

**EFFECTS OF GENDER AND SEASON ON SPATIAL AND TEMPORAL PATTERNS OF DEER-VEHICLE COLLISIONS**

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Abstract: White-tailed deer (Odocoileus virginianus) are a serious accident hazard, especially in suburban communities with high deer densities. Such areas are becoming more common as deer populations continue to grow throughout the northeastern United States. This study analyzed deer-vehicle collision data collected from police reports in Connecticut for 2000, 2001 and 2002. The purpose of this project was to integrate the use of standard crime mapping tools, multi-temporal remotely sensed vegetation imagery, human infrastructure, and the behavioral aspect of white-tailed deer to create a spatially explicit model of gender-specific deer-vehicle accident probabilities. We found marked differences between number, location, and seasonality of male and female accidents. Through most of the year, the number of males and females involved in accidents were relative to their proportion in the population. However, during the breeding season, there were a higher proportion of males involved in accidents. The spatial distribution of accidents involving deer also varied by season and sex – outside of the breeding season, accidents involving male deer were concentrated in a few key locations in the state. The difference in the spatial location of male and female accidents could be the result of resource partitioning exhibited by the species, with males occupying broader ranges in peripheral habitats. This model can be used to predict high risk areas as they change over the different seasons and design warning programs and adaptive education to these target areas.

Introduction

Nationwide, deer have been estimated to cause 1.5 million motor vehicle accidents annually, resulting in 1.3 million deer killed and $1.1 billion in vehicular damage (Conover et al. 1995). Deer-vehicle collisions (DVC) have also been estimated to result in 29,000 human injuries and over 200 fatalities annually (Conover et al. 1995). If the economic estimate of $1,313 for a hunter-harvested deer (Romin and Bissonette 1996) is applied to the estimated annual road-killed deer, then $1.7 billion in potential economic revenue is lost annually (Conover et al. 1995). Conover et al. (1995) also estimate that less than 50 percent of DVC are actually reported. State Farm Insurance reports that each DVC typically causes $2,000 in property damage, though it can exceed $10,000. Deer strikes are on the increase in the United States as human and deer populations are growing, and habitat continues to be fragmented. Perhaps local analysis of documented DVC could better predict time and place of such collisions by examining habitat preferences, seasonality, and gender differences in collision timing and location.
In 2000, 3,123 legitimate deer-kill incident reports (DKIR) were completed in the state of Connecticut, 3,209 in 2001, and 2,571 in 2002. These numbers are on the increase from only 10 years ago. In Connecticut, the Department of Environmental Protection (DEP) gathers information about DVC by using these DKIR. These reports are kept by state and local police officers and conservation officers, and are filled out when a reported DVC occurs. Insurance claims pertaining to DVC will be paid only if the claim is accompanied by a DKIR. If vehicles sustain damage in a DVC, it is most likely that occupants will notify authorities to obtain and fill out a DKIR to make a claim to their insurance carrier. However, numerous DVC are never reported. Drivers of larger vehicles and trucks may not know if they struck a deer, and damage sustained to such a vehicle may be minimal. It has been estimated that there are probably closer to 18,000 deer killed annually by vehicles statewide (Kilpatrick 2004).

**Overview and Methodology**

The data were collected from reported DVC for 2000-2002, which is only a fraction of the actual number of accidents that occurred state-wide. Of the reported accidents, nearly half did not identify the sex of the animal. In 2000, 57 percent recorded the sex of the animal involved (n = 1,781); in 2001, 56 percent were reported (n = 1,801); and in 2002, 53 percent were reported (n = 1,369). The spatial coordinates of each accident were geo-coded using Street Atlas USA 2003 (DeLorme, Yarmouth, ME). The data were combined with topographic data from the national elevation dataset, vegetation data derived from the Landsat and MODIS satellite, road data from Connecticut Department of Transportation, and state and national census data. The project borrowed analytic techniques from crime mapping (CrimeStat® 3.0, Levine 2004), vegetation analysis using remotely sensed data (Lillesand et al. 2003), generalized spatial regressions (Lehmann et al. 2002), and a tree-based risk assessment method called recursive partitioning to analyze the data (Brieman et al. 1984).

