

**ANALYSIS OF LANDSCAPE CHARACTERISTICS
SURROUNDING DEER VEHICLE ACCIDENTS
IN ST. LOUIS COUNTY, MISSOURI**

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By
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VEHICLE ACCIDENTS IN ST. LOUIS COUNTY, MISSOURI

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TABLE OF CONTENTS

ACKNOWLEDGEMENTS	II
LIST OF FIGURES	V
LIST OF TABLES	IX
ABSTRACT	XIII
1 INTRODUCTION	1
BACKGROUND	1
<i>Road Ecology</i>	1
<i>History of deer in US and Missouri</i>	2
<i>Deer Habitat</i>	5
HUMAN-DEER CONFLICTS.....	6
<i>Relevant Literature</i>	11
STUDY RELEVANCE	14
RESEARCH OBJECTIVES.....	15
STUDY AREA.....	16
2 METHODS	20
DATA DESCRIPTION.....	20
<i>Point Map of DVA's</i>	22
<i>Random Points</i>	24
<i>K function</i>	24
<i>Road Density</i>	27
<i>Land Use/Land Cover Classes</i>	27
Grassland.....	32
Forest.....	33
Water, Wetland, Cropland (WWC)	34
Low Intensity Urban (LIU)	35
High Intensity Urban (HIU)	36
<i>Intersections of Streams and Roads</i>	37
<i>Slope</i>	38
<i>Aspect</i>	38

MODEL	39
<i>Model Validation</i>	40
<i>Land Use/Land Cover Classes in model categories</i>	40
<i>Comparison of DVA's in model categories and road types</i>	41
3 RESULTS	42
K FUNCTION.....	42
ROAD DENSITY	42
LAND USE/LAND COVER CLASS VARIABLES.....	49
<i>Distance to Grassland</i>	52
<i>Distance to Forest</i>	56
<i>Distance to Water, Wetland, Cropland</i>	60
<i>Distance to High and Low Intensity Urban</i>	60
INTERSECTIONS OF STREAMS AND ROADS	64
SLOPE AND ASPECT	64
MODEL	68
<i>Model Validation</i>	75
<i>Land Use/Land Cover Classes in model categories</i>	77
<i>Comparison of DVA's in model categories and road types</i>	80
4 DISCUSSION	83
K FUNCTION.....	83
ROAD DENSITY	84
LAND USE/LAND COVER CLASS VARIABLES.....	86
<i>Distance to Grassland</i>	86
<i>Distance to Forest</i>	87
<i>Distance to Water, Wetland, Cropland</i>	88
DISTANCE TO INTERSECTIONS OF STREAMS AND ROADS.....	88
MODEL	89
<i>Distance to grassland/road density</i>	90
Model Validation.....	90
Land Use/Land Cover Classes in model categories	91
Comparison of DVA's in model categories and road types	93
5 CONCLUSION	94
MANAGEMENT IMPLICATIONS.....	96
LITERATURE CITED.....	99

LIST OF FIGURES

- Figure 1. Road Network in St. Louis County, Missouri. This includes all major highways and roads under MoDOT supervision, as well as private roads, obtained from the St. Louis County Planning Department. All DVA's and random points in this study fall within this network of roads. 18
- Figure 2. Map of Ecological Subsections in St. Louis County, Missouri. The majority of the county is in the Outer Ozark Border Subsection, with the Mississippi and Missouri Alluvial Plains subsections making up the rest of the county..... 19
- Figure 3. DVA locations in St. Louis County from 2000-2004. There are a total of 861 points, mapped out by the Missouri Department of Conservation. They represent carcasses from private roads and roads under MoDOT supervision. 23
- Figure 4. Random points located in the road network of St. Louis County. 861 points were created using R statistical software. This is the same number of points as the DVA's . They were used for comparison with the actual DVA points that occur within the same network of roads. All statistical tests were performed on the random and actual DVA points for comparison. 26
- Figure 5. Land Use/Land Cover categories for St. Louis County, Missouri. These are the original 12 categories generated by MoRAP. These categories were further broken down into five classes for this study (see Figure 10). 30

Figure 6. Analysis of K function for DVA's. This graph shows that DVA's are in fact clustered. If they occurred on the dotted line, they would be configured randomly throughout the landscape, and if below the dotted line, they would be regularly configured. 44

Figure 7. Percent variance explained by road density when comparing random points and DVA points, for different search radii. The percent variance continues to increase as search radius distances increase until it reaches 3000 m, at which point the variance then decreases. The 2500 m search radius had the largest percent variance, thus this was the radius used for this variable. 45

Figure 8. Grid of road densities using 2500 m search radius. The input was the entire road network for St. Louis County shown in Figure 1. DVA points are overlain on top. Very few DVA's fall in the high road density regions (pink), and most fall in the dark blue areas of medium road density. 46

Figure 9. Line chart showing number of points (DVA and Random) falling between ranges of road densities (expressed in km/km²), based on 2500 m search radius. The majority of DVA points fall in the medium road density ranges, and the random points fall throughout the ranges, with many in the higher ranges of densities. The random points have a higher overall average road density than the DVA's because very few DVA's fall in the areas of high road density which occur mostly in the eastern half of St. Louis County. 48

Figure 10. Reclassified LULC classes for St. Louis County, Missouri. These classes were broken down from the original 12 classes obtained from MoRAP in order to simplify statistical comparisons between DVA points and random points in each LULC category. Classes were broken down in a manner that would reflect the ways deer in their habitat related to human land use..... 50

Figure 11. Grassland area in St. Louis County with DVA's overlain. The MoRAP LULC map was used to create this grassland layer for this study. A grid was calculated using ArcGIS showing the distances from grassland for any area on the map. Corresponding distances from grassland were then determined for each DVA and random point. 53

Figure 12. Line graph showing number of points (DVA and Random) falling at specified distances from grassland. The majority of random points were found further away from grassland than DVA's..... 55

Figure 13. Forested area in St. Louis County with DVA's overlain. The MoRAP LULC map was used to create a combined forested category above that was used for this study. A grid was calculated from this forested area to show all distances from forest. The corresponding distance from forest was then determined for each DVA and random point. 57

Figure 14. Line graph showing the number of DVA's and random points falling within specified distances from forested areas. A greater number of DVA's than random points are found closer to forested areas. There are approximately 100 more total DVA's than random points up until 112 meters from forests. The number of random points exceeds DVA points at distances greater than 112 meters from forest. 59

Figure 15. Area of Water, Wetland, and Cropland in St. Louis County. A grid from this map was created showing distances to these areas, from which the corresponding values for DVA's and random points were determined..... 61

Figure 16. Line graph depicting the proximity of DVA and random points to areas of water, wetland, and cropland. There are significantly more DVA's closer to these areas than there are random points. There are more random points than DVA points as the distance from WWC areas increases. 63

Figure 17. DVA's overlain on streams and roads. Note that DVA's appear to cluster around the junctions where streams cross roads, or very close to streams. The inset illustrates an example of DVA's that have occurred at these intersections..... 65

Figure 18. Line graph showing number of points (DVA and Random) falling at a range of distances from intersections of streams and roads. DVA's tend to fall closer to these intersections than random points..... 67

Figure 19. Reclassified distance to grassland categories used in model development. The three classes were created based on natural breaks of corresponding DVA values for this variable. The natural break values for all three classes can be seen in Table 13. The first class (dark green) represents areas of grassland that contain the most DVA's; they are closest to grassland. Likewise, the third class (pale green) contains the fewest DVA's in this category and is furthest from grassland. 70

Figure 20. Reclassified road density classes used for model development. These classes were created based on the natural breaks of road density values for each DVA. The dark grey category (2) represents the medium road density values, and contains the highest density of DVA's. The first and third categories represent low and high road density areas that contain fewer DVA's. 71

Figure 21. Map of reclassified combined two variable model using road density and distance to grassland. For simplicity, the categories in Table 14 were condensed from the nine categories to include only these four. Categories are numbered 1-4 from highest to lowest probability of containing a DVA. 74

Figure 22. LULC classes with DVA's overlain. The categorical breakdown of these classes was analyzed in the model categories. 78

Figure 23. Road network showing DVA's overlain on Private and MoDOT roads. DVA's on MoDOT roads are in navy, and DVA's occurring on private roads are shown in burgundy. 81

LIST OF TABLES

- Table 1. This table color codes the groups that were classified together for the LULC reclassification in St. Louis County, Missouri. The table shows the breakdown of area and percentages of the twelve original classes. The largest class is Low Intensity Urban and the smallest class is Herbaceous-Dominated Wetland. The total area of land covered by all 12 classes is 1356.7 km². 31
- Table 2. Summary of statistics between DVA and Random points for road density variable. Random points had a larger average road density, and a larger variance. There was slightly more variance between random points than between DVA's. 47
- Table 3. ANOVA statistics for DVA and Random points for road density variable. The percent variance explained by this variable was 10.08. The F value, at 192.81 was much higher than the critical F, and higher than any of the other tested variables. The P-value in this test shows that the probability these groups are the same is very low. 47
- Table 4. Reclassified LULC Map for St. Louis County, Missouri, with percentage and area breakdowns for the five classes. Low-Intensity Urban continues to comprise the largest area, with forest and grassland making up the second and third largest areas, respectively. 51
- Table 5. Summary of statistics between DVA and Random points for distance to grassland variable. On average, DVA's occurred about 50 meters closer to grassland than random points. There is a greater amount of variance between random points than between DVA points. 54

Table 6. ANOVA statistics for DVA and random points for distance to grassland variable. The percent variance explained by this variable was 7.27, and the F value far exceeded the critical F value, so this variable can be considered important. The very low P-value indicates there is a low probability that these groups are not the same. 54

Table 7. Summary of statistics for DVA's and random points for distance to forest variable. The average DVA was closer to forested areas than random points, at 111.3 and 141.66 meters respectively. There is slightly more variance between random points than there is between DVA points. 58

Table 8. ANOVA statistics for DVA's and random points for distance to forest variable. The F value exceeded the critical F value, so the two groups can be considered different from one another with regard to this variable. The P-value indicates these groups are significantly different, however with a percent variance of 1.54, this variable offers a low explanatory power..... 58

Table 9. Summary Statistics for Distance to Water/Wetland/Cropland. The average DVA was found almost 100 meters closer than the average random point to these areas. There is more variance between random points than there is between DVA's. 62

Table 10. Anova statistics between random and DVA points for Distance to Water/Wetland/Cropland. The F value is a lot higher than the critical F, indicating that this variable is important. The percent variance explained by this variable is 4.81, which is relatively high compared to other tested variables. 62

Table 11. Summary of statistics between DVA and Random points for distance to intersections of streams and roads. The average DVA distance to the intersection of roads and streams was 75 meters less than the average for random points. There is slightly more variance between random points than there is between DVA points. 66

- Table 12. ANOVA statistics for DVA and Random points for distance to intersections of streams and roads. The F value exceeded the critical F value, thus the random and DVA points can be considered different from one another. The very low P-value indicates that there is a very low probability that the two groups are the same. The percent variance explained by this variable was obtained by dividing between group variation by total variation. In this case this variable explained only 1.2% of the variance between the random and DVA groups. 66
- Table 13. Natural break values for variables used in model. DVA's exhibited a continuous range of values for each variable. These values were divided by natural breaks into three categories in ArcMap for the two tabulated variables. Distances up to 67.08 meters from grassland had the largest number of DVA's, as did the road density range between 5.13 and 7.78 km/km². 69
- Table 14. Combined two variable model using distance to grassland and road density. Categories are sorted by density, which is expressed in DVA's/km². The color coding shows the four final categories. The category where a DVA is most likely to occur is G1_RD2, close to grassland with medium road density. The density of DVA's in this category is 1.37 DVA's/km². The category least likely to have a DVA is G3_RD1, furthest from grassland, with low road density..... 73
- Table 15. Model applied to 2005 DVA's for validation. The categories with the highest densities are the same as the categories derived from the 2000-2004 data. A weighted density field was added to compare densities from this year's data to the original densities that were based on five years of data. Like the original data in the model, the top categories for 2005 also have DVA's close to grassland and with medium road density. 76

Table 16. Comparison of private versus state roads in model categories in St. Louis County. Private roads make up 8974.42 km and 90.8% of all roads in the county, but only 42.86% of DVA's occurred on these roads. MoDOT roads make up only 9.2% of all roads in the county, yet 57.14% of all DVA's occurred on MoDOT roads. Category 1 had 19.36% of all roads, of which 1.79% (of total roads) were MoDOT and 17.57% were private. 43.44% of all DVA's were in Category 1, which were split between private and MoDOT roads. 82

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ABSTRACT

Increased suburbanization of rural landscapes is leading to a greater number of human-animal interactions. One of the most dangerous and costly of these interactions is collisions between vehicles and white-tailed deer (*Odocoileus virginianus*). This study quantifies landscape factors that contribute to deer vehicle accidents in St. Louis County, Missouri, and provides a predictive model of areas in which DVA's would likely be found.

A Geographic Information System (GIS) was used to plot deer collisions and perform clustering analyses, in conjunction with ancillary data, to identify the surrounding landscape characteristics of DVA's. DVA's are spatially clustered within the road network more than random chance would allow. They are found in regions with average road density relative to other roads in St. Louis County, and close to grasslands. The analysis and model can be used as predictive tools during road planning and assessment stages. They will also be useful for identifying areas in which mitigation strategies can be implemented in regions prone to high deer vehicle accidents.

1 INTRODUCTION

Background

Road Ecology

In the past century, roads have become an integral part of a functioning human society. According to the National Research Council, the extensive network of public roads in the United States spans 6.2 million kilometers. These roads and roadsides represent 1% of the area of the land (Forman 2000). There are many direct and indirect effects of roads, ranging from blocking wildlife corridors and species isolation, to soil erosion and reduced water quality (Forman 2000).

Forman referred to these effects when he said, "the linkage between roads and wildlife is deeply ingrained in North America" (2003). Forman calculated that when the complex network of variables influencing the road-effect zone are taken into account, 22% of the contiguous United States is impacted ecologically by roads (2000). This may be a conservative estimate, as many ecological variables were excluded from this calculation, including the channelization of streams and rivers for road placement, and the spread of exotic species. Richard

Forman points out in his book, "Road Ecology," that the corridors roads form can act as barriers, conduits, source, sink, or habitat (2003). Roads can act as barriers by blocking species from movement. This can also create sinks of individuals of a species that can no longer interact or be sustained as a population. Landscapes are dynamic mosaics which are constantly changing over time (Turner et al. 2001), as a result of human or natural causes. The challenge for ecologists is to find a way for human and non-human occupants to harmoniously exist within this ever-changing landscape.

History of deer in US and Missouri

Among the many species affected by the ever-expanding network of roads are white-tailed deer (*Odocoileus virginiana*). National deer populations currently exceed 20 million (Cook and Daggett 1995). White-tailed deer were extirpated from the Midwest in the early 1900's due to habitat alterations and uncontrolled market hunting. In the 1930's, deer recovery in the Midwest began as a result of strict law enforcement and restocking with native deer from refuges and game farms (Halls 1984). The population of deer in Missouri was estimated at 15,000 in the early 1940's, and was up to 400,000 thirty years later (Hansen 2008). By 1995, deer populations in Missouri were up to 800,000, which is what they were

estimated to be in the 1600's, before modern weapons were introduced to Native Americans (Hansen 2008).

In the past 40 years white-tailed deer have been successfully managed to increasing populations in large part due to human activities in suburban areas.

In addition to taking advantage of conditions that have often provided favorable habitat, deer are often encouraged to visit human residences (Conover 2002).

Historically, landscapes were dominated by more late-successional species and more continuous canopy cover than today's landscapes (Waller and Alverson 1997). This, coupled with greater numbers of carnivorous predators, led to lower and more varying deer densities (Waller and Alverson 1997). Today, however, landscapes favor edge and disturbed habitats, which elevate deer densities throughout the region (Waller and Alverson 1997).

Deer are considered a keystone species since they affect many other species of plants and animals in the trophic hierarchy (Waller and Alverson 1997). Because of this interdependent relationship deer have with the habitat and other species, manipulating habitat can affect deer and sensitive species that are impacted by deer. Habitat modifications such as urban sprawl have had a direct impact on deer densities, contributing to increased populations. As trees have been cleared for strip malls and housing developments, edge habitat has increased, along with

favorable vegetation for deer to browse. Increased fragmentation of habitat has been correlated with higher deer populations in Missouri (Pullins 2004). In fact, deer densities are highly correlated with higher human populations and higher road densities (Mladenoff et al. 1995). Barriers like highways, fences, and large urban areas can prevent yearlings from dispersing (MDC 2005). This in turn can intensify deer densities in suburban areas. This emphasizes the consequences of habitat modification and manipulation that lead to increased deer densities.

As road densities increase, favorable browse increases along the road-sides, fields, and newly cleared forests, expanding available deer habitat (Pullins 2004).

Missouri has close to a million deer, and densities are higher in suburban areas than in rural areas (MDC 2005). Pre-human settlement deer densities in Missouri were estimated to be 10-30 deer/mi². Deer contended with species such as elk, bison, and black bears for space and resources, while historically wolves and mountain lions served as predators in the region (MDC 2005). The remaining population pressures today come from cars, people, coyotes, domestic dogs, and other deer (MDC 2005). As generalists, white-tailed deer occupy the areas where forests, which provide cover, interface with agricultural and residential suburban areas that provide forage for deer (MDC 2005).

While deer densities in rural parts of Missouri are between 5 and 15 deer/mi², below estimated pre-settlement densities, they are higher in suburban areas (MDC 2005).

Deer Habitat

A white-tailed deer's basic requirements include food, space, cover, and water, according to Fulbright and Ortegas (2006). Deer are browsers and selectively feed on forbs, grasses, fruit, and nuts (mast). They also like ornamental plants and garden vegetables, lichens, mushrooms, and fungi (Hiller 1996). Deer prefer the intersection of woods and fields or grassland and shrubs that provide a diversity of food, shelter, habitat components, and an abundance of edge (Hiller 1996). Logging often clears space for ground vegetation to grow, which in turn increases deer numbers. Nearby forests will provide cover for safety, bedding, and warmth (Fulbright and Ortega-S 2006). Ideal conditions for deer include a mixture of creeks, mixed growth forests, open areas, and corridors. This provides the optimum combination of food, water, shelter, and escape (Hiller 1996). The centers of white-tailed deer home ranges are often watering sites (Hiller 1996). Assuming all habitat resource needs are met, many deer spend their life in an area of only 200-350 acres (80-142 ha) at a given time (Hiller 1996). Home ranges in rural areas are significantly larger than in suburban areas, where

deer exhibit a high degree of site-fidelity, in areas of just 20-40 ha (Porter et al. 2004).

