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An Analysis of Deer and Elk-Vehicle Collision Sites along State Highways in Washington State

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Approximately 3,000 deer and 85 elk carcasses are removed by WSDOT personnel from Washington state highways annually. The report provides an analysis of temporal and spatial relationships associated with carcass removal sites. Models were developed to asses influences of road characteristics, habitat features, deer densities, and deer behavior to frequency of vehicle collisions at carcass removal sites.

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AN ANALYSIS OF DEER AND ELK –VEHICLE COLLISION SITES ALONG STATE HIGHWAYS IN WASHINGTON STATE

A Completion Report to Washington State Department of Transportation

by

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EXECUTIVE SUMMARY

We analyzed records of deer and elk carcasses removed from Washington State highways between 2000-2004 where 14,969 deer (6,135 mule deer, 4,543 white-tailed deer, 4,014 black-tailed deer, and 277 unidentified) and 415 elk (249 in western Washington and 166 in eastern Washington) were removed following collisions with vehicles. Our goals were to model the frequency of ungulate-vehicle collisions (UVCs) on state highways and identify key factors associated with collision sites, describe temporal and spatial characteristics associated with deer and elk carcass removal sites, and identify sites of potential conflict or hazard where highways were bisected by deer and elk movement corridors.

A key factor influencing the potential for UVCs on Washington State Highways was the level of deer concentration in the surrounding area. Improved knowledge of deer concentration areas and migration corridors may be an important tool for mitigating the likelihood of UVCs in Washington.

The presence of roadside cover and forage, both important deer habitat components, was associated with higher collision counts in both our white-tailed and mule deer models. In eastern Washington, most deer cover occurred in the form of forested upland, which is a commonly preferred habitat type of white-tailed deer. Habitat covariates usually associated with lower quality deer habitats showed negative associations with collision counts. Watercourses and associated riparian areas contain important components of quality deer habitat including forage, cover, and travel corridors. The covariate “total water” was important only in the mule deer model and suggests that riparian areas may have use in predicting UVCs in more arid environments.

Scale may be an important consideration when attempting to interpret factors potentially influencing UVCs. Important variables which could affect UVCs such as roadway, adjacent roadside features, deer movement patterns, and habitat quality can change considerably within a mile of distance which may result in misinterpretations of covariate influences. Because of the potential effects of spatial scale, there are likely a number of factors that may contribute to where and when UVCs occur on Washington’s state highways that should be measured at a finer scale.

Increasing levels of average annual daily traffic (AADT) were associated with higher numbers of collisions in most eastern Washington models. Conversely, AADT was negatively associated with collision counts in our overall and urban western Washington models; this negative association may have been a result of confounding effects due to the highly positive correlation between AADT and total developed area in western Washington. Highly developed areas generally provide little, if any, deer habitat, so a negative association with collision counts could be expected.

Speed limit and 2 arterial road types, rural interstate and rural principal arterial, were found to be positively associated with collision counts Higher vehicle speed limits are generally associated with arterial road types, and the results suggest a confounding influence between increased speed limits and some road types, making differentiation of independent effects difficult.

The seasonality we observed in UVCs in Washington likely was related to changes in ungulate behavior and environmental factors. Most vehicle collisions involving mule deer occurred during October – January; most white-tailed deer were killed during the months of December, October, and January. Similarly, we also found more black-tailed deer were killed by vehicles during October and November. Autumn and early winter over-lap with deer hunting seasons, a time of increased disturbance to deer. Deer may increase their movement to avoid hunters, increasing the likelihood of their being near or crossing highways. Fall (particularly November) is also the breeding season for most deer populations; during this time deer increase movements in search of mates. In addition, day length is declining and precipitation is increasing during this period, lowering driver visibility and causing peak drive times (early morning and early evening) to coincide with dawn and dusk, periods of high deer activity.

