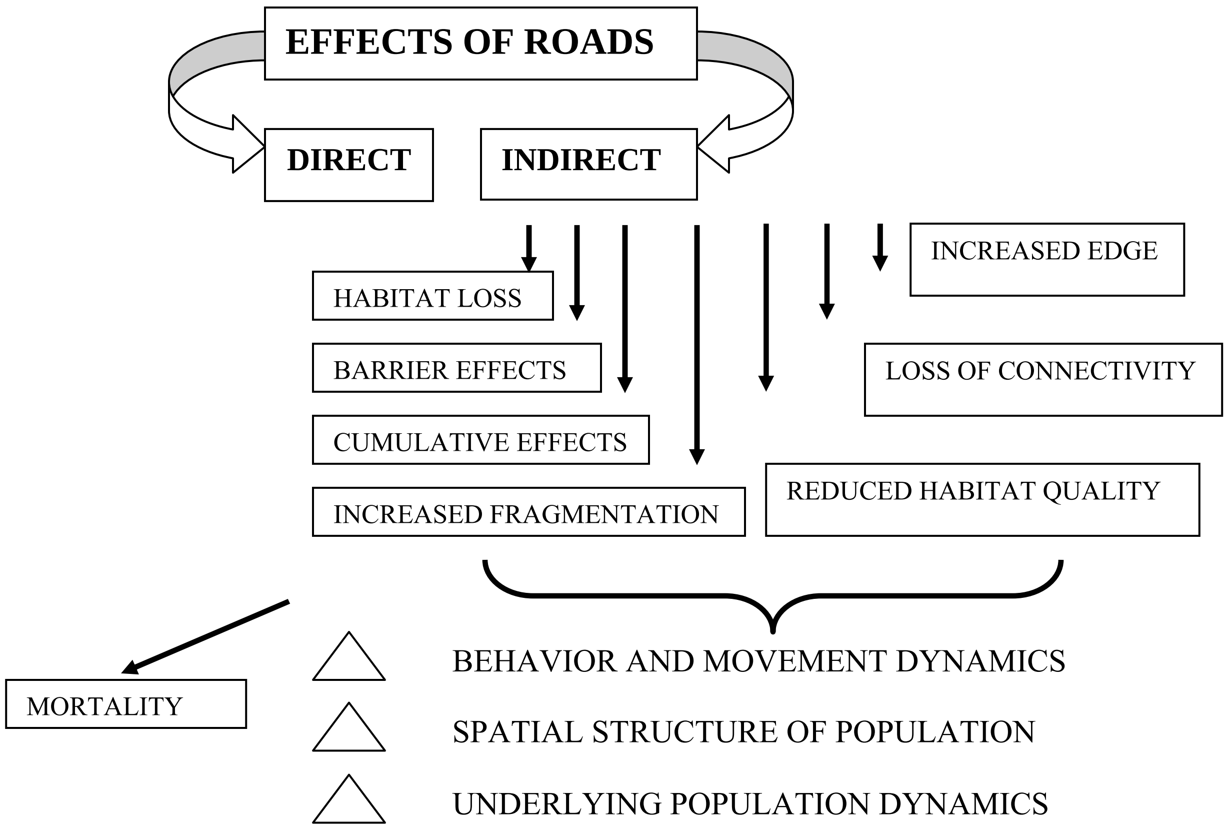
Hubbard et al. (2000) studying DVCs in Iowa found that the probability of a DVC increased with number of bridges and lanes of traffic. They suggest that bridges act as corridors and funnel deer across the highway and hence the positive relationship. This supports Finder et al. (1999) who also found riparian corridors to be a significant predictor of DVC ‘hotspots’.

In an urban environment (suburbs of Minneapolis, Minnesota) DVC areas compared to control areas were most affected by number of buildings and number of public land patches (Nielsen et al. 2003). DVC areas were observed to have fewer buildings supporting Bashore et al. (1985) and contradicting Finder et al. (1999). Nielsen et al. (2003) suggest that buildings are an indicator of increased human activity and an urban landscape with well-maintained lawns and parking lots do not provide adequate foraging or cover value to deer. DVCs were higher on roads next to or on public lands because these areas provided high quality habitat leading to increased localized densities of deer. This finding along with the reported high incidence of DVCs in more diverse landscapes (Shannon’s diversity index was used) are in accord with Finder et al. (1999).

It is clear from these studies that habitat factors that comprise or contribute to DVC ‘hotspots’ may vary between landscapes. In Michigan the only study done on DVCs was by Allen and McCullough (1976). The results of Allen and McCullough (1976) may or may not be applicable today, as the Michigan landscape has changed in the last thirty years. In southern Michigan areas have typically become more urbanized. This study will shed light on habitat factors that influence DVC locations in southern Michigan in this present time.

Road Effects and Deer Ecology

Road effects may be defined as the ecological effects that extend outward from a road. The area over which these ecological effects are significant is called the “road-effect zone” (Forman and Deblinger 1999). Road effects may be both direct and indirect (Bissonette and Logan 2002). An example of a direct road effect is road mortality. Road mortality of white-tailed deer is well documented. In Michigan it was estimated that 92% of deer in a collision die as a result (Allen and McCullough 1976). Decker et al. (1990) indicate that the problem may be more serious since only one out of six deer hit were counted. Examples of indirect road effects include habitat degradation, barrier effects, increased edge, reduced habitat quality etc. Indirect effects on a species can impact its behavior and movement dynamics, change the spatial structure of population, and change population dynamics (Appendix Figure 3; modified from Bissonette and Logan 2002). Furthermore, the indirect effects of roads on a species can often be more important than direct effects (Bissonette and Logan 2002). Indirect effects and their impact on the spatial structure of deer populations and population dynamics have not been studied.