We analyzed the data by seasons. For this study, seasons were broadly classified into three categories based on deer biology in Connecticut. January through April is the herding (or yarding) season, when sexually segregated herds are formed and most females are pregnant. This is followed by the fawning season from May through August. Males are generally alone or in small bachelor herds. The home-range of females with fawns shrinks to a fraction of its size during this season as fawns are nursed and the mother-infant bond is cemented (Ozoga et al. 1982, Scanlon and Vaughan 1985). Yearling deer are forced to disperse by expecting does, increasing their susceptibility to predation or vehicle collisions. Finally, the breeding season occurs from September through December. During this time, male home ranges expand significantly as they search for receptive does and defend territories.

We also examined the spatial distribution of accidents involving male and female deer during the three deer seasons by township. The point data for deer accident locations were interpolated using a kernel density smoothing process commonly used in the identification of crime and disease hotspots. The CrimeStat 2.0 software (CrimeStat® 3.0) was used to perform the estimation. This was done to overcome two issues. The first is that the deer location data were only accurate to about 100 meters, and thus an accident could be assigned to the wrong township without the kernel density estimator. The other issue is that the social and structural factors affecting the likelihood of the accidents at a given point are more likely a function of all of the townships very near an accident than just the township where each accident occurred (e.g., traffic patterns between towns, road density, etc.). The interpolation approach used will more accurately reflect these relationships. The data thus represent a localized statistical estimation of the density of accidents in that region.
To examine the impact of vegetation on the spatial and temporal patterns of deer-vehicle collision, we used remotely sensed Normalized Difference Vegetation Index (NDVI) imagery. Monthly NDVI data were downloaded from the Global Land Cover Facility at the University of Maryland (http://glcf.umiacs.umd.edu). The vegetation index is calculated from the infrared and near infrared sensor on the MODIS satellite and has a spatial resolution of 250 meters per pixel. NDVI values, being a differenced ratio range from -1 to 1. Given that the images are quite large, the -1 to 1 values are rescaled to a 0-255 range to reduce the image storage requirements. The formula used was scaled_value=NDVI x 200 +50. These scaled index values are used in the NDVI analysis in this paper (e.g., see fig. 5 and table1 for a comparison table). These index values were queried and attached to the accident location for accident vs. NDVI analyses. One-kilometer buffers were also used in the 2001 analysis to determine if the localized NDVI gave different results than a regionalized NDVI. The results were qualitatively the same, so we stayed with the point assignment of values. Future analysis of landscape metrics will require buffering however. The ByteNDVI values were averaged over the township polygons for each township for analysis at the township level.

**Results**

Statewide, 36 percent of recorded road-killed deer were male and 64 percent female for 2000. For 2001, 34 percent were male; 66 percent, female. The sex ratio of road-killed deer changed with the seasons (figs. 1a, 1b, and 1c). Females accounted for the majority of mortality throughout most of the year (fig. 1a, b), but male mortality increased through the breeding season (fig. 1c). These patterns appear to be consistent over the three years of the study.
Deer-vehicle collisions throughout the months of September, October, November, and December accounted for 54 percent of the total collisions in 2000, 43 percent of the total in 2001, and 45 percent of the total in 2002. Increased DVC were witnessed between 0500 and 0900 hours and again between 1700 and 2100 hours for all three years of the study. For the year 2000, 18 percent of all DVC occurred between 0500 and 0900 hours, 36 percent occurred between 1700 and 2100 hours, and 50 percent occurred between 1700-0100 hours. For 2001, 18 percent of all DVC occurred between 0500 and 0900 hours, 33 percent occurred between 1700 and 2100 hours, and 54 percent occurred between 1700-0100 hours. For 2002, 17 percent of all DVC occurred between 0500 and 0900, 28 percent occurred between 1700 and 2100, and 42 percent occurred between 1700 - 0100 hours. We then compared deer density with the number of reported DVC. We gathered deer density data from the Connecticut Department of Environmental Protection aerial surveys for the 12 management areas for 1999 and 2003 (Gregonis 2003). As expected, the number of accidents involving deer increased with increase in deer density ($r^2 = 0.4521$).
Figure 5. Maps of Connecticut representing the monthly NDVI data for 2001.
We also found significant differences in the spatial distribution of accidents involving males and females in the herding season (fig. 2a, b) and the fawning season (fig. 3a, b). Male accident hotspots outside of the breeding season were restricted to one to two locations statewide. Female accident hotspots were more widely distributed throughout the state. However, during the breeding season, accidents involving both males and females were more evenly distributed spatially, and the location of the accident “hotspots” was similar between males and females (fig. 4a, b). The spatial location of these accident hotspots was consistent across multiple years.