We identified sites or aggregates of sites that incurred very high numbers of vehicle collisions with deer and elk in Washington. The number of collisions at these sites demonstrated their uniqueness and required additional study and attention. All sites in eastern Washington were within deer winter ranges and 2 were located at the intersection of an active migration corridor and state highway. Winter ranges are traditional use areas, usually at lower elevations, where forage is relatively more available and deer concentrate to spend the winter season. During migratory periods, relatively high numbers of deer moving between seasonal use ranges tend to use traditional movement corridors and where migration corridors intersect highways, seasonally high incidents of deer-vehicle collisions will occur. Further investigation into these high-kill areas, including site visits, may help identify unique characteristics that can be used in management.

The WDOT dataset and the accidents they represent are most likely minimum estimates; documented removals of deer and elk carcasses from Washington state highways probably represent only a portion of an unknown number of road kills that actually occur.

Our modeling demonstrated those parameters indicative of higher quality deer habitat (modest slopes, near water/watercourses, southern exposure, forage, cover), as well as deer concentrations, were associated with higher collision counts. Similarly, highways bisecting areas of high deer use such as winter ranges or migration corridors experienced higher numbers of UVCs. These results suggest that providing passageways for deer to cross over or under highways, constructing barriers that prohibit entry onto roadways, and discouraging deer use near highways indirectly by affecting the quality of adjacent habitats or directly reducing deer densities through harassment or lethal removal may reduce UVC rates on state highways. Similarly, when new highways are being designed, evaluating potential UVC rates should be an integral part of the planning process. To achieve the lowest potential level of UVCs, new routes should avoid deer concentration areas and known migration corridors; habitat and geographic features shown by our models to have significant relationships with high UVC rates also should be avoided. Improved delineation of deer concentration areas and migration corridors should be a priority for guiding placement of future roadways.

Our analysis provided unique insights into characteristics associated with sites of collisions between deer or elk and vehicles on Washington highways. While this information will be valuable to traffic planners and wildlife managers, we view these efforts to date to be introductory. Additional research to accurately identify, predict, and mitigate ungulate-vehicle collision sites is needed to help reduce and prevent future accidents, personal injuries, property damage, and loss of deer and elk resources. Future work should focus on: 1) review of existing telemetry data sets of deer and elk locations collected from animals wearing GPS collars to assess movement patterns near and across state highways; 2) field inspection and mapping of high level deer and elk collision sites identified in this study to document road, vegetation, and terrain features at a local scale, and to identify site-specific options for mitigation; 3) implementation and evaluation of mitigation techniques at test locations; 4) field studies of deer movement patterns and mortality factors in relation to highway crossing patterns and habitat use adjacent to state highways to identify key factors associated with deer-vehicle collisions and accurately estimate number of deer killed by collisions with vehicles; 5) improved UVC data base including more accurate kill locations and, where possible, descriptors of drivers, vehicles involved, and extent of vehicle damage; 6) driver surveys to assess driver attitudes and collision involvement; and 7) experimental hunting seasons to reduce deer densities and gauge its affects on deer-vehicle collisions.

INTRODUCTION

Washington State is home to multiple deer species including the northwest and Columbian white-tailed deer (*Odocoileus virginianus ochrourus* and *O. v. columbianus*), the Rocky Mountain mule deer (*O. heminonus heminonus*), and the Columbia black-tailed deer (*O. h. columbianus*), and two subspecies of elk, the Rocky Mountain elk (*Cervus elaphus nelsoni*) and the Roosevelt elk (*C. e. roosevelti*). Collectively, deer and elk have wide distributions within Washington and can be found across much of the state. Given the wide distribution of these large ungulates, Washington residents share a high level of interest in the well being of the state's deer and elk populations. At the same time, deer and elk provide significant recreational, aesthetic, cultural, and economic benefit to the residents of Washington.