Human-Deer Conflicts

Deer densities are higher in suburban regions than rural and urban areas, and human-deer conflicts occur most commonly in these areas. In Missouri, 296 Deer Vehicle Accidents (DVA's) led to personal injury, and 3 precipitated human fatalities in 2006 (Police 2007). According to police reports, deer were involved in .5% of all fatalities involving cars, .6% of all vehicle-related personal injuries, and 3% of personal property damage to vehicles. According to State Farm Insurance, the average estimated property damage per deer vehicle collision was \$2,900 between July 1st, 2006 and June 30th, 2007 (2007). During this same period, the total number of State Farm Insurance claims for deer vehicle accidents in the United States was 205,121, up 6.3% from the previous year. Conover estimated the annual cumulative costs from DVA's in the United States to be over 1.2 billion dollars in the 1990's (1995). For the past several years, the projected number of deer vehicle accidents in the United States has been estimated at around 1 million (SFI 2007), equivalent to the estimated deer population in the entire state of Missouri . Incorporating updated insurance estimates, this

translates to about \$2.9 billion in damages per year. In Missouri, the insurance industry estimates that there were a total of 29,804 deer vehicle accidents in the 2006-2007 fiscal year. The total projected monetary losses to Missourians in this time period exceed \$86 million. Deer vehicle accident rates vary by state.

Motorists in West Virginia have the highest likelihood of hitting a deer, with 1 in 57 registered drivers per year. One in 154 Missourians risk a collision with deer.

State DNR's and Departments of Transportation (DOT's) are compiling statistics and data regarding animal vehicle collisions (AVC's) and trying to determine what they can do to prevent them from occurring (Huijser et al. 2007). As DNR agencies and DOT's collect overlapping information at times, often working towards overlapping goals, it would be most efficient for them to collaborate.

Each agency strives towards greater safety for motorists and wildlife. As DOT's continue to build roads that encroach into habitat and displace wildlife, it becomes incumbent upon them to create the smallest environmental footprint and do their best to prevent human-wildlife conflicts. Since DNR's have much of the expertise needed to prevent these conflicts, it is logical that they would work together. Recent legislation has been enacted to compel wildlife/conservation agencies to work together with state DOT's in making roads safer for wildlife and motorists and to have the smallest impact on the environment (White 2007).

In 2005, the Safe, Accountable, Flexible, Efficient Transportation Equity Act: A Legacy for Users (SAFETEA-LU) was passed. Title 23 in the Code of Federal Regulations explains laws pertaining to federal highways (GPO 2008). Part 450 deals with planning assistance and standards. Regulation 450.322, which explains the development and content of metropolitan transportation plans, says:

Sections 3005, 3006, and 6001 of the SAFETEA-LU established formal consultation requirements for MPOs and State DOTs to employ with environmental, regulatory, and resource agencies in the development of long-range transportation plans. For example, metropolitan transportation plans now “shall include a discussion of the types of potential environmental mitigation activities and potential areas to carry out these activities, including activities that may have the greatest potential to restore and maintain the environmental functions affected by the [transportation] plan,” and that these planning-level discussions “shall be developed in consultation with Federal, State, and Tribal land management, wildlife, and regulatory agencies.” In addition, MPOs “shall consult, as appropriate, with State and local agencies responsible for land use management, natural resources, environmental protection, conservation, and historic preservation concerning the development of a long-range transportation plan,” and that this consultation “shall involve, as appropriate, comparison of transportation plans with State conservation plans or maps, if available, or comparison of transportation plans to inventories of natural or historic resources, if available.”

Section (i) of regulation 450.214, which explains the development and content of the long-range statewide transportation plans, says that:

“The long-range statewide transportation plan shall be developed, as appropriate, in consultation with State, Tribal, and local

agencies responsible for land use management, natural resources, environmental protection, conservation, and historic preservation. This consultation shall involve comparison of transportation plans to State and Tribal conservation plans or maps, if available, and comparison of transportation plans to inventories of natural or historic resources, if available.”

Section (j) of this regulation further states that:

“A long range statewide transportation plan shall include a discussion of potential environmental mitigation activities and potential areas to carry out these activities, including activities that may have the greatest potential to restore and maintain the environmental functions affected by the long-range statewide transportation plan.

This presentation of SAFETEA-LU regulations is meant to emphasize federal recognition of the need for inter-agency cooperation to maintain natural resources and prevent damage to the environment from roads, as well as to mitigate any further damage. It seems that in order to comply with the SAFETEA-LU regulations, a collaboration between MoDOT and MDC would be required for the mitigation of DVA’s in Missouri.

Despite this federal recognition, an historical absence of collaboration has necessitated judicial intervention. A landmark verdict in 2003 favored Jerry Booth (2003), who sued the state of Arizona for severe injuries sustained from colliding with an elk carcass on I-40. This eleven mile region of highway had confirmed 168 deer or elk collisions within seven years. The plaintiff contended

that: “the state negligently had failed to evaluate known hazard of elk crossing the highway, use appropriate fencing, clear cut vegetation, or reduce the speed limit.” Negligence was established because “the state concedes that it has a duty to keep the highways reasonably safe for the traveling public.” In this case evidence showed the state was aware of the high risk of hitting a deer or elk on this portion of the highway, and further that they had made significant efforts to reduce deer or elk collisions in other regions that posed considerably *lower* risks, and effectively reduced collisions in those areas by 96%. This case may set a precedent for other states recognizing similar liabilities and negligence in failing to mitigate roads with high risks of DVA’s.

While DVA’s pose a threat to human safety, clearly the deer are most in danger of injury and death resulting from these conflicts. It is estimated that 92% of deer die in deer vehicle accidents(Allen and McCullough 1976). From the nationally projected 1 million DVA’s per year, 920,000 will die, and those struck will suffer the rest of their lives.

As these collisions increasingly threaten deer and human life, it is in the interest of both species to reduce these conflicts.

Relevant Literature

In order to reduce DVA's in Missouri it is important to understand deer habitat and studies on DVA's in other regions. Knowing what types of habitat deer need and the landscape characteristics that correlate or contribute to DVA's will assist with future mitigation. The following studies relate to DVA's and landscape characteristics of deer habitat.

Hubbard et al. (2000) wanted to examine the influence of highway and landscape variables on the number of DVA's in Iowa, because these factors are not well understood. They used 30 meter resolution USGS habitat maps, several classes of land types, deer harvest numbers for each county, and DVA points for the years 1990-1997. In addition, traffic volume estimates, distance to nearest town or city from each DVA, distance to nearest town with a population over 2,000, number of bridges and lanes of traffic were used. In their study bridge frequency was the best predictor of high density DVA sites. Bridges can be an indication of riparian corridor habitat, which can act as drift fences, funneling individuals along specific paths (Haddad and Baum 1999), in this case across the roadways. Bridges can also be good indicators of edge habitat, providing deer

with optimal browse. Increased lanes of traffic were also associated with increased DVA frequency, as were large areas of grass and large woody areas. 25% of all the DVA's in this study were found on only 3.4% of the roadways.

Nielson studied deer vehicle accidents from 1993-2000 in two suburbs of Minneapolis (Nielsen et al. 2003). Road segment buffers were overlain on land cover and land class maps. Five variables entered into their logistic regression model, including the number of buildings in the buffered area, number of forest cover patches, number of public land patches, the proportion of forest cover, and Shannon's Diversity Index (SDI). The most important variables were the number of buildings and the number of public land patches. These variables produced the best model. DVA's occurred more frequently on public land patches and where there were fewer buildings. Forested areas were not significant in predicting DVA occurrence possibly due to the fact that they were not dominant in the buffered areas.

Finder and others (1999) examined site and landscape conditions at white tailed deer vehicle collision locations in Illinois using landscape metrics and topographic features. They found that riparian corridors crossing road segments

related to DVA occurrence. The wider the corridor, the higher the probability of a road segment being a high DVA site. They noted deer's use of riparian areas as travel corridors for movement to and from desirable feeding, bedding, and refuge habitats (Dusek et al. 1988). They also pointed out that topography can funnel deer into certain areas, and the presence of woods, public lands, and riparian corridors contribute to deer abundance. Woods or gullies adjacent to the road can obstruct visibility and lead to DVA's. Distance to forest cover was most important predictor of high DVA sites. Roads should be directed away from woodlots where deer feed. Public land and residential areas within wooded habitat can act as refuges from hunting, and may increase DVA's in these areas.

Roseberry and Woolf (1998) used remote sensing, GIS, and habitat modeling to develop a white-tailed deer habitat model which could be used to map potential white-tailed deer habitat in Illinois . They found that the optimum habitat was 40% cover and 60% forage. The cover category included open and closed canopy forests, coniferous and bottomlands forests. The forage category included row crops, small grain, rural and urban grasslands, and orchards or nurseries. The optimum cover type was closed canopy and the optimum forage was grassland.

The critical element in determining deer density was forest cover. Forest less than 500 meters from forage had the best predictive ability. Habitat was found to be positively correlated with the proportion of areas with slopes over 8%. Over 80% of deer density on the county level could be explained by the habitat suitability index, but this relationship was not linear, which may be a result of hunters controlling deer densities more than habitat would.

Study relevance

As roads fragment the landscape and create conflicts for deer and humans to coexist, it is becoming evident that action needs to be taken to reduce these conflicts. The Department of Conservation in Missouri recognizes the problem of DVA's and has been plotting them out for the past few years. Thus far, no studies in St. Louis County, Missouri have described the landscape characteristics that might be associated with DVA's. This research can be utilized to improve habitat connectivity and reduce the dangers of deer and other animal vehicle collisions. Once these patterns are known, agencies can work together to determine ways to reduce these conflicts.

Research Objectives

The purpose of this study is to explore landscape characteristics and spatial patterns associated with Deer Vehicle Accidents in St. Louis County, Missouri in order to understand the probability of a DVA occurring within St. Louis County.

Research objectives include:

- 1) Determine which landscape characteristics and patterns are associated with DVA's.
- 2) Use these characteristics, based on their importance, to predict where DVA's are most likely to occur in St. Louis County.
- 3) Correlate Land Use/Land Cover (LULC) compositions with DVA occurrences.
- 4) Determine if there is a correlation between DVA probabilities and vehicle speed/traffic volume.

Study Area

The St. Louis County study area is 1357 km², with 10,000 km of roads (Figure 1).

The majority of St. Louis County falls inside the Ozark Highland Section (Figure 2) of Missouri's Ecoregions (Nigh and Schroeder 2002), and contains deeply dissected hills and blufflands bordering the Missouri and Mississippi Rivers, along with smooth karst plains. This ecoregion was historically comprised of oak savanna, woodland, oak and mixed-hardwood forests, with occasional expanses of prairie (Nigh and Schroeder 2002). Some of the woodland, oak, or mixed-hardwood forests remain, and provide white-tailed deer with cover and vegetation. Some grassland remains where prairie or forest used to exist, providing abundant vegetation for deer to browse. Suburban areas are sprinkled throughout the large areas of forest and grassland, especially in West St. Louis County, providing an optimal interface for deer habitat needs. Aerial surveys conducted in 2004 estimate that suburban St. Louis County white-tailed deer densities ranged from 40-86 deer/mi² (MDC 2005).

Interstate-270 bisects the eastern and western halves of the county. The eastern section is older, with high road densities and neighborhoods packed together.

There is little space between single family residential homes. The western section reveals an extensive swell of suburban sprawl that has been developed over the past four decades. Single family homes have large yards with a wider area between homes than the eastern section. Residential roads tend to follow drainages, and produce sinuous roads that often dead-end into the drainage.

The eastern section's roads do not follow the drainage feature of the landscape and have a gridded pattern that maximizes space.

Deer are more populous in the western section of the county, and very scarce in the eastern half (Shank 2008). It may be that the limitations of access to habitat due to road impediments have limited deer populations in the eastern section of the county. Deer have to cross too many roads to access the forests and grasslands. However in the western section, deer often only have to cross one road to get to the heavily wooded drainages that provide food and water.

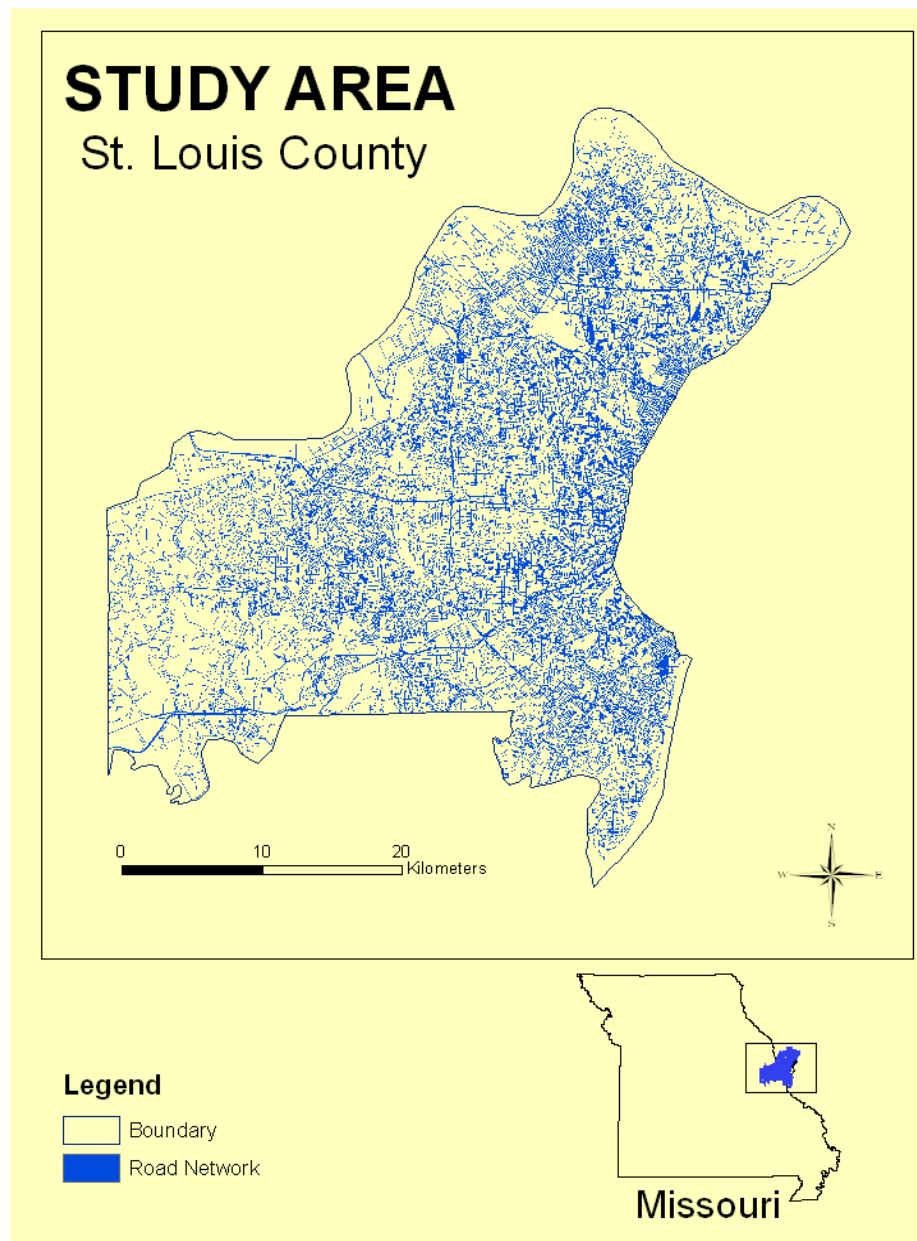


Figure 1. Road Network in St. Louis County, Missouri. This includes all major highways and roads under MoDOT supervision, as well as private roads, obtained from the St. Louis County Planning Department. All DVA's and random points in this study fall within this network of roads.

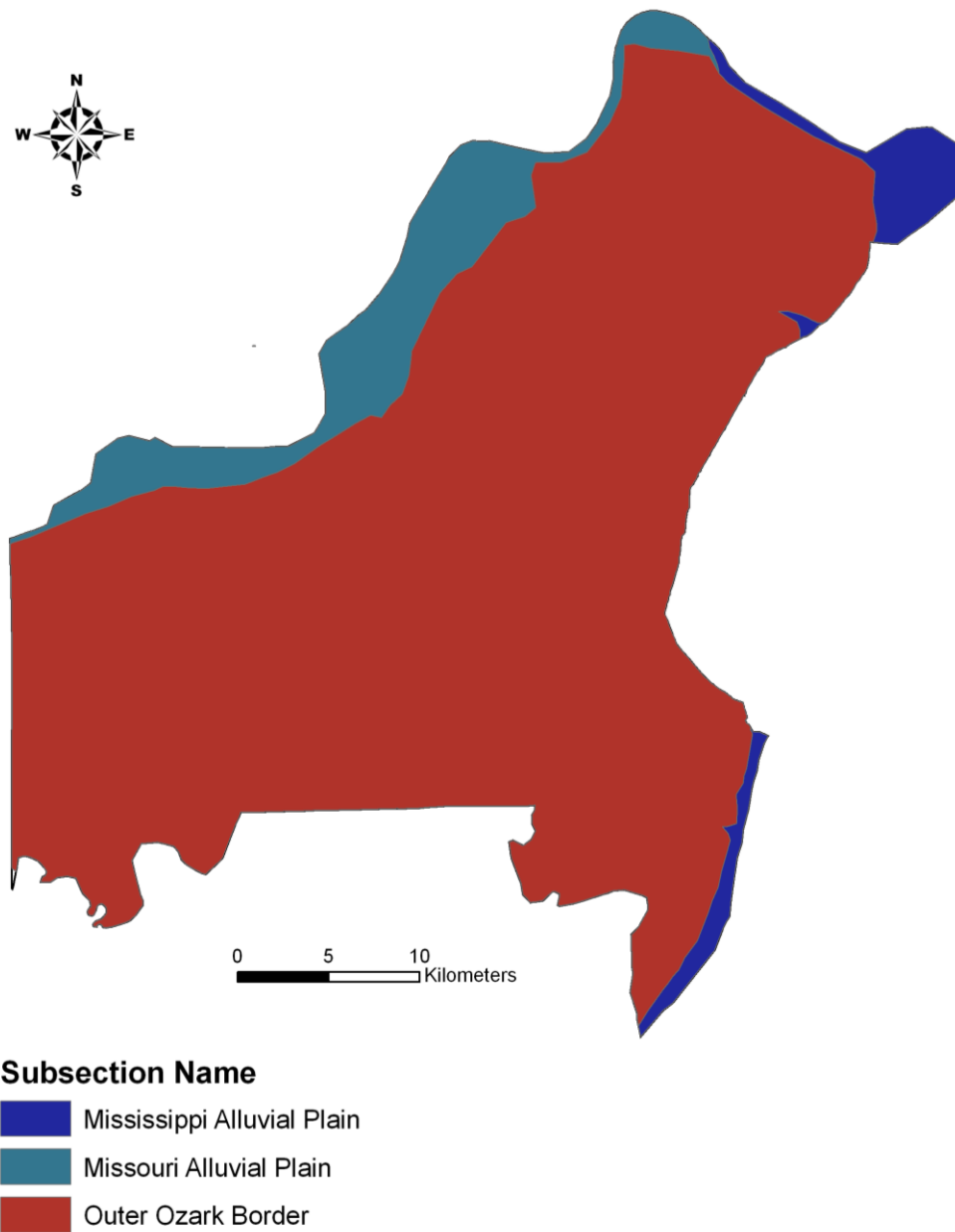


Figure 2. Map of Ecological Subsections in St. Louis County, Missouri. The majority of the county is in the Outer Ozark Border Subsection, with the Mississippi and Missouri Alluvial Plains subsections making up the rest of the county.