Maps of Connecticut representing the monthly NDVI data for 2001 are presented in figure 5. To examine the impact of vegetation and seasonal vegetation changes on the location of accidents involving males and females, we compared the spatial distribution of male and female deer-vehicle collisions with the NDVI data for the same season (fig. 6). While there were significant changes in the NDVI values over the different seasons and between years, we found that females appeared to track more specific vegetation conditions as measured by NDVI, and through most of the year males covered a broader range of NDVI.

Table 1. Comparison of NDVI valued to scaled values

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<tr>
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Figure 6. A comparison of the spatial distribution of male and female deer-vehicle collisions with the NDVI data for the same month.
Finally, we examined other factors that could potentially affect the movement behavior of males and females. We compared the distance between roads with the number of males and females involved in vehicle collisions (fig. 7). We found significant differences between males and females: accidents involving males were more likely to occur in areas of higher road density, with shorter distances between roads (Kruskal-Wallis $X^2 = 4.26; p<0.05$; fig. 7). Human density also had a significant effect on the number of males and females involved in accidents, with males having a higher incidence of accidents in areas of higher human density (Kruskal-Wallis $X^2 = 3.60; p=0.05$; fig. 8). Accidents involving males were also higher in areas of higher crime rate than areas where female accidents occurred (Kruskal-Wallis $X^2 = 4.06; p<0.05$; fig. 9). These results can be viewed graphically in figures 7-9 where the error bars are one standard error. Thus, if the bars do not overlap, there is roughly a significant difference at the 0.05 level.

Conclusions and DVC Mitigation Recommendations

Seasonal differences between the number of accidents involving males and females differed significantly. Through most of the year, the number of females involved in accidents is higher than the number of males involved in accidents. This is most likely a result of there being a higher proportion of females in the population; long-term data on white-tailed deer have estimated the adult male:female ratio to be approximately 1:2 (Gavin et al. 1984, McCullough 1979). However, the number of males involved in accidents during the breeding season is higher than the number of females involved in accidents during the same period. Other studies have reported higher incidents of deer-vehicle collisions in the fall (Hubbard et al. 2000; Puglisi et al. 1974), which have been associated to increased movement in the breeding and hunting periods. While hunting could result in increased movement and thus increased collision rates involving all deer, the raise in buck-vehicle collisions is better explained by the enlarged home range size seen among male deer during the breeding season (Kammermeyer and Marchinton 1976, Welch 1960). The beginning of the breeding season also coincides with the time when the majority of yearling males have been known to disperse from their natal range (Kammermeyer and Marchinton 1976). Dispersal is associated with higher mortality and dispersing males would be more vulnerable to vehicle collisions since they are in unfamiliar territory (Case 1978, Feldhammer et al. 1986). The increased number of deer involved in accidents during dawn and dusk could be related to the peak movement time for deer. This pattern could also be related to traffic volume, but this study did not measure the corresponding traffic volume to make that comparison.

The observed differences in the spatial distribution of accidents involving males and females could be a result of resource partitioning or sexual segregation exhibited by white-tailed deer. Differences between the sexes of adult white-tailed deer in the use of resources or intersexual resource partitioning have been reported in many populations (McCullough 1979, 1985; Berier 1987; Verme 1988). While sexual segregation could potentially explain the differences in the location of accident hotspots between males and females, it does not account for the fewer number of accident hotspots involving males in the herding and fawning seasons. In fact, females have been reported to exhibit higher degree of site fidelity than males (Berier and McCullough 1990, Marchinton and Jeter 1967), with males occupying larger areas and consuming poorer quality habitat (Berier 1987, Weckerly 1993). Our results from the comparisons of accident locations with NDVI data indicate that male deer, in fact, do occupy a broader range of habitat types than females through most of the year (fig. 6). Male deer also have significantly larger home range sizes than females (Olson 1938, Carlsen and Farmes 1957), which in turn implies that they cover a broader range of habitat types.
Other factors that appeared to be related to the number and distribution of deer-vehicle collisions include distance between roads, human density, and crime rate. Distance between roads and human densities are related; we would expect to see a higher road density in areas of higher human density. We found more accidents involving males in areas of higher road density and higher human density. Similarly, there were significantly more accidents involving males than females in areas of higher crime rate. Areas of high road density, high human density, and increased crime rate (indicating poverty), could represent areas with poorer quality deer habitat. All these patterns could be a result of males covering a broader range of habitats, and being more willing to include peripheral habitat in their range (Berier 1987, Weckerly 1993).