Washington has within its borders a vast diversity of landscapes and associated vegetative communities, from ocean beaches to alpine meadows and arid shrub-steppe to temperate rain forests, each with a unique ability to support deer and elk. Healthy deer and elk populations require habitats containing high quality forage and cover for fawning or calving, and escape from disturbance, predators, and weather (Dietz and Nagy 1976, Smith et al. 1986). However, forage availability, nutritional requirements, and weather change seasonally, necessitating seasonal movements (sometimes local, elevational, or long distance, migratory) by many deer and elk herds (Wallmo and Regelin 1981). Although individual deer and elk herds exhibit diverse movement patterns, those that seasonally move long distances habitually follow established migration corridors and show strong fidelity to seasonal ranges (Greull and Papez 1963, Brown 1992). Within Washington State, there exists a mixture of both migratory and resident deer and elk herds.

Over time, the landscape across major portions of deer and elk range in Washington has changed, usually to the detriment of deer and elk. Residential, industrial, and transportation development have increasingly fragmented large tracts of open land, directly impacting deer and elk ranges and potentially increasing the risk of interruptions to established movement corridors and migration routes. The Washington landscape is now a complex mix of private, government, and tribal ownership within which seasonal home ranges and migration corridors are increasingly threatened by development (Ritters and Wickham 2003, Feeney et al. 2004). Simultaneously, human population levels have increased and associated development has spread across the state, necessitating greater use of Washington's highway and road system. Washington now has 7,046 miles of state and federal highways receiving 31.6 billion miles of vehicle travel annually, a figure that has doubled since 1960 (Washington State Department of Transportation 2005).

With many miles of highway bisecting deer and elk ranges, collisions with vehicles resulting in property damage, human injuries or deaths, loss of valued wildlife, and habitat loss, have reached elevated levels. Vehicle collisions with deer and elk on state and federal highways in Washington State killed at least 14,969 deer and 415 elk between 2000-2004. These totals include only deer and elk that were recovered from state and federal highways and do not include animals hit by vehicles that died away from the roadway or any deer or elk killed on county or city roadways. Decker et al. (1990), by comparing numbers of carcass possession tags issued for road killed deer with estimates of actual deer-vehicle collisions within their study area, estimated that for every deer recovered from the roadway as a result of a vehicle collision in New York, 5 deer were hit and not recovered or reported. Precise numbers of human deaths, injuries, and property damage caused by deer or elk vehicle collisions in Washington State are unknown as a result of Washington State Patrol's reporting system. Nationally, such accidents result in approximately 200 people killed (Conover et al. 1995) and insurance costs of nearly 2 billion dollars each year (Sudharson 2006).

The direct costs of habitat loss associated with highways bisecting deer and elk ranges, and human and animal suffering as accidents occur, are obvious. But other effects, particularly to the native ungulates, can be more insidious.

For example, a migration corridor blocked by a fence near Rawlins, WY resulted in approximately 1,000 pronghorn dying by starvation and exposure before the situation was remedied (Feeney et al. 2004). Highway development may also reduce migration corridor widths, causing bottlenecks through which deer and elk become concentrated. When such bottlenecks occur near roads, migrating animals may suffer increased traffic-related stress and collision-related mortality, and the traveling public is exposed to greater safety risks (Bissonette and Lehnert 1996, Feeney et al. 2004). Movement patterns within seasonal home ranges of resident (non-migratory) deer and elk can be similarly affected. Access to fawning areas, feeding areas, bedding sites, or escape cover can be blocked or diverted. These areas are important components of daily and seasonal activity patterns and survival can be affected by fragmentation, lowering the overall habitat quality. Even when movement corridors are not blocked by highway construction, but only bisected, there are likely increased costs to animals that have to cross a highway to access food or cover. Those costs may come in the form of added stress or energy demands that, in turn, can have cumulative deleterious effects.