2 METHODS

Data Description

The data used in this study were selected based on two criteria. The first is deer habitat, which is expected to be strongly correlated with deer activity, and ultimately DVA's. Deer have a limited home range, especially in suburban areas (Porter et al. 2004), and habitat characteristics include forested areas for cover, access to open grasslands containing suitable browse, and watering sites (Hiller 1996). The other criterion used for this study is related to human activity and movement. The two criteria are essentially interconnected, because available deer habitat is influenced and strictly controlled by people. Human-deer conflicts logically require the convergence of these two components: human and deer activity. Land Use/Land Cover Classes (LULC) created by Missouri Resource Assessment Partnership (MoRAP 2005) were obtained in order to determine the areas of possible human and deer activity in St. Louis County. The LULC map used in this study contained 12 classes which were condensed (reclassified) into fewer classes in order to simplify the analyses. The

reclassification was based on ways the classes would be expected to reflect deer-human interactions.

Almost all analyses of the data involved some processing in ArcMap, a software created by Environmental Systems Research Institute (ESRI 2006). ArcMap is a resource used in Geographic Information Systems (GIS). The two types of data used in this study were vector and raster data. The point maps of DVA's and random points, road network, and streams are vector data. The LULC map was a raster map which contains a grid of 30 by 30 meter cells that contain their respective LULC values. The classes from this map were processed using ArcMap's spatial analyst. With this tool, classes were reclassified into smaller numbers of classes based on input criteria. Surface analyses were performed on the digital elevation models (DEM's) downloaded from the Missouri Spatial Data Information Service (MSDIS 2007) through spatial analyst to determine slope and aspect. Spatial analyst also contains distance and density functions which were used in this study. Another instrument that was added to ArcMap to facilitate manipulations of data was Hawth's Tools (Beyer 2004). It was used to assign DVA's and random points their respective values for all of the variables tested.

Point Map of DVA's

Shapefiles of DVA points in St. Louis County (Figure 3) documenting carcass pickups from 2000-2005 were obtained from the Missouri Department of Conservation (MDC). These points are based on information from the Missouri Department of Transportation (MoDOT) and Animal Care Services. MoDOT picks up deer carcasses from state maintained roads, and Animal Care Services was contracted out by MDC to pick up the remaining carcasses in St. Louis County (Shank 2008). The attribute tables of the shapefiles documented whether the carcass was picked up by MoDOT or ACS, along with other information such as the exact date and location of the pickup. The shapefiles for 2000-2004 data were combined, and the 2005 data was set aside in order to validate the patterns observed in this study.

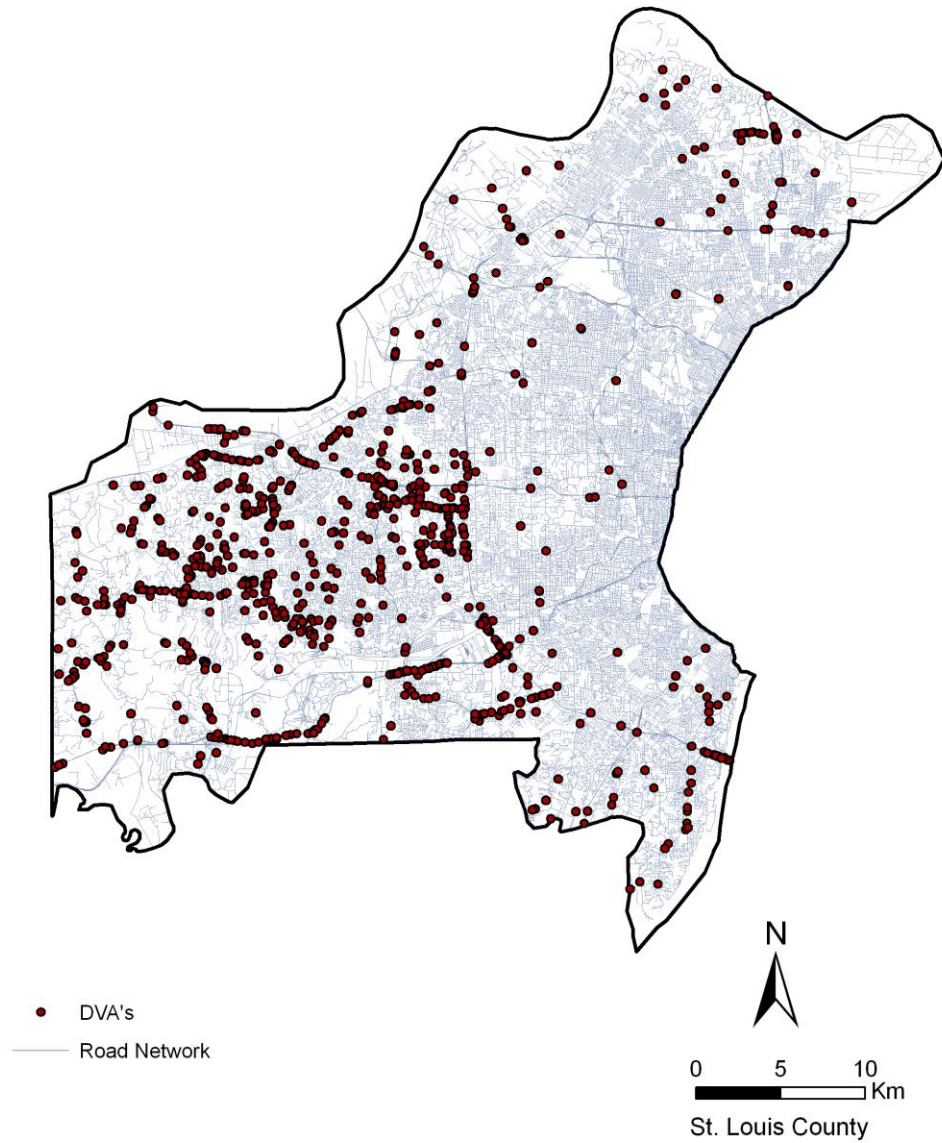


Figure 3. DVA locations in St. Louis County from 2000-2004. There are a total of 861 points, mapped out by the Missouri Department of Conservation. They represent carcasses from private roads and roads under MoDOT supervision.

Random Points

A randomly generated set of points (Figure 4) that fell within the same network of roads in St. Louis County was generated using R statistical software. All of the variable analyses conducted on the DVA points were also conducted on the random points. The purpose of comparing DVA's to random points is to determine the explanatory power of each variable. For each variable tested, DVA's were compared to the random points through analysis of variance (ANOVA) tests. The percentage of variance explained by the variable was used to show explanatory power. If this value was low then the variable would not be useful in explaining whether there was a relationship between DVA occurrence and this variable.

K function

Ripley's K-function is a cluster detection method in which the covariance of spatial points depends on the distance between two locations, independent of direction (Bailey and Gatrell 1995). An analysis of K function was assessed using the DVA points to determine if spatial clustering was occurring. If DVA points were found to occur randomly then there may be no significant landscape patterns that can explain their distribution, and no further analyses would be

required. However, if there is spatial clustering, then further tests conducted in this study would analyze the landscape variables associated with DVA's that contribute to clustering.

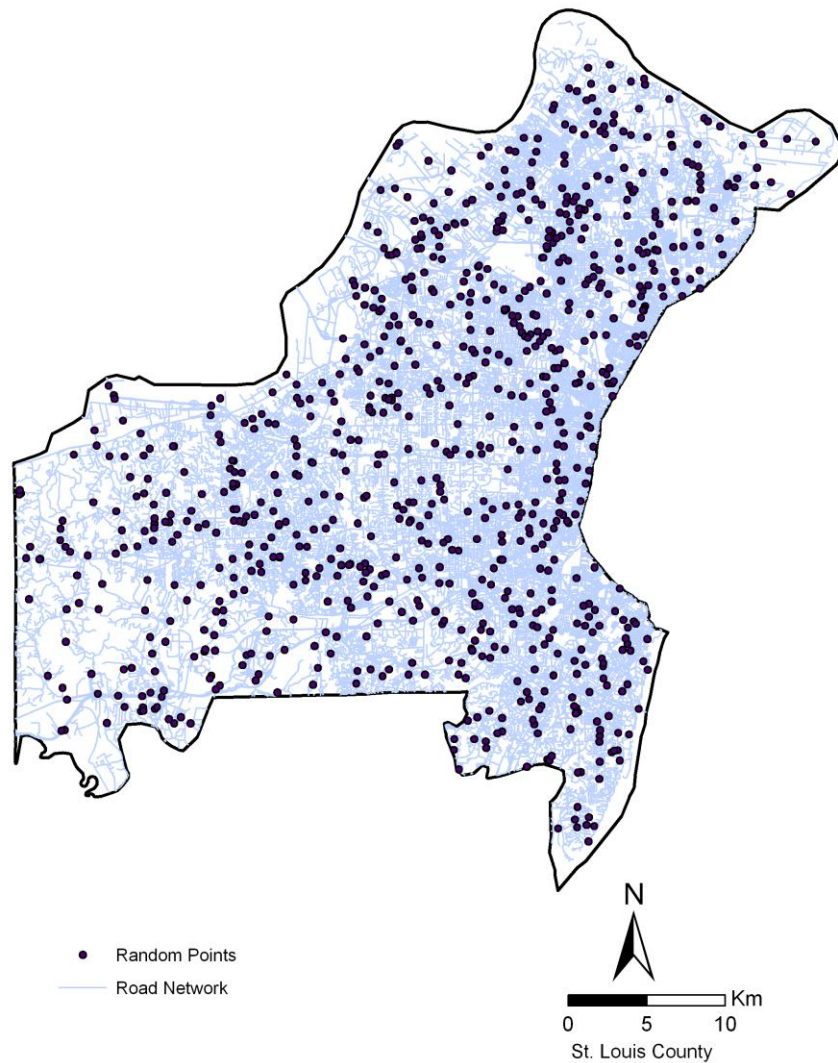


Figure 4. Random points located in the road network of St. Louis County. 861 points were created using R statistical software. This is the same number of points as the DVA's . They were used for comparison with the actual DVA points that occur within the same network of roads. All statistical tests were performed on the random and actual DVA points for comparison.

Road Density

Road density was tested to determine if there was a range of densities associated with DVA occurrences. If there were a relationship then this variable may help explain where DVA's occur in the landscape and it may predict where DVA's are likely to occur in St. Louis County.

The road network created by St. Louis County Department of Planning was used to create a grid in ArcMap depicting the range of road densities in St. Louis County. Each DVA and random point was assigned its corresponding road density using Hawth's Tools (Beyer 2004).

Road density is expressed in km/km². Road density grids were created using search radii that ranged between 500 and 3000 meters to determine the greatest prediction value. ANOVA tests were performed between random and DVA points for each of the grids. The search radius that produced the highest F value before the subsequent values dropped was considered to have the highest prediction value.

Land Use/Land Cover Classes

The goal of using the LULC classes was to find the areas in which deer and human activity would be expected to overlap. This interface is where conflicts

would be expected to occur. Deer habitat consists of an interface between grassland for browse, and forested area for cover (Hiller 1996). The forest categories included in the reclassified map consist of open and closed canopy, along with a small portion of coniferous forest cover. These are documented cover types for Midwestern deer in neighboring Illinois, based on a habitat suitability study by Roseberry and Woolf (1998) that used land cover data. This study listed grassland as the optimal forage habitat for deer, followed by row crops. Deer can be active in the Water, Wetland, and Cropland cover classes, based on their need for water (Fulbright and Ortega-S 2006), and their occasional use of cropland as forage . Humans are active in Low and High Intensity Urban areas. Many of the Low Intensity Urban areas are overlapped by forest and grassland areas. In addition to this, any time roads cross these areas of high deer activity, a DVA can occur. The purpose of analyzing these LULC classes is to determine if there is a relationship between specific classes and DVA's.

A 16-class Land Use/Land Cover map based on 2000-2004 satellite imagery classified by MoRAP (2005), was used as the basis for analysis in determining landscape variables associated with deer vehicles accidents in St. Louis County, Missouri (Figure 5). Only 12 of these classes occur in St. Louis County. Features in an LULC map could reveal where DVA's are most likely to occur in the

landscape. According to the 2005 Land Use Land Class classification system developed by MoRAP, low intensity urban, comprising 42.5% of the St. Louis County, makes up the largest percentage of the 12 classes (Table 1), with a total area of 576.9 km². Deciduous forest is the second most common, with 21.8 %, and Grassland is third, with 14%. This map was reclassified into the smallest number of categories that would fill the criteria of representing areas where humans impact deer. This includes the overlapping areas where deer and humans are active.

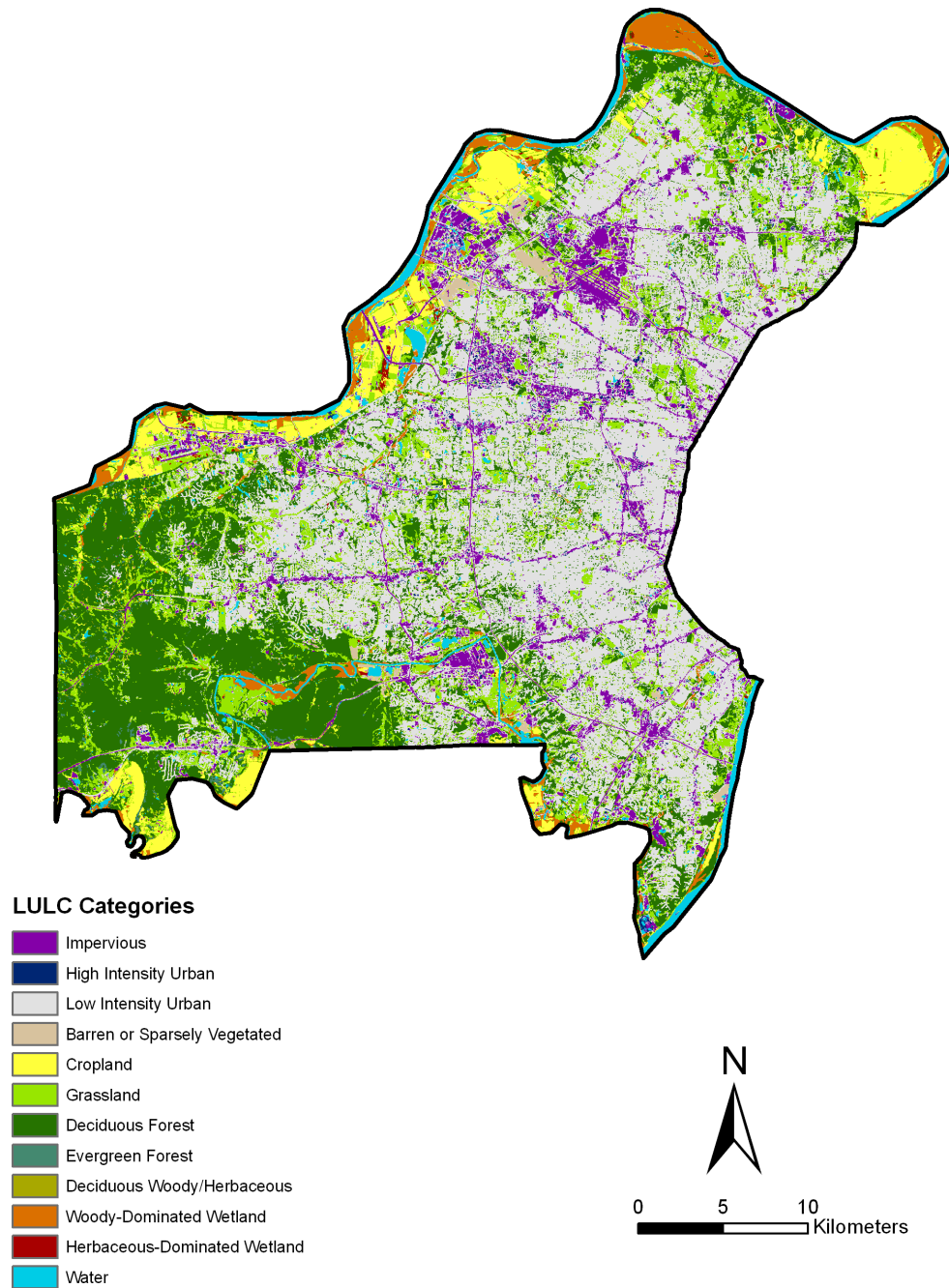


Figure 5. Land Use/Land Cover categories for St. Louis County, Missouri. These are the original 12 categories generated by MoRAP. These categories were further broken down into five classes for this study (see Figure 10).

Table 1. This table color codes the groups that were classified together for the LULC reclassification in St. Louis County, Missouri. The table shows the breakdown of area and percentages of the twelve original classes. The largest class is Low Intensity Urban and the smallest class is Herbaceous-Dominated Wetland. The total area of land covered by all 12 classes is 1356.7 km².

LULC Class	% Landscape	Total Area- km ²
Low Intensity Urban	42.52	576.86
High Intensity Urban	0.62	8.41
Impervious	7.43	100.83
Deciduous Forest	21.79	295.67
Deciduous Woody/Herbaceous	0.37	5.00
Evergreen Forest	0.31	4.21
Grassland	13.98	189.68
Barren or Sparsely Vegetated	0.65	8.82
Cropland	5.76	78.18
Herbaceous-Dominated Wetland	0.18	2.47
Woody-Dominated Wetland	2.81	38.09
Water	3.57	48.43
Total		1356.65

Grassland

The grassland cover class provides the optimum source of forage (Roseberry and Woolf 1998) for deer. This category may be significant in explaining areas of deer activity interfaced with human activity. The 12-Category Land Use/Land Cover map was reclassified to exclusively analyze the areas of grassland in St. Louis County. The Barren or Sparsely Vegetated class was combined with Grassland to form one class. The metadata from MoRAP (2005) describe the Barren or Sparsely Vegetated class as “minimally vegetated areas including bluffs, quarries, and natural expanses of rock, mud, or sand,” and “areas in transition.” Deer browsing in open areas would be expected to use the Sparsely Vegetated areas in conjunction with the Grassland areas which provide some vegetation that meets their dietary needs. Additionally, this class is found adjacent to Grassland in most of the landscape, and makes up only .65% of the landscape. All areas that were not in the grassland category were excluded and the resulting map was used to create a grid of distances to grassland areas (in meters) whose values were then assigned to each DVA and random point. Distances were calculated from a minimum of 900 m² of grassland (30 m by 30 m

cells). This variable was analyzed through ANOVA tests to determine if it was significant or important in predicting DVA occurrence. If ANOVA testing produced a large explanatory power for this variable, then a relationship between DVA's and their proximity to grassland would be revealed.