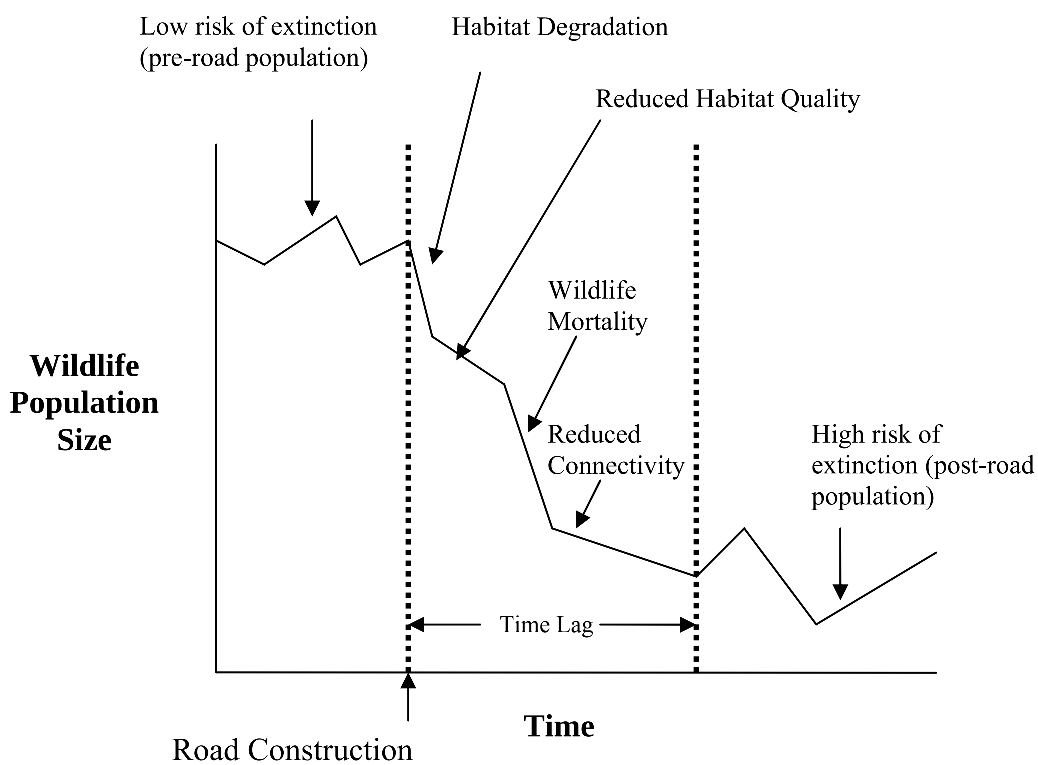


Appendix Figure 3. Direct and Indirect effects of roadways that may impact populations of different species (modified from Bissonette and Logan 2002)

There are certain qualities (attraction to road habitat, high intrinsic mobility, habitat generalist, multiple-resource needs, low density/large area requirement, and low reproductive rate) that make some species more susceptible to road mortality (a direct effect) than other species.

Out of the 6 qualities (attraction to road habitat, high intrinsic mobility, habitat generalist, multiple-resource needs, low density/large area requirement, and low reproductive rates) outlined by Forman et al. (2003) deer possess 4. Deer are attracted to vegetation (Carbaugh et al. 1975; Feldhammer et al. 1986; Waring et al. 1991) and salt along roadsides (Wiles et al. 1986). Deer display high intrinsic mobility; they may disperse during spring (Puglisi et al. 1974) and move extensively during the rut (Allen and McCullough 1976). In northern deer there are also well-developed migratory movements to and from wintering areas (Verme 1973; Van Deelen et al. 1998). Deer are also habitat generalists and require multiple resource needs to be met. The two qualities that would make deer populations even more susceptible to road mortality that they lack are low density/large area requirement and low reproductive rates. The four qualities that deer do possess may provide a possible explanation to the magnitude of the DVC problem in Michigan and elsewhere.

Indirect effects of roads can be cumulative and often go undetected due to a time lag (Forman et al. 2003). The immediate effect of roads is habitat degradation, followed by wildlife mortality, and reduced connectivity (Appendix Figure 4; modified from Forman et al. 2003). Each of these processes occurs at varying rates and after a time lag the population of a species can be affected positively or negatively. For example, species that have benefited from roads include meadow voles (*Microtus pennsylvanicus*) (Getz et al. 1978), pocket gophers (*Thomomys bottae*) (Huey 1941), cane toads (*Bufo marinus*) (Seabrook and Dettman 1996). Examples of negatively affected species include Iberian lynx (*Lynx pardalis*) (Ferreras et al. 1992) and woodland birds (Foppen and Reijnen 1994).



Appendix Figure 4. Cumulative effect after a time lag of four ecological effects of roads on an animal population (modified from Forman et al. 2003).

In Michigan the cumulative effect of roads on the deer population has not been studied. The population of deer in the state has grown in the last 50 years and it is estimated by the Michigan Department of Natural Resources (MDNR) that the current population size is between 1.5 and 2 million individuals. The 120,000 miles of roadways seem to have no significant impact on the total deer population within the state; however the impact of roads on local deer populations is unknown. It is easy to make the erroneous conclusion that ecological and anthropogenic effects that contribute to growth in the deer population are stronger than the four ecological effects of roads (Figure 5). The preceding statement is erroneous because it fails to consider the issue of scale. It may be that areas with high road density are biological sinks, areas that represent low quality habitats not capable of maintaining a stable deer population without continuous external input from other habitats (Forman et al. 2003). Road effects on deer population should be studied and interpreted at a consistent scale; viewing system performance at a broad scale may lead to incorrect conclusions.

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