Costs to humans, deer, and elk resulting from vehicle collisions have not escaped the attention of traffic safety personnel, insurance companies, politicians, deer and elk managers, and wildlife researchers. Traffic safety and environmental staff from across the country conduct annual meetings to discuss current and on-going research and development associated with wildlife-vehicle collisions. Insurance companies are paying hundreds of thousands of dollars in damage costs while politicians are pressuring transportation and management agencies to find ways of reducing collisions. Transportation and management agencies around the country and the world have responded by investigating circumstances surrounding vehicle collisions with wildlife and ways of reducing such accidents. Recent studies have examined the characteristics of ungulate-vehicle collision sites. Details of moose-vehicle collision sites have been described in British Columbia (Rea et al. 2006), Quebec (Dussault et al. 2006), New Brunswick (Christie and Nason 2004), Newfoundland (Joyce and Mahoney 2001), and Sweden (Seiler 2004). Similar descriptions of deer-vehicle collision sites have been reported from Utah (Kassar and Bissonette 2005) and New Brunswick (Christie and Nason 2004), and elk-vehicle collision sites from Arizona (Dodd, et al. 2005). Several reports have recommended strategies for reducing or preventing animal-vehicle collisions

(Danielson and Hubbard 1998, Knapp 2004, Leblanc and Martel 2005, Huijser et al. 2006, and Rea et al. 2006), including reducing deer numbers by sport hunting (Schwabe 2002, Sudharson et al. 2006). Recent papers have evaluated attitudes and awareness of drivers involved in deer-vehicle collisions (Riley and Marcoux 2006) and the risk factors associated with human fatalities in animal-vehicle collisions (Langley et al. 2006).

Despite fairly broad-based knowledge surrounding wildlife-vehicle collisions across North America and parts of Europe, few formal investigations of such collisions have occurred in Washington. Washington State Department of Transportation (WASDOT) has documented deer and elk carcass removals from state highways (including interstate highways) but no extensive analysis of these data have been performed. Knowledge of temporal and spatial relationships between wildlife movements, highways, and animal-vehicle collision sites can provide important benefits to highway engineers and transportation professionals in providing safe traffic flow through wildlife habitats. Similarly, such information is important to wildlife managers responsible for maintaining wildlife populations and their habitats.

Our goals with this project were multiple, ranging from identifying sites of potential conflict or hazard where highways were bisected by deer and elk movement corridors, to modeling parameters associated with locations of collisions between deer or elk and motor vehicles on state and federal highways. More specifically, our objectives were:

1. Develop maps delineating spatial relationships between known movement corridors and seasonal ranges of white-tailed deer, mule deer, black-tailed deer and elk throughout Washington in relation to state and federal highways.
2. Develop statistical models which identify significant association between deer-vehicle collisions and highway, landscape, and deer biology attributes.
3. Identify and summarize potential locations where movement corridors are at risk of potential bottlenecks or other barriers that may result in elevated numbers of deer/elk on state highways.

Before beginning our analysis, there were a number of factors to consider that affect ungulate-vehicle collisions. There are the 3 principal components (the highway, the vehicle, and the animal [deer or elk]) that must intersect spatially and temporally for a collision to occur. The highway is basically a fixed entity surrounded by or passing through a varied landscape. Existing roadways initially changed the landscape but have now become a component of that landscape.

Vehicles travel across the landscape but only on existing roadways. Even though the vehicle's travel is limited to the highway pavement, the manner in which a vehicle is driven (speed, driver ability, driver alertness), the condition of the roadway (traffic level, night vs. daytime, sinuosity and visibility, and precipitation), and the environment surrounding the vehicle (heavy cover vs. open, terrain attributes, cover type, deer/elk densities) influence the probability of a collision and provide quantifiable information to help answer the question, "Why did the vehicle strike a deer or elk?"

Similarly, deer and elk move across the landscape in search of the basic necessities for living: food, water, and cover. Their daily and seasonal movements are affected by the nutritional quality of the habitat and juxtaposition of landscape features (terrain attributes, available forage and accessible cover, anthropogenic features) that provide these necessities as well as their relative population densities, home range size, the season of the year (spring and fall migrations, rut/breeding, wintering, fawning, hunting), level of disturbance, and behavior patterns (feeding, breeding, fawning, and escape). All of the features that affect landscape use by deer or elk can potentially influence the probability of an animal being involved in a collision with a vehicle (when a highway bisects deer or elk range) and assist in answering the question, "Why did the deer or elk cross the road?"