Forest

Deer require forest cover as a component of their habitat (Fulbright and Ortega-S 2006). The forested areas in the LULC map of St. Louis County include the categories of Deciduous Woody/Herbaceous, Deciduous, and Evergreen Forest. According to the LULC metadata (MoRAP 2005) the Deciduous Forests category has "greater than 60% cover of deciduous trees." Evergreen Forests," with greater than 60% cover of evergreen trees," are rarely found in this region (.31% of the landscape), so grouping them together in this class would not be expected to impact the results. Additionally, evergreen forests and Deciduous Forests both provide the deer habitat requirement of cover, and are found in close proximity to one another. The Deciduous Woody/Herbaceous category contains "open woodland (including young woodland) with less than 60% cover of deciduous trees." It comprises only .4% of the landscape, and fulfills many of the same habitat requirements for cover as the Deciduous and Evergreen Forest

categories. The 12-category Land Use Land Class map was reclassified to exclude all other categories and only analyze the forested regions with reference to DVA's in St. Louis County. A new map that only included forested areas in St. Louis County was used to create a grid of distances to forested areas (in meters). Each DVA and random point was then assigned its corresponding distance from forest. This variable was then analyzed through ANOVA tests to determine if there was a relationship between distance to forest and DVA's. If this were the case, then it could explain landscape characteristics surrounding DVA's and predict where DVA's are likely to occur.

Water, Wetland, Cropland (WWC)

Deer are active in areas that provide an abundance of forage, thus areas close to wetland, cropland and water may be areas of high deer activity. The WWC category was created from four classes, including Cropland, Woody-Dominated Wetland, Herbaceous-Dominated Wetland, and Open Water. Cropland is "predominantly cropland including row, close-grown, and forage crops," Woody-Dominated Wetland is "forest with greater than 60% cover of trees with semi-permanent or permanent flood waters." Herbaceous-Dominated Wetland is "woody shrubland with less than 60% cover of trees with semi-permanent or

permanent flood waters,” Open Water includes “rivers, lakes, ponds, and other open water areas,” (MoRAP 2005). The wetland categories combined make up just three percent of the total area of St. Louis County, and these four categories are primarily found in close proximity to one another in this region and were classified together for this reason. They also provide similar functions in offering lush and abundant areas of forage.

Low Intensity Urban (LIU)

Based on the LULC metadata description (MoRAP 2005), the Low Intensity Urban class represents “vegetated urban environments with a low density of buildings.” LIU areas would indicate moderate human activity relative to the HIU’s that would be expected to have higher densities of humans and increased human activity based on high densities of concrete and buildings. A moderate level of human activity could allow deer to coexist in the interspersed regions of grassland and forest cover that provide habitat, with some level of human disturbance.

This class was not combined with any others and remains the same as it is in the 12-category LULC map. The LIU area of the Land Use/Land Cover map was reclassified to exclude all other areas and analyze the low intensity urban areas

with reference to DVA's in St. Louis County. It was used to create a grid of distances to urban areas (in meters) whose values were then assigned to each DVA and random point. The distance to LIU variable was then analyzed through ANOVA tests to determine if it was significant or important in explaining the occurrence of DVA's. If the distance to LIU variable has a significant explanatory power then it could indicate a relationship between DVA's and their proximity to LIU's, and could predict where DVA's are likely to occur in St. Louis County.

High Intensity Urban (HIU)

Since HIU's represent areas of intense human activity, it is expected that deer would be hindered by high traffic and human interference. Deer that manage to settle near these areas are likely to be struck by vehicles.

The High Intensity Urban areas represent "vegetated urban environments with a high density of buildings." The impervious class makes up 7.4% of St. Louis County, and according to LULC metadata (MoRAP 2005) represents "non-vegetated, impervious surfaces., areas dominated by streets, parking lots, buildings, little, if any, vegetation." For the purposes of this analysis, the Impervious and High Intensity Urban classes were combined into a unified HIU

class. A grid of distance to HIU areas (in meters) was created from the reclassified LULC map. Corresponding values for DVA's and random points were then assigned. This variable was then analyzed through ANOVA tests to determine if there was a relationship between DVA's and their proximity to HIU cover areas.

Intersections of Streams and Roads

Streams from the National Hydrography Dataset (USGS 2007) were used for this analysis. The scale of these streams was 1:24,000. ArcMap was used to show all intersections between streams and roads, and then a grid was created showing the distance to any of these intersections. This variable was studied because previous research has indicated that bridges crossing riparian corridors are DVA hotspots (Hubbard et al. 2000). Since deer congregate near streams for food and water (Hiller 1996), the intersection of roads and streams would be a good measure of the interface between human and deer activity. DVA and random points were assigned their corresponding distance to a stream/road intersection value. These values were then analyzed through ANOVA tests to determine if this variable was significant or important in predicting DVA occurrence. If there were a higher incidence of DVA's near these intersections, this variable could

explain what landscape characteristics surround DVA's and it could predict where DVA's are likely to occur.

Slope

A 30 meter DEM (MSDIS 2007) was analyzed in ArcMap's Spatial Analyst to create a map of slopes in St. Louis County. Slope was tested to see if there was a relationship between this variable and DVA occurrence. This element of the landscape could affect where DVA's occur, and comparing corresponding slope values assigned to DVA and random points will determine if there is a relationship between DVA's and slope. This variable was analyzed through ANOVA tests to determine if it had a high explanatory power.

Aspect

The 30 meter DEM was analyzed in ArcMap's Spatial Analyst to create a map of aspects in St. Louis County. DVA and random points were assigned their corresponding aspect. This variable was then analyzed through ANOVA tests to determine if it had a high explanatory power, and if there was a relationship between DVA's and aspect. If a relationship were found, aspect could be used in a model to predict areas where DVA's are likely to occur.

Model

Variables were ranked from highest to lowest explanatory power based on ANOVA tests. The explanatory power was determined by looking at the percentage of variance explained by the variable. Various models were created to see if combinations of variables with lower explanatory powers might nevertheless produce categories with a high predictability as a result of variable interactions. In the end, the variables with the highest explanatory power were selected for the model. These variables would be expected to show where DVA's were most likely to occur based on the landscape characteristics surrounding them. DVA values for these variables were classified into three classes using Natural Breaks (Jenks) in ArcMap. Raster Calculator, a utility within the Spatial Analyst of ArcMap, was used to combine the classes within each variable to produce a new map with a combination of categories. These categories were further aggregated for simplicity based on ranges of DVA densities. Categories were ranked by DVA density. The categories with the highest densities indicated the highest probability of finding a DVA.

Model Validation

After the model categories were created, the 2005 DVA points were used to validate the model. The number of DVA's per model category were calculated and divided by the category's area to determine DVA density. These values were weighted for comparison with DVA densities for 2000-2004 to determine if the model was valid for 2005 data. If predicted densities based on 2005 data match the 2000-2004 data, this validation would demonstrate that model categories can predict future DVA occurrences in St. Louis County.

Land Use/Land Cover Classes in model categories

The model was classified from nine categories into four, and the area and percentage of the five LULC categories were determined for each model category, using the 2000-2004 DVA points. This analysis was performed to further explain the landscape characteristics surrounding DVA's in high and low probability categories.

Comparison of DVA's in model categories and road types

MoDOT roads have higher average traffic volumes and higher speeds than private roads. Analyzing the proportions of DVA's within the categories on MoDOT and private roads can reveal correlations between DVA probabilities and road types. The model was analyzed to determine the area of MoDOT and private roads within each category, along with the number and percentage of DVA's on each type of road. If a high proportion of DVA's occur on MoDOT roads, for example, this could be an area of focus for mitigation of DVA's.

3 RESULTS

K function

Figure 6 illustrates that the DVA's do follow a clustered configuration in the landscape. The solid line is above the dotted red line that would have indicated a random configuration.

Road Density

The search radius determines the area used to calculate road density. At a 2500 meter radius, the density values offer the highest explanatory power. Figure 7 depicts the range of variances attributed to different search radii. The density values produced by the 2500 m search radius yielded the highest F value.

Subsequently higher search radii tested had density values yielding a lower explanatory power. The densities produced from the 2500 m search radius explained (10.08%) of variance between DVA's and random points located within the road network. Figure 8 is a spatial representation of the road densities produced using the 2500 meter search radius, with the DVA points overlain on top. The p-value for the ANOVA test (Table 3) was very low, indicating that the

likelihood that the DVA and random points are the same is very low. The average road density surrounding DVA's was 6.61 km/km², and 8.20 km/ km² for random points (Table 2). These intermediate road density values are illustrated in the dark blue areas on the map in Figure 8. They are the regions in which most of the DVA's are clustered.

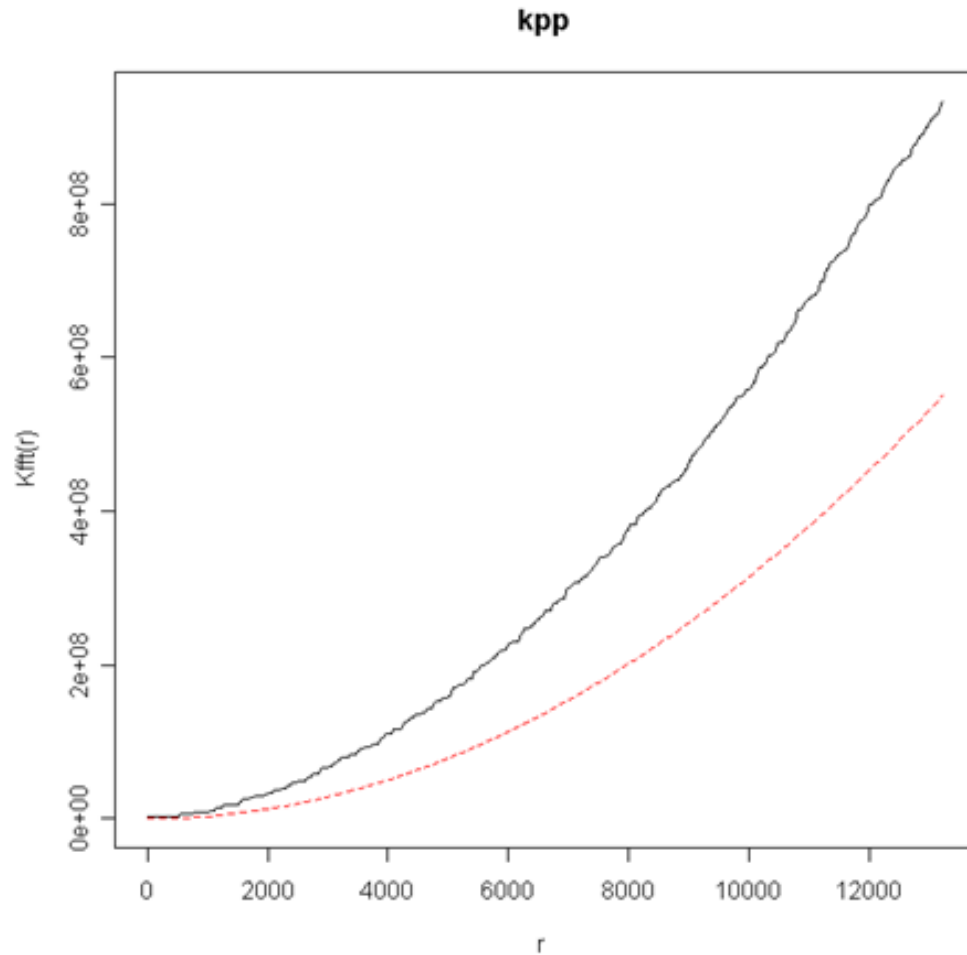


Figure 6. Analysis of K function for DVA's. This graph shows that DVA's are in fact clustered. If they occurred on the dotted line, they would be configured randomly throughout the landscape, and if below the dotted line, they would be regularly configured.

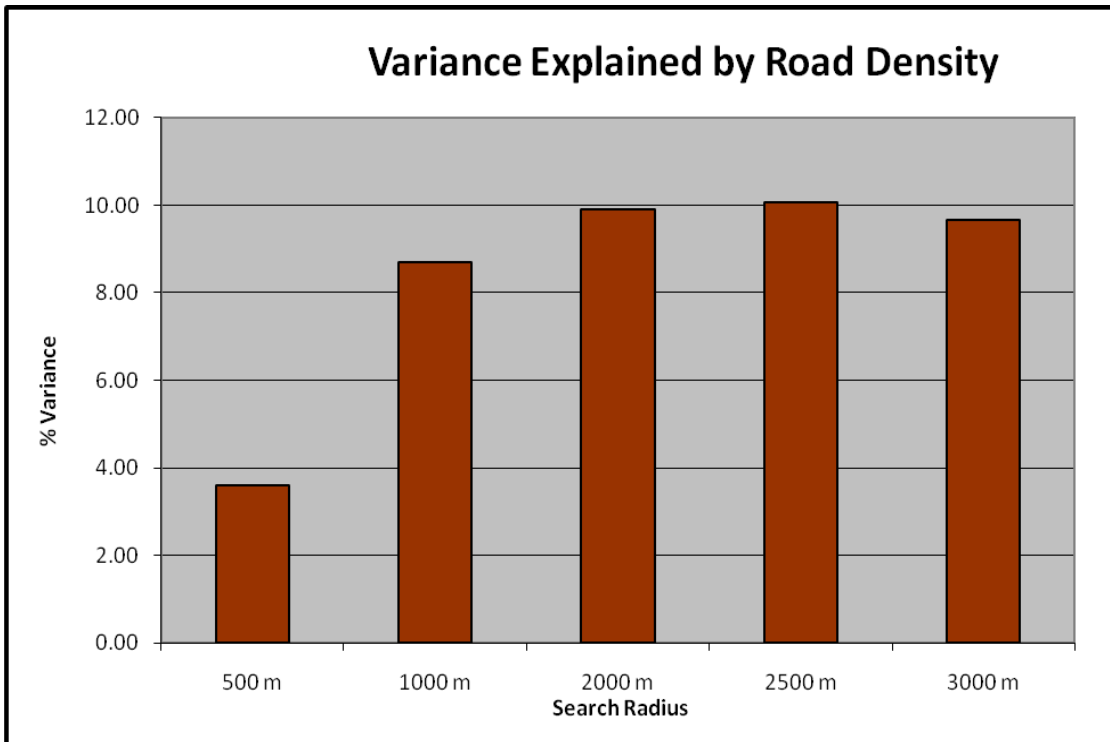


Figure 7. Percent variance explained by road density when comparing random points and DVA points, for different search radii. The percent variance continues to increase as search radius distances increase until it reaches 3000 m, at which point the variance then decreases. The 2500 m search radius had the largest percent variance, thus this was the radius used for this variable.

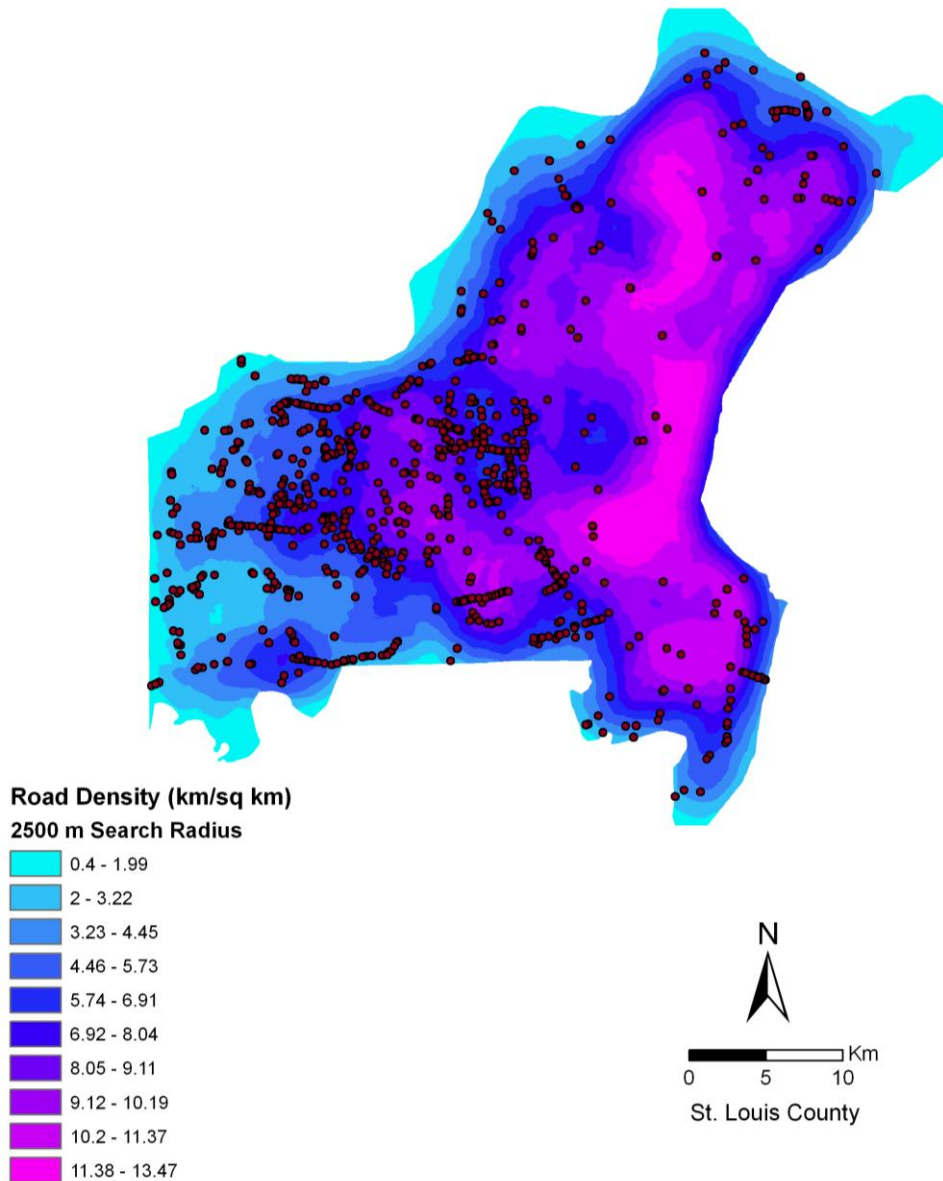


Figure 8. Grid of road densities using 2500 m search radius. The input was the entire road network for St. Louis County shown in Figure 1. DVA points are overlain on top. Very few DVA's fall in the high road density regions (pink), and most fall in the dark blue areas of medium road density.

Table 2. Summary of statistics between DVA and Random points for road density variable. Random points had a larger average road density, and a larger variance. There was slightly more variance between random points than between DVA's.