Numerous options have been explored nationwide to reduce the number of DVC with mixed results. Deer whistles are a popular and inexpensive option available to the public. These whistles are fixed to the front bumper of a vehicle, and airflow from the moving vehicle creates a sound at 16 to 20 kHz to warn animals of approaching vehicles. There is no research to show deer are startled by sound at any particular frequency or decibel level (DeNicola et al. 2000). One study showed that deer whistles did not alter deer behavior enough to prevent them from crossing highways (Romin and Dalton 1992). It was suspected that animals could not hear the sound of the whistle over the sound of the oncoming engine. Thus, it can be assumed that deer warning whistles are not an effective strategy to avoid deer. People who use such devices should not rely on them to avoid deer, and should remain alert when driving wooded roads during twilight hours.

Light reflectors are also devices that have been used to try to deter deer from roadsides. These devices deflect the headlights of oncoming vehicles parallel to the road, thus creating a “wall” of light that may or may not discourage deer from crossing. Usage of these reflectors has had mixed results (Gilbert 1982, Gladfelter 1982, Schafer and Penland 1985, Ford and Villa 1993). Even if reflectors are effective, they can only function in the presence of an oncoming vehicle, allowing deer behavior to go unaltered in the absence of vehicles (Putman 1997).

Reed et al. (1975) found that an underpass in west central Colorado was successful in permitting about 61 percent of a local mule deer (Odocoileus hemionus) population to migrate safely under the highway. Foster and Humphrey (1995)
found that fencing and a series of underpasses constructed to permit crossing of Florida panther (*Felis concolor coryi*) along Highway 84 (Alligator Alley) were also successful in allowing bobcat (*Lynx rufus*), white-tailed deer, raccoon (*Procyon lotor*), alligator (*Alligator mississippiensis*), and black bear (*Ursus americanus*) to safely cross. However, highway underpasses are difficult to construct under already existing roads in urban areas. They are also very expensive.

Fencing has been proven effective at reducing DVC along stretches of highway in Colorado (Ward 1982), Minnesota (Ludwig and Bremicker 1983), and Pennsylvania (Feldhamer et al. 1986). Fencing must be 2.4 to 3.0 m high and inspected regularly, as deer can and will utilize openings in the fence and will crawl between the fence and the ground. Fencing is a proven and cost-effective solution along short lengths of highway, but can get expensive and laborious over long stretches. Fencing should be utilized in areas of high DVC.

Static road signs alerting motorists about the possible presence of deer in the area are often ignored as there are so many of them, and few motorists have actually been involved in a DVC in the vicinity of these signs (Putman 1997). Pojar et al. (1975) experimented with a lighted and animated deer crossing sign in Colorado. They found no difference in the number of DVC with the sign on and with the sign off. Average vehicle speed decreased 4.83 km/hr (3.00 mph) with sign on, 10.09 km/hr (6.27 mph) with sign on and three deer carcasses placed on the road, and 12.63 km/hr (7.85 mph) with carcasses in place and signs off.

The results here suggest that spatio-temporal models can be used to predict high risk areas based on season and vegetation conditions. While current deer signs do not help people get a search image for deer or get them to slow down very much, carcasses appear to have a substantial impact on speed. Thus, targeted impact-based warning signs and displays can be used to create a search image approach be used to minimize deer vehicular accidents. Our research suggests that these targeted displays can be moved to the appropriate hotspots based on changing vegetation and seasonal conditions.

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**References**