<i>Groups</i>	Count	Sum	Average	Variance
DVA's	861	5694.91	6.61	4.41
Random Points	861	7061.98	8.20	6.85

Table 3. ANOVA statistics for DVA and Random points for road density variable. The percent variance explained by this variable was 10.08. The F value, at 192.81 was much higher than the critical F, and higher than any of the other tested variables. The P-value in this test shows that the probability these groups are the same is very low.

ANOVA

<i>Source of Variation</i>	<i>SS</i>	<i>df</i>	<i>MS</i>	<i>F</i>	<i>P-value</i>	<i>F crit</i>
Between Groups	1085.29	1	1085.29	192.81	1.25E-41	3.85
Within Groups	9681.55	1720	5.63			
Total	10766.84	1721				
% variance	10.08					

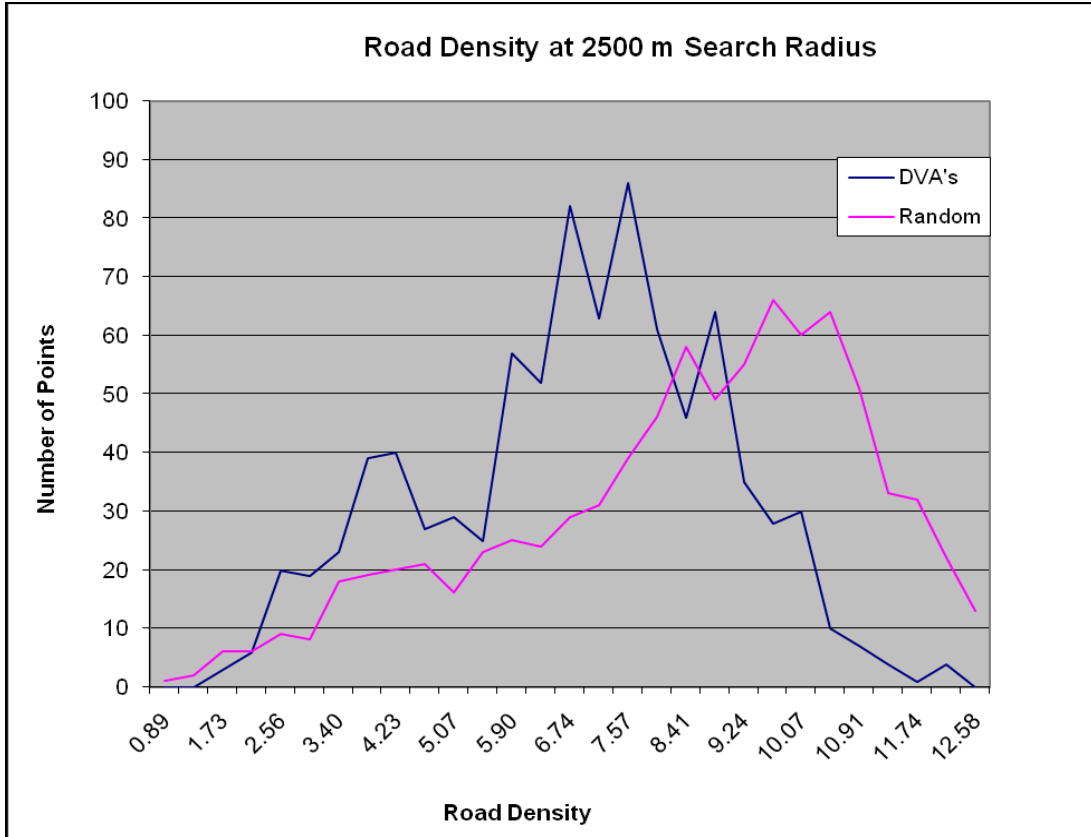


Figure 9. Line chart showing number of points (DVA and Random) falling between ranges of road densities (expressed in km/km²), based on 2500 m search radius. The majority of DVA points fall in the medium road density ranges, and the random points fall throughout the ranges, with many in the higher ranges of densities. The random points have a higher overall average road density than the DVA's because very few DVA's fall in the areas of high road density which occur mostly in the eastern half of St. Louis County.

Land Use/Land Cover Class Variables

The 12-category LULC map was reclassified into the smallest number of categories that would characterize areas of the landscape representing basic human-wildlife impacts and deer habitat requirements. The reclassified map can be viewed in Figure 10, and the landscape area and percentage breakdowns for each new class can be viewed in Table 4. Low Intensity Urban continues to occupy the largest area (42.5%), and Forest and Grassland occupy the second and third largest areas, with 22.5% and 12.3%, respectively.

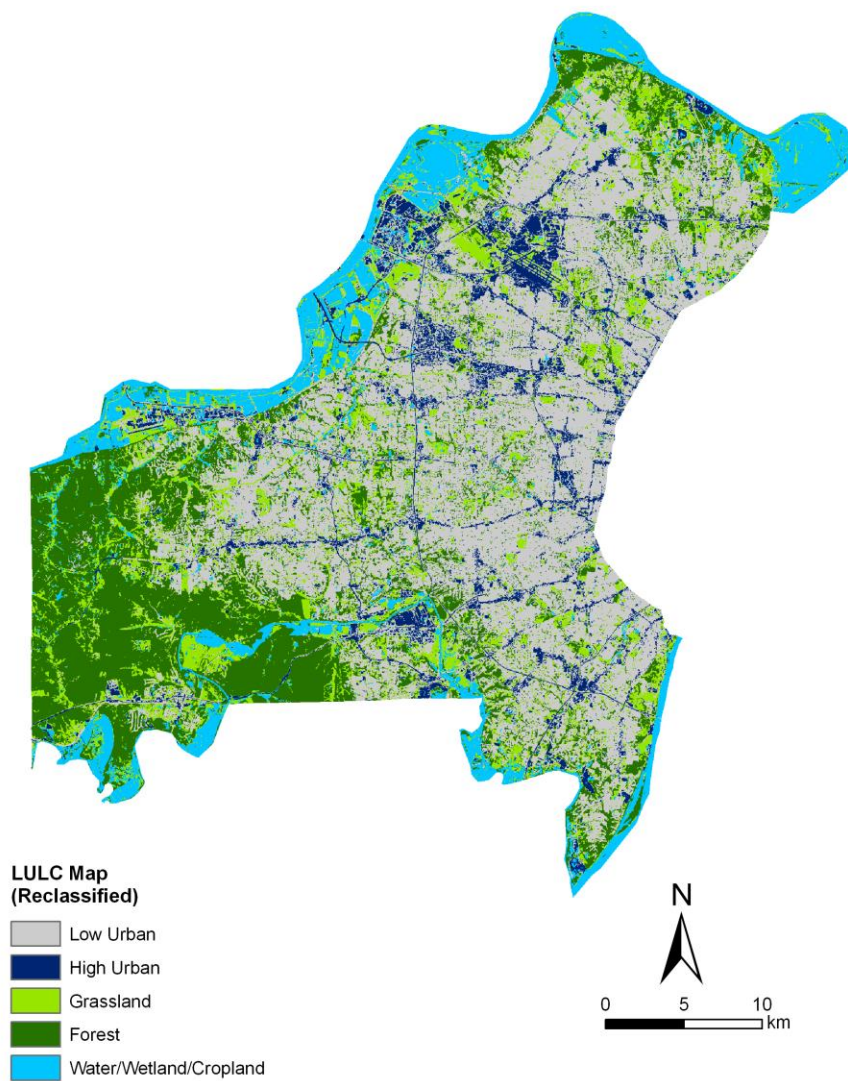


Figure 10. Reclassified LULC classes for St. Louis County, Missouri. These classes were broken down from the original 12 classes obtained from MoRAP in order to simplify statistical comparisons between DVA points and random points in each LULC category. Classes were broken down in a manner that would reflect the ways deer in their habitat related to human land use.

Table 4. Reclassified LULC Map for St. Louis County, Missouri, with percentage and area breakdowns for the five classes. Low-Intensity Urban continues to comprise the largest area, with forest and grassland making up the second and third largest areas, respectively.

LULC Class	Percent Landscape	Total Area (km²)
Low Intensity Urban	42.5	576.9
High Intensity Urban	8.1	109.2
Grassland	14.6	198.5
Forest	22.5	304.9
Water/Wetland/Cropland	12.3	167.2

Distance to Grassland

Figure 11 shows the grassland area in St. Louis County with the DVA's overlain. The average distance to grassland was 73.24 m for DVA's, and 120.80 m for random points (Table 5). Table 6 shows that 7.27 % of the variance between the random points and DVA's can be explained by this variable. The F value is 134.79, exceeding the critical F value of 3.85. This variable has the second highest explanatory power compared to the other tested variables in this study. The line graph in Figure 12 shows that a greater number of DVA's than random points are found closer to grassland areas. The random and DVA lines follow similar curves. Both groups peak around 44 meters from grassland, however there are more DVA's at this peak than random points, as the random points are more dispersed.

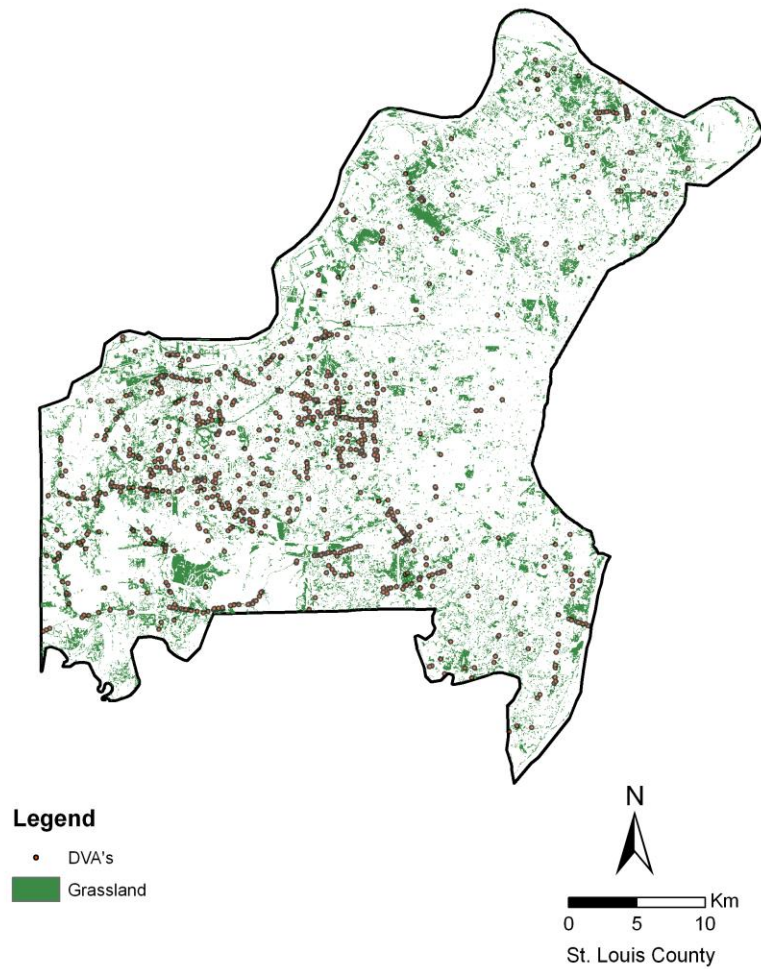


Figure 11. Grassland area in St. Louis County with DVA's overlain. The MoRAP LULC map was used to create this grassland layer for this study. A grid was calculated using ArcGIS showing the distances from grassland for any area on the map. Corresponding distances from grassland were then determined for each DVA and random point.

Table 5. Summary of statistics between DVA and Random points for distance to grassland variable. On average, DVA's occurred about 50 meters closer to grassland than random points. There is a greater amount of variance between random points than between DVA points.

<i>Groups</i>	<i>Count</i>	<i>Sum</i>	<i>Average</i>	<i>Variance</i>
DVA's	861	63055.50	73.24	3688.98
Random Points	861	104005.45	120.80	10759.82

Table 6. ANOVA statistics for DVA and random points for distance to grassland variable. The percent variance explained by this variable was 7.27, and the F value far exceeded the critical F value, so this variable can be considered important. The very low P-value indicates there is a low probability that these groups are not the same.

ANOVA

<i>Source of Group Variation</i>	<i>SS</i>	<i>df</i>	<i>MS</i>	<i>F</i>	<i>P-value</i>	<i>F crit</i>
Between Group	973808.65	1	973808.65	134.79	4.68E-30	3.85
Within Group	12425965.72	1720	7224.40			
Total	13399774.37	1721				
% Variance	7.27					

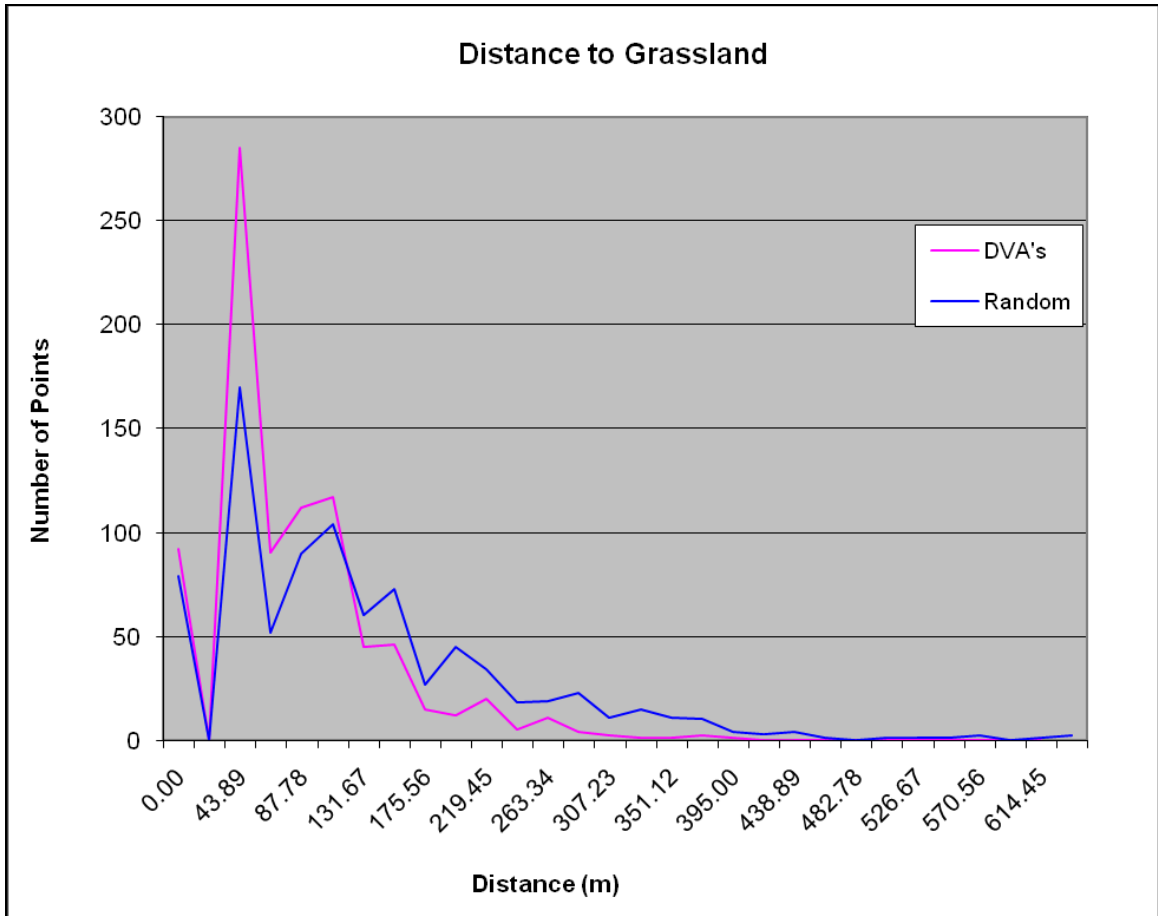


Figure 12. Line graph showing number of points (DVA and Random) falling at specified distances from grassland. The majority of random points were found further away from grassland than DVA's.

Distance to Forest

Figure 13 shows the forested area in St. Louis County that was extracted from the reclassified LULC map, with DVA's overlain. A grid of distances to these forested areas was created and the values for distances of DVA's and random points can be seen in the line graph in Figure 14. A greater number of DVA's than random points are found closer to forested areas. The random and DVA distributions follow similar curves, and both peak around 75 meters from forest, however there are about 50 more DVA points than random points at this distance.

The average distance from forest for DVA's was 111.31 m, and 141.66 m for random points (Table 7). Table 8 shows that the F value for this variable was 26.88, which exceeded the critical F of 3.85. The percent variance explained by this variable (Table 8) is low compared to some of the other tested variables, at 1.54%.

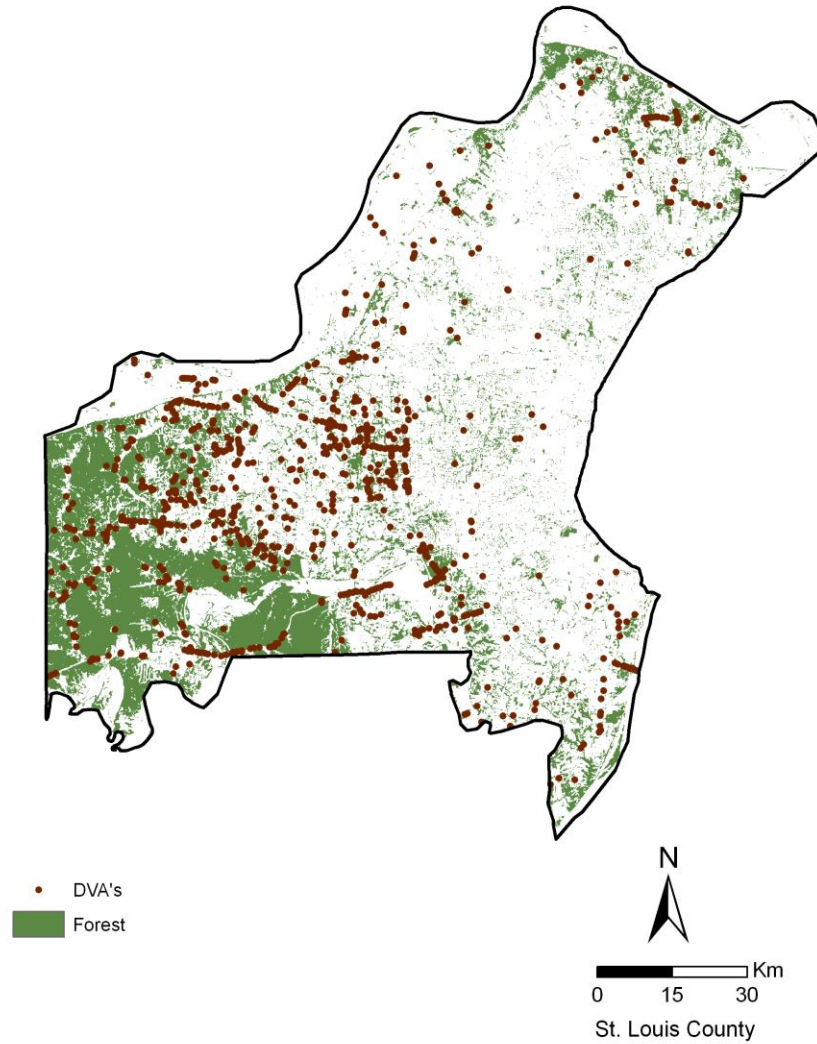


Figure 13. Forested area in St. Louis County with DVA's overlain. The MoRAP LULC map was used to create a combined forested category above that was used for this study. A grid was calculated from this forested area to show all distances from forest. The corresponding distance from forest was then determined for each DVA and random point.

Table 7. Summary of statistics for DVA's and random points for distance to forest variable. The average DVA was closer to forested areas than random points, at 111.3 and 141.66 meters respectively. There is slightly more variance between random points than there is between DVA points.

SUMMARY

<i>Groups</i>	<i>Count</i>	<i>Sum</i>	<i>Average</i>	<i>Variance</i>
DVA's	861	95841.21	111.31	10212.03
Random Points	861	121970.60	141.66	19293.09

Table 8. ANOVA statistics for DVA's and random points for distance to forest variable. The F value exceeded the critical F value, so the two groups can be considered different from one another with regard to this variable. The P-value indicates these groups are significantly different, however with a percent variance of 1.54, this variable offers a low explanatory power.

ANOVA

<i>Source of Variation</i>	<i>SS</i>	<i>df</i>	<i>MS</i>	<i>F</i>	<i>P-value</i>	<i>F crit</i>
Between Groups	396483.599	1	396483.60	26.88	2.43E-07	3.85
Within Groups	25374402.93	1720	14752.56			
Total	25770886.53	1721				
% variance	1.54					

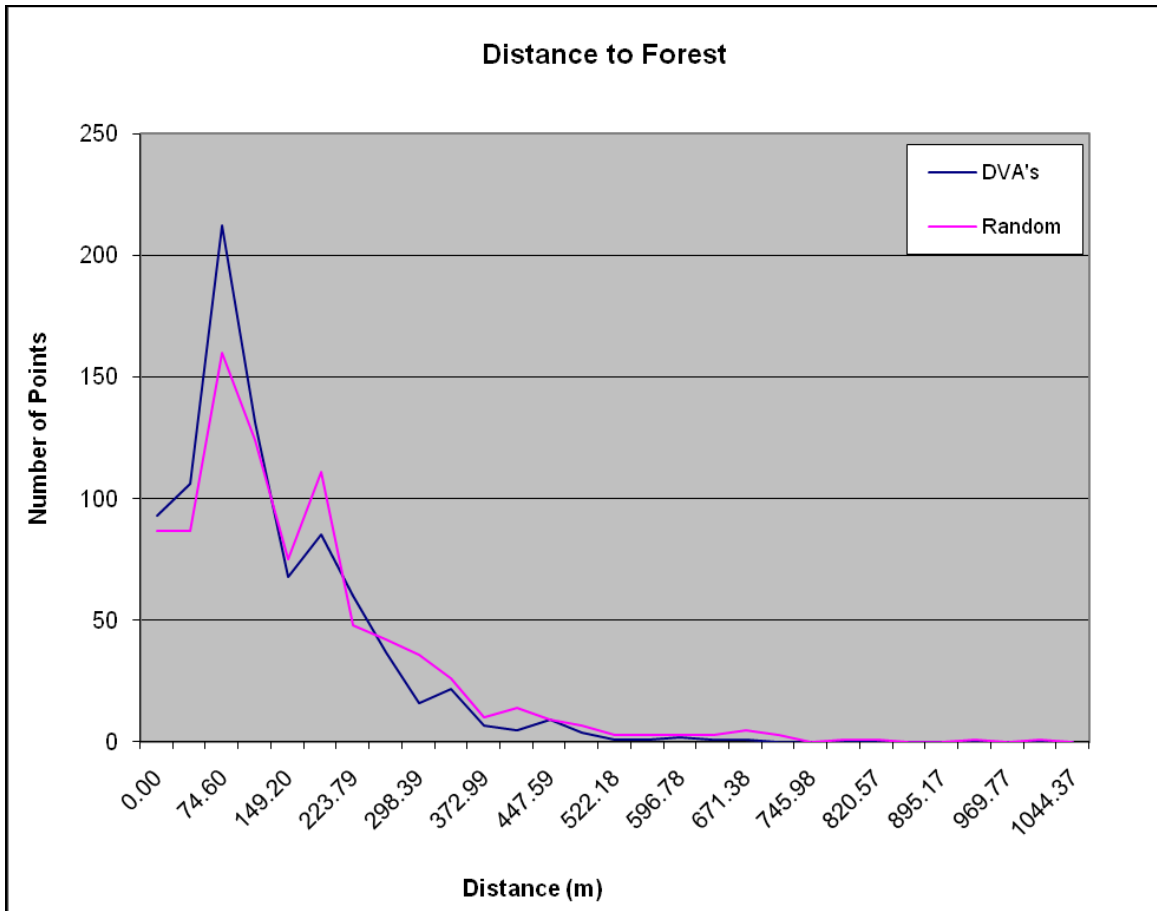


Figure 14. Line graph showing the number of DVA's and random points falling within specified distances from forested areas. A greater number of DVA's than random points are found closer to forested areas. There are approximately 100 more total DVA's than random points up until 112 meters from forests. The number of random points exceeds DVA points at distances greater than 112 meters from forest.

Distance to Water, Wetland, Cropland

This variable explains 4.81% of the variance between the random and DVA groups of points (Table 10), with the average DVA falling almost 100 meters closer to these areas than random points. The F statistic was also quite high relative to other variables analyzed. Significantly more DVA's than random points were found closer to these areas. As with the distance to forest and grassland line graphs, the random and DVA distributions for this variable follow parallel curves (Figure 16).

Distance to High and Low Intensity Urban

These variables produced low explanatory powers and or insignificant p-values, and therefore the results of these analyses were excluded from this section.



Figure 15. Area of Water, Wetland, and Cropland in St. Louis County. A grid from this map was created showing distances to these areas, from which the corresponding values for DVA's and random points were determined.

Table 9. Summary Statistics for Distance to Water/Wetland/Cropland. The average DVA was found almost 100 meters closer than the average random point to these areas. There is more variance between random points than there is between DVA's.

SUMMARY

<i>Groups</i>	<i>Count</i>	<i>Sum</i>	<i>Average</i>	<i>Variance</i>
DVA's	861	213759.23	248.27	34404.77
Random Points	861	295940.47	343.712	55902.54

Table 10. Anova statistics between random and DVA points for Distance to Water/Wetland/Cropland. The F value is a lot higher than the critical F, indicating that this variable is important. The percent variance explained by this variable is 4.81, which is relatively high compared to other tested variables.

ANOVA

<i>Source of Variation</i>	<i>SS</i>	<i>df</i>	<i>MS</i>	<i>F</i>	<i>P-value</i>	<i>F crit</i>
Between Groups	3922041.44	1	3922041	86.86	3.45E-20	3.846871
Within Groups	77664287.02	1720	45153.66			
Total	81586328.46	1721				
% Variance	4.81					

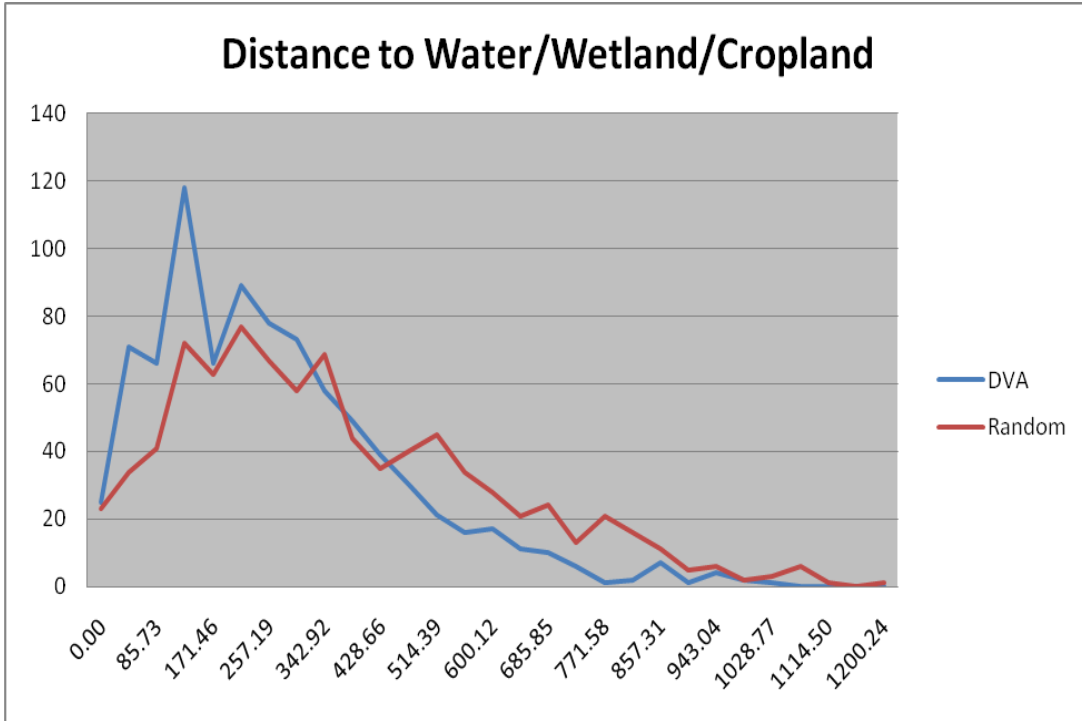


Figure 16. Line graph depicting the distance (m) of DVA and random points from areas of water, wetland, and cropland. There are significantly more DVA's closer to these areas than there are random points. There are more random points than DVA points as the distance from WWC areas increases.

Intersections of Streams and Roads

Figure 17 illustrates where streams intersect with roads in St. Louis County, with the DVA's overlain. The line graph in Figure 18 shows the distribution of DVA and random points in a range of distances from these intersections. The DVA and random point distributions follow identical curves, a phenomenon also exhibited by the distance to LULC variables. Table 11 shows that the average distance for random points is 474.32 meters, which is 75 meters further than the average DVA point. There are many more DVA's than random points at distances closer to these intersections. Table 12 shows that the percent variance explained by this variable is 1.20, a low explanatory power, in spite of the fact that the F value is 20.82, which exceeds the critical F value of 3.85.

Slope and Aspect

These variables had low explanatory powers and or insignificant p-values in St. Louis County, and therefore the content of the analysis is excluded from this section.

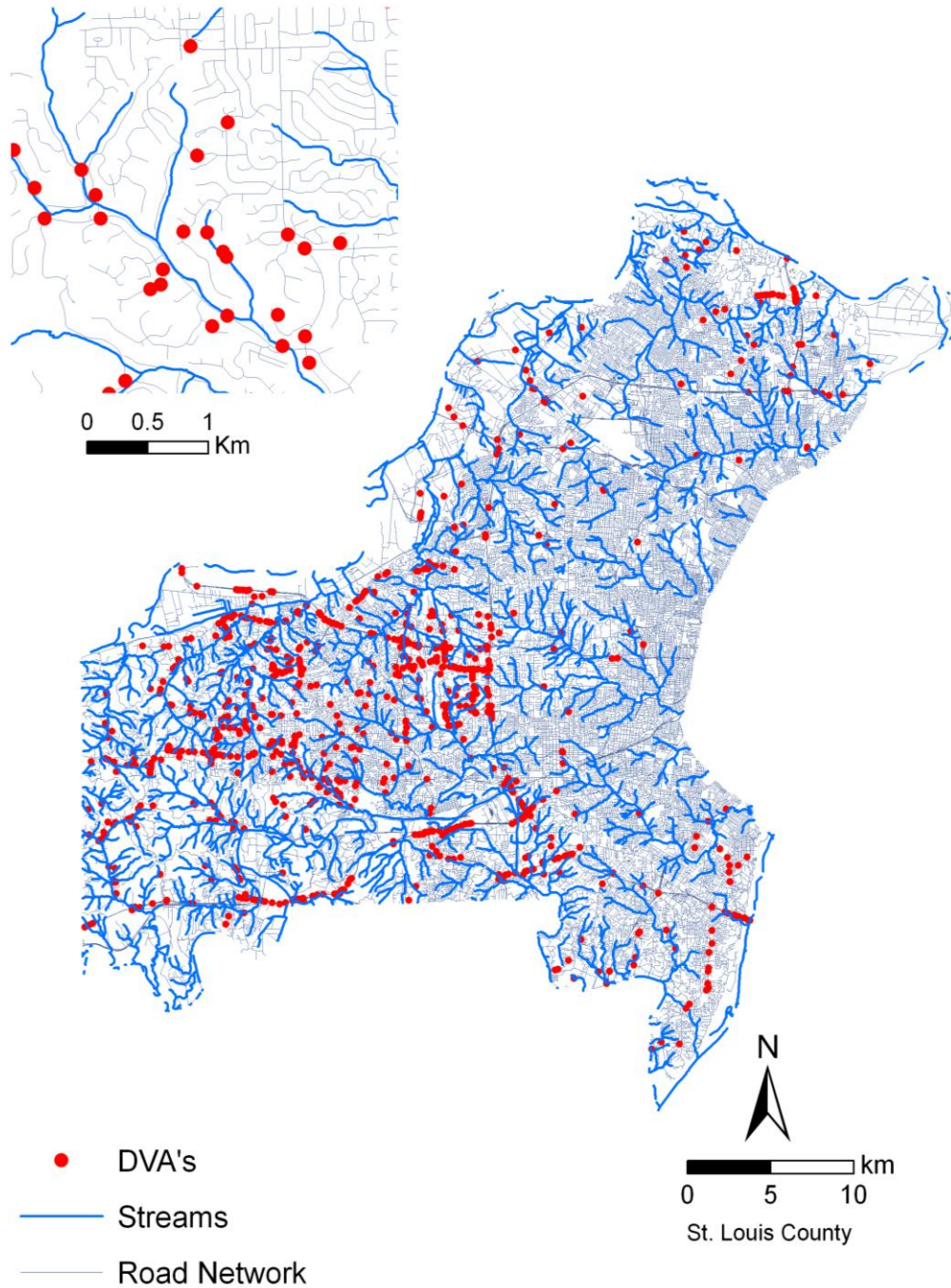


Figure 17. DVA's overlain on streams and roads. Note that DVA's appear to cluster around the junctions where streams cross roads, or very close to streams. The inset illustrates an example of DVA's that have occurred at these intersections.

Table 11. Summary of statistics between DVA and Random points for distance to intersections of streams and roads. The average DVA distance to the intersection of roads and streams was 75 meters less than the average for random points. There is slightly more variance between random points than there is between DVA points.

SUMMARY

<i>Groups</i>	<i>Count</i>	<i>Sum</i>	<i>Average</i>	<i>Variance</i>
DVA's	861	343721.1	399.2	103492.9
Random Points	861	408391.4	474.3	129711.6

Table 12. ANOVA statistics for DVA and Random points for distance to intersections of streams and roads. The F value exceeded the critical F value, thus the random and DVA points can be considered different from one another. The very low P-value indicates that there is a very low probability that the two groups are the same. The percent variance explained by this variable was obtained by dividing between group variation by total variation. In this case this variable explained only 1.2% of the variance between the random and DVA groups.

ANOVA

<i>Source of Variation</i>	<i>SS</i>	<i>df</i>	<i>MS</i>	<i>F</i>	<i>P-value</i>	<i>F crit</i>
Between Groups	2428717	1	2428717	20.83	5.38E-06	3.847
Within Groups	2.01E+08	1720	116602.2			
Total	2.03E+08	1721				
% variance	1.196503					

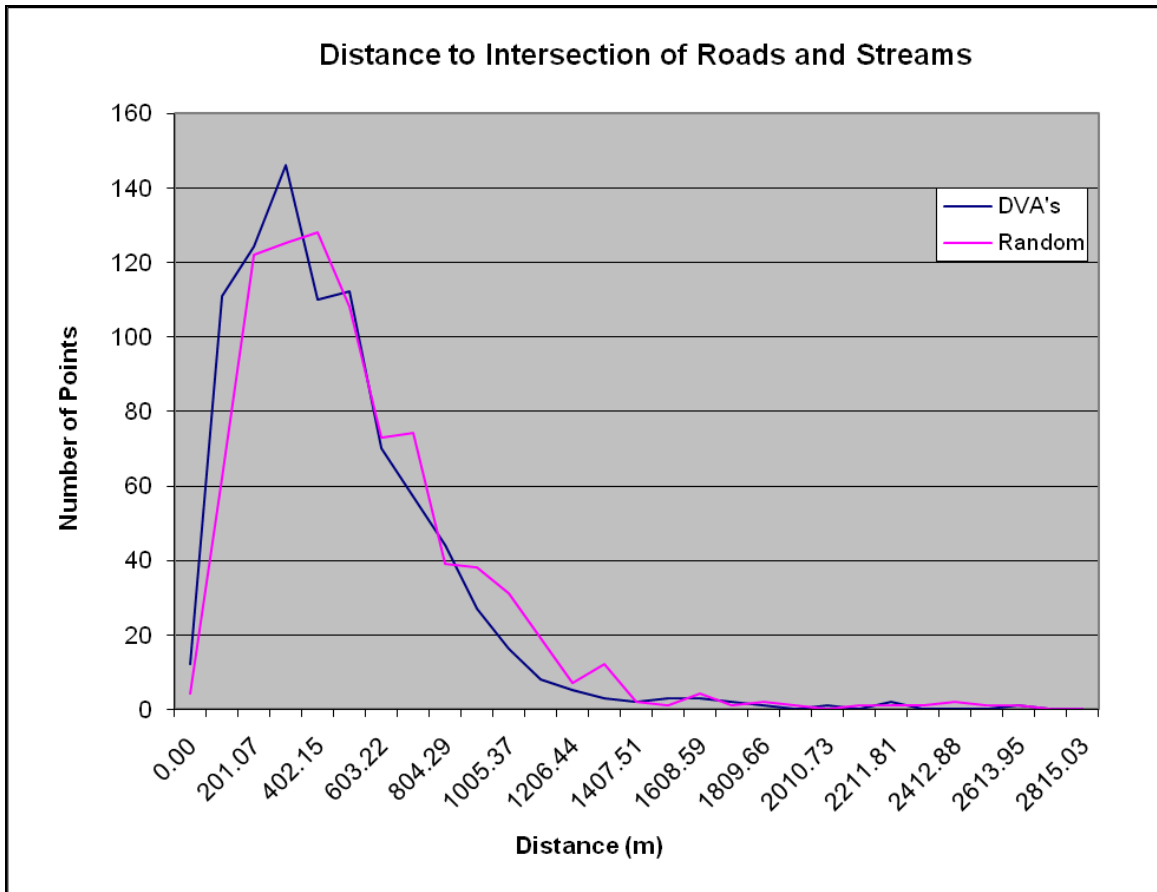


Figure 18. Line graph showing number of points (DVA and Random) falling at a range of distances from intersections of streams and roads. DVA's tend to fall closer to these intersections than random points.

Model

After all variables were analyzed, the two variables with the highest explanatory power were chosen for the model. These variables were road density and distance to grassland. Since the values associated with these variables are continuous, they had to be broken down into three discrete classes in order to simplify the results the model would yield. The three classes in each variable category were combined for a total of 9 categories. Table 13 shows the natural break values that were used in reclassifying each variable into three categories. The maps in Figure 19 and Figure 20 spatially illustrate where the categories occur for these variables in St. Louis County. The nine categories were further broken down into 4 final categories for simplicity (Table 14).

Table 13. Natural break values for variables used in model. DVA's exhibited a continuous range of values for each variable. These values were divided by natural breaks into three categories in ArcMap for the two tabulated variables. Distances up to 67.08 meters from grassland had the largest number of DVA's, as did the road density range between 5.13 and 7.78 km/km².

Distance to Grassland (m)	Road Density (km/km²)
0 - 67.08	0-5.12
67.09 - 169.71	5.13 - 7.78
169.72 - 379.47	7.79 - 12.16

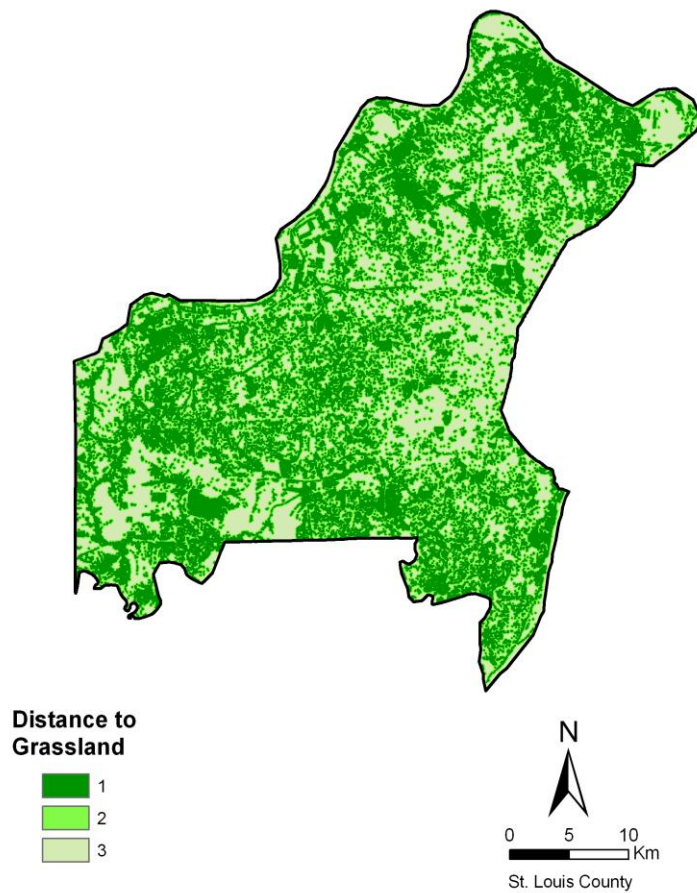


Figure 19. Reclassified distance to grassland categories used in model development. The three classes were created based on natural breaks of corresponding DVA values for this variable. The natural break values for all three classes can be seen in Table 13. The first class (dark green) represents areas of grassland that contain the most DVA's; they are closest to grassland. Likewise, the third class (pale green) contains the fewest DVA's in this category and is furthest from grassland.

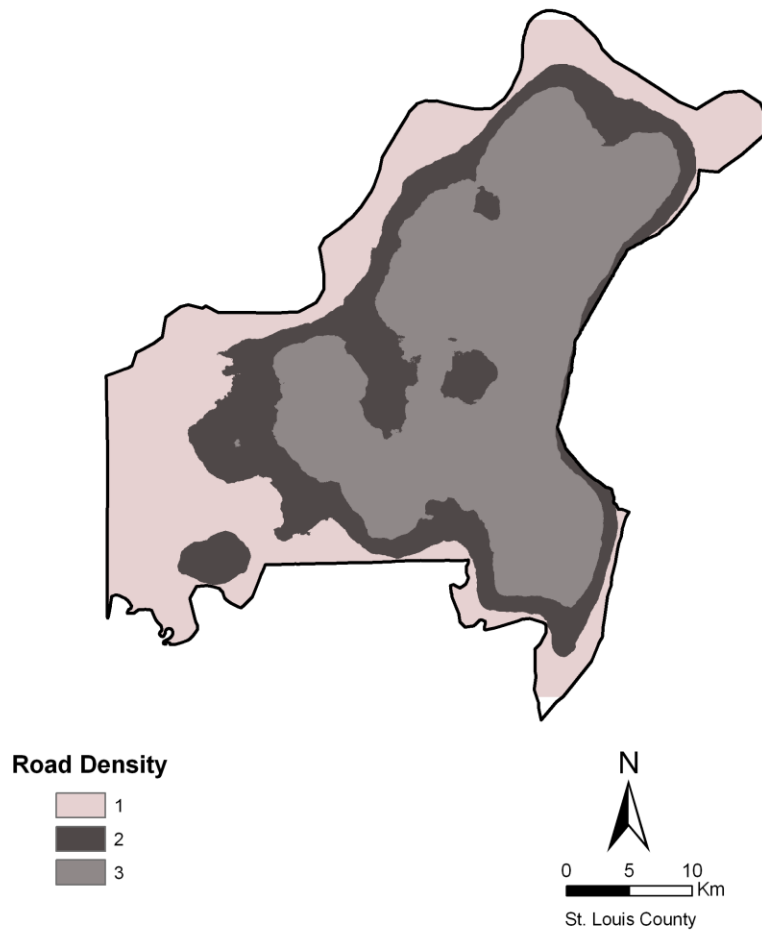


Figure 20. Reclassified road density classes used for model development. These classes were created based on the natural breaks of road density values for each DVA. The dark grey category (2) represents the medium road density values, and contains the highest density of DVA's. The first and third categories represent low and high road density areas that contain fewer DVA's.

Table 14 shows the categories generated from the combination of the distance to grassland and road density categories, color coded from highest to lowest density, and also color-coding the four final categories. Since each variable had three categories, a total of nine categories resulted from this combination. The table shows the density of DVA's per category based on the division of the number of DVA's by the category's area. Categories are sorted from highest to lowest density, with the GR1_RD2 (closest to grassland, medium road density) category having the largest density of DVA's. The category with the fewest DVA's and lowest density was GR3_RD1 (furthest from grassland, with the lowest road density). Figure 21 matches the color coding scheme in Table 14 and shows the 4 category model created by combining categories that differed by less than 20% in DVA density, starting with the most dense category (1), that was 1.37 DVA's/km². The new Category 1 is colored orange in the table. It is also orange in the categorical map (Figure 21). The second category has the smallest overall area of land and the third category has the largest overall area.

Table 14. Combined two variable model using distance to grassland and road density. Categories are sorted by density, which is expressed in DVA's/km². The color coding shows the four final categories. The category where a DVA is most likely to occur is G1_RD2, close to grassland with medium road density. The density of DVA's in this category is 1.37 DVA's/km². The category least likely to have a DVA is G3_RD1, furthest from grassland, with low road density.

Category	# DVA's	Area (km ²)	Density	Description
1	262	191.40	1.37	G1_RD2
	112	84.35	1.33	G2_RD2
2	154	198.50	0.78	G1_RD1
3	19	35.45	0.54	G3_RD2
	97	195.90	0.50	G2_RD3
	129	274.40	0.47	G1_RD3
4	41	104.90	0.39	G2_RD1
	34	146.70	0.23	G3_RD3
	13	120.80	0.11	G3_RD1

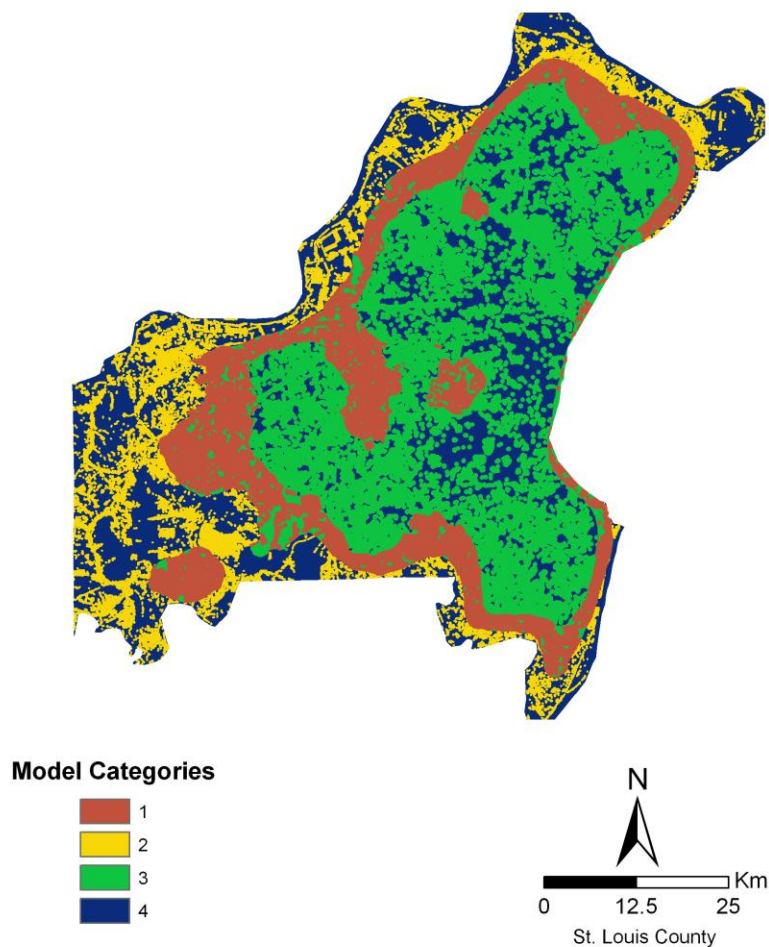


Figure 21. Map of reclassified combined two variable model using road density and distance to grassland. For simplicity, the categories in Table 14 were condensed from the nine categories to include only these four. Categories are numbered 1-4 from highest to lowest probability of containing a DVA.

Model Validation

Table 15 shows the breakdown of categories generated from the application of the road density/distance to grassland model to the 2005 DVA points. The densities were weighted to the model by dividing the 2000-2004 DVA total (861) by the 2005 total (315). The resulting number, 2.73, was then multiplied by each density to give the weighted density values that could be compared to the original model. Using the 9 original categories, 92% of DVA's were classified in the same categories as the original data. Using the 4 final categories for this model, 100% of DVA's were correctly classified into categories.

Table 15. Model applied to 2005 DVA's for validation. The categories with the highest densities are the same as the categories derived from the 2000-2004 data. A weighted density field was added to compare densities from this year's data to the original densities that were based on five years of data. Like the original data in the model, the top categories for 2005 also have DVA's close to grassland and with medium road density.

Category	# DVA's	Area	Density	Description	Weighted Density
1	91	191.40	0.48	G1_RD2	1.30
	40	84.35	0.47	G2_RD2	1.30
2	63	198.50	0.32	G1_RD1	0.87
3	8	35.45	0.23	G3_RD2	0.62
	39	195.90	0.20	G2_RD3	0.54
	44	274.40	0.16	G1_RD3	0.44
4	15	146.70	0.10	G3_RD3	0.28
	9	104.90	0.09	G2_RD1	0.23
	6	120.80	0.05	G3_RD1	0.14

Land Use/Land Cover Classes in model categories

Category 1, which is where DVA's are most likely to occur, has 25% forest, 22% grassland, 6% HIU, and 42% LIU. It contains the lowest percentage of WWC, with just 5%. Category 2 is similarly high in forested and grassland areas, with very low HIU, 12% LIU, and 21% water, wetland, and cropland. This category has the largest percentage of grassland, with 33%. Category 4 has no grassland, but a greater percentage of forest (33%) than any of the other categories.

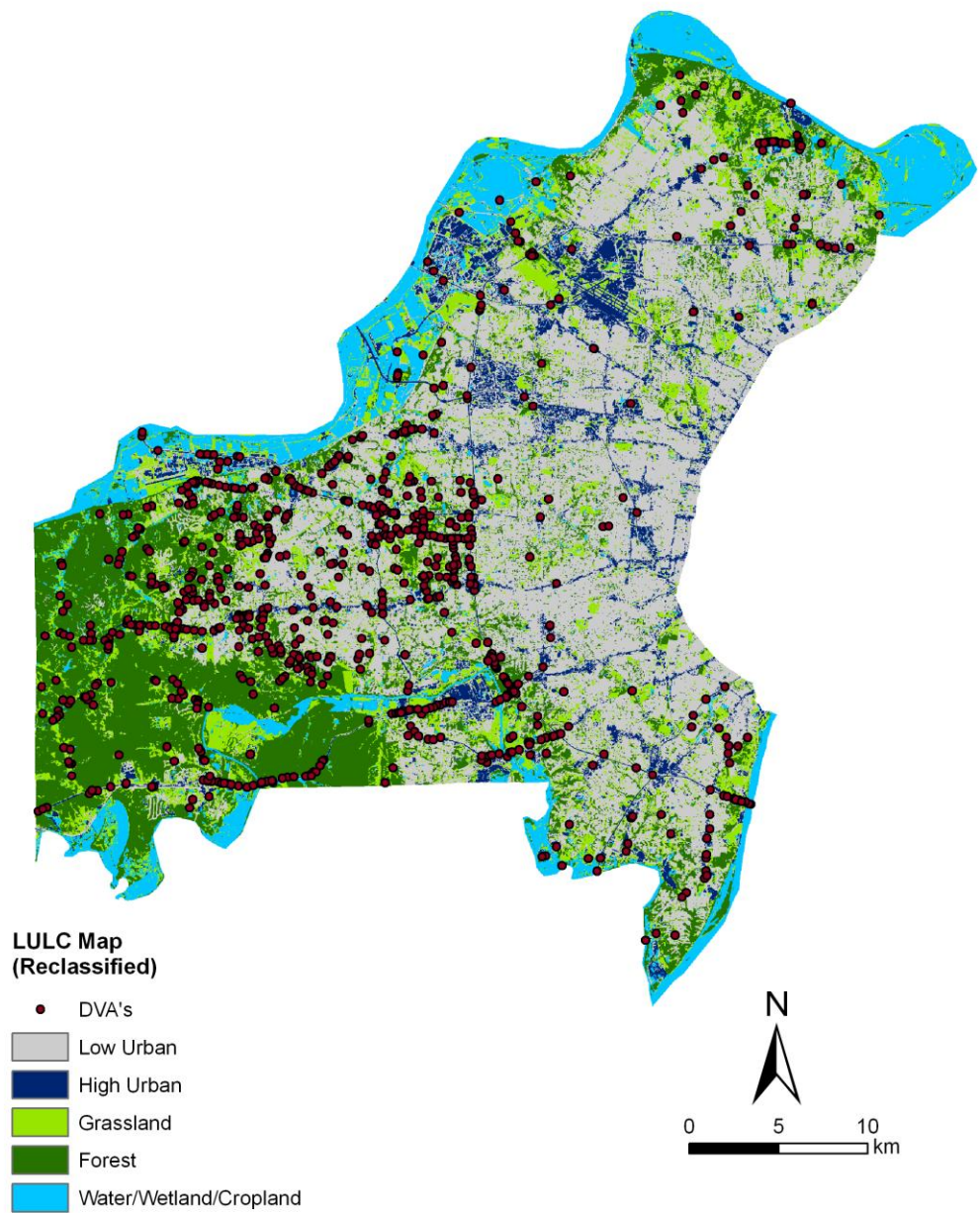


Figure 22. LULC classes with DVA's overlain. The categorical breakdown of these classes was analyzed in the model categories.

Table 23. Area (in km²) of LULC classes in the model categories. Percentage of each category the LULC comprises is shown in parentheses. Category 3 has the largest total area and has the most LIU and HIU areas. Category 2 has the smallest area of High Intensity Urban. Category 4 has the most Water/Wetland/Cropland area, the most forested area, and no grassland.

	Category 1	Category 2	Category 3	Category 4	Total LULC Area (km ²)
Forest	68 (25%)	59 (30%)	61 (12%)	117 (32%)	305 (23%)
Grassland	60 (22%)	66 (33%)	72 (14%)	0	198 (15%)
HIU	16 (6%)	8 (4%)	49 (9.7%)	36 (9.7%)	109 (8%)
LIU	117 (42%)	23 (12%)	312 (62%)	124 (33%)	576 (43%)
Water/ Wetland/ Cropland	15 (5%)	42 (21%)	11 (2.2%)	95 (26%)	163 (12%)
Area in STL	276 (20%)	198 (15%)	505 (37%)	372 (28%)	1351

Comparison of DVA's in model categories and road types

Figure 23 illustrates the types of road DVA's fall on, and distinguishing between the private and public roads. Table 16 shows the length and percentage of MoDOT and private roads per model category. It also shows the number and percentage of DVA's that occurred on either MoDOT or private roads in each category. There are ten times more private roads than MoDOT roads in St. Louis County, yet 57% of all DVA's occur on MoDOT roads. 1.79% of the roads in all of St. Louis County fall into Category 1, and are MoDOT roads. The total number of DVA's in this category was 374, and the number of DVA's falling on MoDOT roads was 185, which is 21.49 % of all DVA's in St. Louis County. Thus, 21.49% of all DVA's happened on 1.79% of all roads in the county. Including Category 2, 34% of all DVA's occurred on MoDOT roads that made up just under 3% of all roads in the county. This is a considerable number of DVA's occurring on a small percentage of roads, in the highest risk categories.

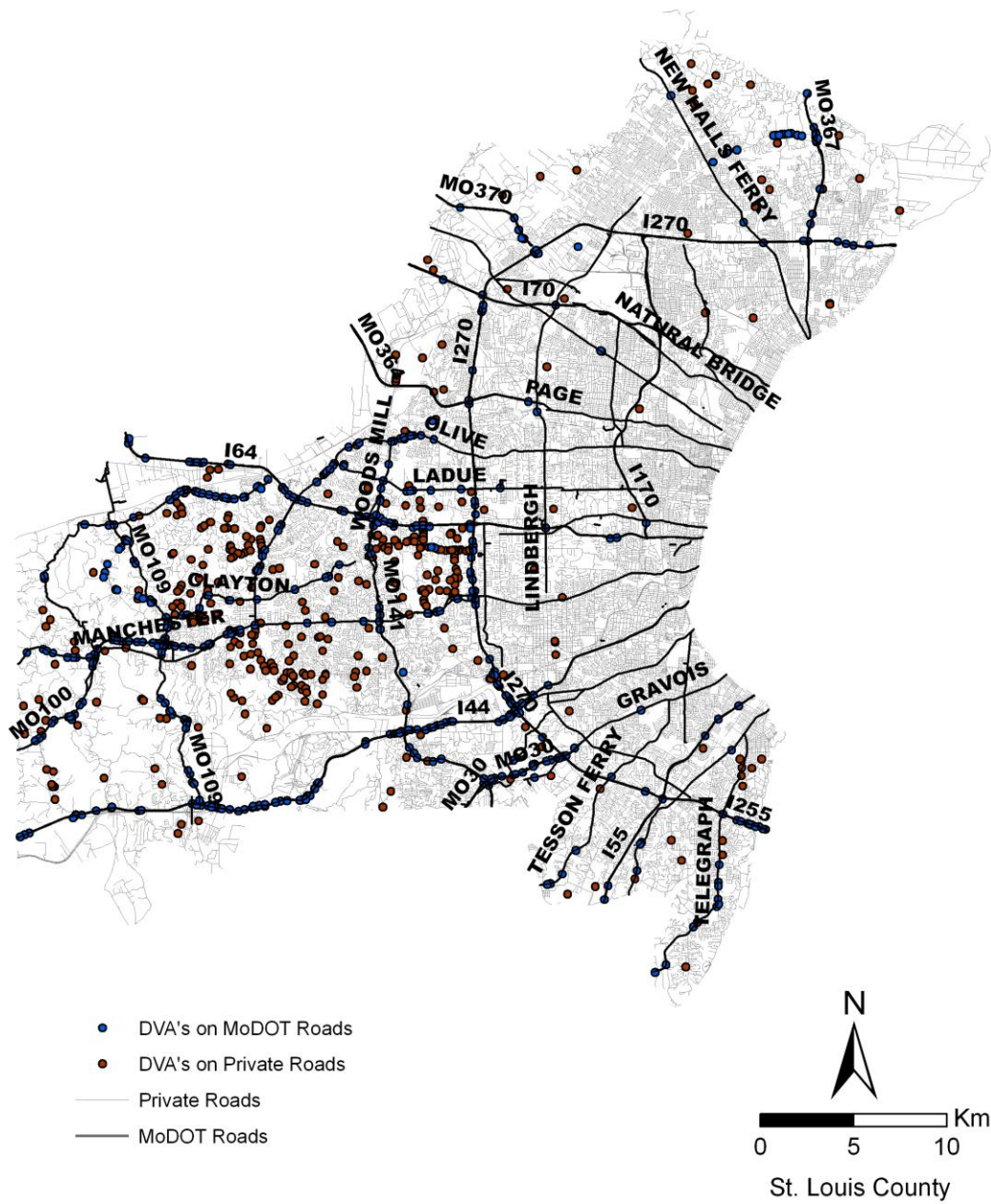


Figure 23. Road network showing DVA's overlain on Private and MoDOT roads. DVA's on MoDOT roads are in navy, and DVA's occurring on private roads are shown in burgundy.

Table 16. Comparison of private versus state roads in model categories in St. Louis County. Private roads make up 8974.42 km and 90.8% of all roads in the county, but only 42.86% of DVA's occurred on these roads. MoDOT roads make up only 9.2% of all roads in the county, yet 57.14% of all DVA's occurred on MoDOT roads. Category 1 had 19.36% of all roads, of which 1.79% (of total roads) were MoDOT and 17.57% were private. 43.44% of all DVA's were in Category 1, which were split between private and MoDOT roads.

Category	Length MoDOT (km)	% Roads that are MoDOT	Length private (km)	% Roads that are private	Total Length (km)	% of all roads in categories
1	177.28	1.79	1736.74	17.57	1914.02	19.36
2	117.98	1.19	800.57	8.10	918.55	9.29
3	443.36	4.49	4297.08	43.47	4740.44	47.96
4	171.08	1.73	2140.04	21.65	2311.12	23.38
Totals	909.71	9.20	8974.42	90.80	9884.13	

Category	#DVA's	%DVA's	DVA MoDOT	% DVA on MoDOT	DVA Private	% DVA on Private
1	374	43.44	185	21.49	189	21.95
2	154	17.89	109	12.66	45	5.23
3	245	28.46	153	17.77	92	10.69
4	88	10.22	45	5.23	43	4.99
Totals	861		492	57.14	369	42.86

4 DISCUSSION

K function

Since the analysis of K function revealed DVA's were clustered in the landscape, the objective was to then find out what patterns in the landscape were contributing to this. The variable analyses were selected to determine if any landscape characteristics could predict patterns associated with DVA's which might lead to clustering. An additional analysis of K function on the random points within the road network would be worth performing in future studies. As it stands, the analysis was limited because it tested DVA's within the two-dimensional landscape, and not the one-dimensional road network. It compared the spatial arrangement of DVA's to the spatial arrangement of random points that fell anywhere in the entire landscape, and not the one-dimensional road network. The landscape constrains the road network, and in turn the configuration of any points that fall within this network. Thus, if the random points had strictly fallen within the road network, there would likely have been clustering as well. Based on a visual analysis of the dispersal of the 861 random

points in the road network, the K function analysis would likely produce less clustering than the DVA's. Additionally, the variable analyses conducted in this study demonstrate that DVA's are clustered in specific areas based on their relationship to landscape characteristics further described in their respective sections of the discussion below. They also reveal similar patterns within the random points in the road network. The results, however, indicate that these points are much more dispersed.

Road Density

The wide range of variances produced depending on the search radius used when creating the road density grids illustrates the importance of carefully designing and evaluating guidelines for creating map variables. Percent variance explained by this variable is only 3.59 at the 500 meter search radius, and gradually increases up to the 2500 meter radius, which explains 10.08 % (Table 3). This analysis would have produced a remarkably different result if a smaller search radius had been used.

The grid of road densities (Figure 8) illustrates that the highest road densities occur in the eastern half of St. Louis County. A visual inspection of DVA locations indicates very few points fall in this portion of the county. The majority

of DVA's occur in the regions of the map corresponding to medium road density (dark blue), with an average of 6.61 km/km².

There are very few DVA's in the areas of high road density in St. Louis County, however many random points fall in these areas. This explains why the random points have a higher average road density than DVA points. The line graph (Figure 9) illustrates the contrasting differences between the actual DVA's and randomly generated points. Although the general pattern of both curves is similar, the range of densities where points are found is distinct, with random points falling at a wider spectrum of densities than DVA's. Additionally, there is a middle range of road densities, between 6.32 and 8.82 km/km², where the DVA's peak. 52.7% of the DVA points fall between this range, whereas only 32.0% of random points fall into this range. Road density was the best predictor of DVA's based on the largest percentage of variance explained in comparison to the other variables. It was thus the number one choice for inclusion in the model. The similar curves illustrated by points in the line graphs, regardless of whether DVA or random, are a byproduct of the landscape. The landscape dictates where the roads are built and thus where any point has the potential to fall. All of the line graphs for the variables tested generated similar curves between the random and DVA points, a reflection of where the roads are in the landscape.

Land Use/Land Cover Class Variables

Distance to Grassland

This variable was the second most important in the analyses of variables, explaining 7.27% of the variance. Since grasslands are commonly used by deer for feeding, this is not surprising. This variable was chosen for inclusion in the model for these reasons. Although grassland makes up only 14.6% of St. Louis County, DVA's occur on average within 73 meters of these areas. In West St. Louis County, large areas of grassland have been created by clearing forests for residential development and for building roads. This creates an abundance of edge with superior forage where deer are inclined to gravitate. Deer are edge browsers, and increased habitat fragmentation has been correlated with higher deer populations in Missouri (Pullins 2004). The interface between these fragmented areas of grassland in close proximity to roads creates a conflict between humans and deer. Consequently, DVA's are more abundant close to grassland areas where both humans and deer are active.

Distance to Forest

Significantly more DVA's were found closer to forested areas than random points. Random points can be found at a much wider range of distances from forests, whereas it would not be likely to find a DVA more than 500 meters from forested land. This variable was not found to be as important as the road density and distance to grassland variables. A visual inspection of Figure 14 shows that there are heavily forested areas in West St. Louis County that have low incidences of DVA's, likely because they also have a low density of roads. This could account for the lower explanatory power this variable yielded. It is also possible that the minimum 900 m² areas of forest from which DVA distances were measured is too small of an area for deer. The minimum area considered useful to deer for cover is two hectares, according to a habitat suitability analysis conducted by Roseberry and Woolf (1998). A modification of this variable to only include contiguous areas of at least 2 hectares would likely produce a significantly higher explanatory power in the ANOVA analysis.

Distance to Water, Wetland, Cropland

This variable does have a relationship with DVA's, and it had the third highest explanatory power of all the variables tested. It is likely due to the fact that deer are active in areas that have high quality food to forage, as well as water for drinking. Since these three Land Use/Land Cover Classes were predominately located adjacent to one another, they were classified together. However, it could be more useful to look at larger classes like open water and cropland individually for their relationships to DVA's. The smaller classes of wetland forest may be worth examining as well. Despite the fact that the wetland categories make up small areas of the landscape, if there were a strong connection between DVA's and these classes, it could be worth focusing on them for mitigation.

Distance to Intersections of Streams and Roads

The percent variance explained by the variable measuring distance to stream/road intersections was very low, at just 1.20% (Table 12). Although the F statistic exceeded the critical F value, and the p-value was far below 5%, this variable was not an important predictor of DVA's. Since this dataset includes

many orders of streams, perhaps this variable might have been more significant if a different set of streams had been used that distinguished between orders of streams from which deer would be most likely to feed. A visual inspection of DVA's on streams indicates that some may be clustered around the major watersheds. Perhaps a more specialized analysis of major streams would have increased the explanatory power of this variable.

Model

The model (Table 14 and Figure 21) was created using the distance to grassland and road density variables because this was the most straightforward. It had a high level of predictability while maintaining parsimony with relatively few categories. For comparison, other models were created using a combination of variables. A model using distance to grassland and distance to forest was created because these are both important components of deer habitat. It was thought that the combination of these variables might produce a model with high predictability based on variable interactions. This model had considerably lower predictability than the model that used distance to grassland and road density, with its highest category having just .86 DVA's/km². Another model used a combination of distance to forest, distance to grassland, and road density.

The level of predictability of this model was magnified, and the top ranked category had a density of 1.86 DVA's/km². There were a total of 27 categories produced by the input of the three classes per variable, and the high level of predictability was outweighed by the unwieldy number of categories. Thus, a compromise was reached between the combination of variables with the highest explanatory powers (distance to grassland and road density), and the relatively high predictability of this model.

Distance to grassland/road density

The areas with the highest densities of DVA's had medium road density and were close to grassland. Category two in the reclassified 4-category model was closest to grassland with low road density. The areas with the lowest DVA densities were further away from grassland, with either high or low road density.

Model Validation

The model successfully predicted 100% of the 315 points input from 2005 for all 4 categories of the model, and predicted 92% with the original 9 specific categories.

Land Use/Land Cover Classes in model categories

The categorical breakdown of LULC's for the reclassified 4-category model (Table 16) reveals there is no grassland in the fourth category. This is logical since distance to grassland is the second most important variable for predicting DVA occurrences. West St. Louis County has a large area of forest in Category 4, and a low density of roads, so although there is high deer activity in this area based on aerial surveys (Shank 2008), there is low human activity, which accounts for the low density of DVA's. Category 4 also had a considerably larger area of the WWC Land Use Land Class than the other categories (95 km²). The more centralized areas within the county that contain open water, wetland, or cropland interfaced with LIU's, forest, and grassland, as in Category 1, have higher incidences of DVA's. In general the interface of large areas of moderate human activity (LIU's) with large areas of forest and critical grassland, where deer activity is high, would be expected to yield a large number of DVA's. Category 1 seems to be a prime example of this interface. Category 2 has large areas of forest and grassland as well, with a large area of WWC. This category has areas close to grassland with low road density. Being close to grassland is

the second greatest predictor of DVA occurrence after road density. Although road density is low in this category, since there is a large area of prime foraging habitat dissected by roads, DVA's are somewhat dense here. Much of Category 4 is found interspersed between Category 2, but because Category 4 contains no grassland, deer are more protected from vehicle collisions. Deer are likely using the forests for cover in these areas, but perhaps they do not move around as much when confined to the forest cover, and are less likely to be struck than when they are browsing through grasslands that are close to roads. It is also possible that deer are active in the forested areas at night when humans are less active on the roads, and more active around the grasslands during the day or early evening when humans are most active, which contributes to the deer vehicle accidents. These heavily forested areas in Category 4 will be prime targets for DVA's if future residential development exposes large areas of grassland and forest edge that are then intersected by roads.

Category 3 contains a large area of LIU's, with less grassland and forested areas than the first two categories. Because there is a considerable area of grassland, there is still a significant number of DVA's in this category, however at a lower density because they occur over a larger area.

Comparison of DVA's in model categories and road types

Higher traffic volume and speeds associated with state-maintained roads probably contribute to the higher incidence of DVA's on these roads. Hubbard et al found that the number of lanes was positively correlated with DVA's (2000). A more in depth analysis of landscape variables associated specifically with MoDOT roads would likely improve model predictability, revealing areas with even higher densities of DVA's than the model developed in this study. In fact, in light of the prevalence of DVA's on these roads, it could be beneficial to exclusively analyze MoDOT roads using the same analyses performed in this study. Table 16 shows that close to 60% of all DVA's occurred on MoDOT roads, with 21.49 % of these occurring in the top ranking category, on just 1.79% of all the roads in St. Louis County. In comparison, close to 22% of all DVA's that occurred on private roads were also in the first category, but they occurred on close to 18% of all the roads in St. Louis County. With just 9.2% of all roads in the county being state controlled, and a large majority of DVA's occurring on these roads, it would certainly be worthwhile to take a closer look at MoDOT roads.

5 CONCLUSION

The variable with the greatest explanatory power in this analysis was road density. Very few DVA's occur in the highly populated areas east of I-270 in St. Louis County, where road densities are high and the road configuration is tightly gridded. Deer activity is constrained by the high density of roads, even in areas where forest could provide cover and grassland could provide available forage. Due to these constraints, there are few to no deer in these areas (Shank 2008) east of I-270. The random points interspersed throughout these large areas account for higher average road density values than DVA points.

Distance to grassland was the second greatest predictor of where DVA's were likely to occur. This is logical since deer are active around areas that provide abundant forage. On average, DVA's happen 73 meters from grassland. The nature of road placement in the landscape could account for this proximity to grassland. The average random point was found further away from grassland than DVA's, but the lines follow the same curve for both random and DVA points, an indication that the landscape is influencing road placement. In fact, all of the distance variables measure exhibited parallel curves between the DVA's

and random points. However, a greater number of DVA's occurred where the lines peaked in the distributional curves. It is evident from these graphs that landscape pattern is driving the process which controls where the roads are located, and thus where any given point, whether random or DVA, is going to fall. DVA's are more sensitive to this pattern, which is reflected by their higher peaks than the random points. Further studies are needed to reveal the landscape patterns that are leading to this process. Interestingly, since DVA's follow patterns of random points in the roads, and peak in the same places, random points can replace DVA's in areas to predict where DVA's would likely occur. This would be useful in the absence of DVA data points, specifically for predicting areas where DVA's would likely occur in developing residential areas. Distance to forest and intersections between roads and streams were not as important predictors in this analysis, as these variables had low explanatory powers. Finder found that distance to forest cover was the most important predictor of DVA hotspots in Minneapolis, MN (Nielsen et al. 2003). A study in St. Louis County may find similar results if the areas east of I-270 with low DVA incidence are excluded, and if contiguous forested areas of at least 2 hectares are included (Roseberry and Woolf 1998).

There were some significant differences between DVA densities on MoDOT and private roads. A more in depth analysis of landscape characteristics surrounding DVA's exclusively on MoDOT roads would be valuable.

Management Implications

This study did not address temporal and site specific attributes associated with DVA's. The largest number of DVA's did occur in the month of November in St. Louis County. Educational efforts aimed at informing drivers of this dangerous time could help reduce DVA's during this high-risk month. Speed limit reductions in areas prone to DVA's, especially during this month of high deer activity, could also reduce DVA's. Concentrating on mitigating MoDOT roads could prove successful in reducing DVA's in St. Louis County. MoDOT roads make up a small fraction of all roads in the county, and a large percentage of DVA's in the highest risk categories occurred on a very small percentage of the roads. These roads were under MoDOT supervision. Hubbard made a similar discovery with DVA's on Iowa DOT roads, noting that 25% of DVA's were found on just 3.4% of the roadways (Hubbard et al. 2000). With so many DVA's occurring in such a small area, mitigation of DVA's could be cost effective considering the high costs of DVA's. According projected monetary losses to

Missourians based on average State Farm Insurance claims and the total number of deer struck by cars, Missourians lost over \$86 million in monetary damages from DVA's in the 2006-2007 fiscal year (2007). As this number is compounded by yearly losses, mitigation of deer vehicle accidents would become cost effective over time. Other than some fencing and the occasional sign in St. Louis County there do not appear to be any mitigation strategies in place for reducing DVA's. According to a 2004 survey of West St. Louis County residents, 16% of respondents said they or an immediate family member had been in a deer vehicle collision in West County in the previous five years (MDC 2005). Efforts to mitigate DVA's in St. Louis County would likely be welcomed.

In light of the SAFETEA-LU legislation requiring wildlife agencies to work together with DOT's (GPO 2008), such a collaboration in Missouri could focus on reducing DVA's by installing or retrofitting underpasses and fencing, especially around the MoDOT roads where DVA's are mostly likely to occur. This would include the areas in close proximity to grassland where deer are often active. Clevenger found that crossing structures will be used if positioned and designed properly, and even if not positioned properly animals will learn to use them (Clevenger 2001). Clevenger also found that properly placed fencing reduced wildlife-vehicle collisions (Clevenger et al. 2001). Clearing right-of-ways to

increase visibility, keeping areas un-mowed to reduce palatability of browse, and planting unpalatable forage in rights-of-way are less expensive methods that have the potential to effectively reduce DVA's and other wildlife collisions as well (Conover 2002).

New Hampshire DOT Commissioner Carol Murray said, "If you don't link land use and transportation, both will fail." In 2006, NHDOT allowed a Community Advisory Committee (CAC) to produce their long range transportation plan (White 2007). The CAC was comprised of state and local officials, housing advocates, and environmental groups. Similar initiatives in St. Louis County which integrate community involvement could have a positive impact on future road placement in the county resulting in DVA reductions.

With over 29,000 DVA's per year in Missouri, and safety being a high priority of St. Louis County residents, mitigation and responsible road planning to prevent future DVA's would be the next logical step in dealing with this significant issue.

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