Both vehicle and animal influences could be modeled separately but more appropriately, collectively. In either case, potential covariates needed to model vehicle influences in predicting ungulate-vehicle collisions (UVC) could include:

- Posted highway speed limit
- Highway sinuosity
- Driver visibility
- Traffic volume
- Collision date and/or season
- Type of roadway
- Roadside vegetative composition

Covariates to be used in modeling deer or elk habitat, population, and behavior features to predict ungulate-vehicle collisions could include:

- Vegetative cover map
- Measure of Cover/unit area
- Measure of Forage/unit area
- Measure of Development
- Date of collision
- Time of day of collision
- Measure of seasonal deer/elk presence and movements
- Measure of terrain features

METHODS

Deer/Elk-Vehicle Collision Data

We obtained data from WSDOT that recorded deer/elk carcasses removed from all Washington state highways as results of collisions with motor vehicles for years 2000 to 2004. Each record included information from the carcass recovery, including date, species (1.9% missing), sex (10.4% missing), and age (24.1% missing). The location of each carcass removal site along state routes was identified by referencing fixed mileage markers to a precision of one tenth of a mile. The initial inspection of the accuracy of removal locations revealed an unusual pattern in the site frequency distribution. We observed unusually high frequencies at the whole and the half-mile markers suggesting the actual accident sites most likely were within ± 0.5 mile of the reported locations. Consequently, we defined a road unit as a mile long section of state highway centered at each mileage post (MP). Collision sites with recorded locations that fell within each road unit were aggregated and totaled over the 5-year period to yield the number of collisions for each road unit. Collision locations that had been recorded on the half-mile markers were split evenly into the 2 adjacent road units. The total number of collisions for each road unit also was calculated by the deer species (black-tailed, white-tailed or mule deer).

We identified road units where markedly high number of collisions occurred. These sites were mapped and their relationship to deer or elk activities, behavior, densities, and surrounding landscapes were described.

Geographic Information System (GIS) Data and Analysis

All GIS analysis was performed using ArcGIS 9.1 (ESRI, Redlands, CA). We obtained a copy of the National Land Cover Data (NLCD) from the Washington Department of Fish and Wildlife (WDFW), Wildlife Program. NLCD is a vegetation cover layer derived from the early to mid-1990's Landsat Thematic Mapper satellite data, with a spatial resolution of 30 meters. The Washington state portion was published in 1999. Hydrology and Digital Elevation Model (DEM) data layers were similarly acquired from WDFW Wildlife Program. Transportation layers showing state and federal highways with highway mileposts delineated were provided by WSDOT.

We defined three types of buffer for each road unit. The circular buffer was centered at the mid point with a radius of 0.5 mile. The two linear buffers running parallel to the highway were of width of 30 meters and 60 meters from each road shoulder. These 3 buffers associated with each road unit were used to define landscape and habitat characteristics associated with the unit at different scales.

Initially 9 vegetation classes were formed from the original 21 NLCD classified land cover categories (Table 1). For each vegetation class, 4 types of measurements were calculated. Two measurements were based on disjoint, non-road areas framed by the circular buffer boundary and the state highways within the buffer. The first of these measurements was the total acreage within the buffer outside the roadway, and the second was the difference in acres between the largest area and the remaining buffered area, which describes whether the vegetation distribution is even along both sides of the highway. Any uneven vegetation distribution may encourage or discourage deer to cross roads. The other 2 measurements were based on total acreage of non-road areas within the 2 linear buffers.

Table 1. A list of all covariates from all data sources used in GIS analysis.

Data Set	Variable Name	Description
Road & Traffic	Spdlmt	Speed limit
	Meank_AADT	Mean of average annual daily traffic (in thousands)
	Road_type	Roadway functional classification
	Sin_eu	Road sinuosity
NLCD Vegetation Classes	Nfrst	Non-forested woody (total and difference in acres)
	FrstU	Forested upland (total and difference in acres)
	HrbcP	Herbaceous planted (total and difference in acres)
	HrbcU	Herbaceous upland (total and difference in acres)
	Shrb	Shrub land (total and difference in acres)
	Dvlp	Developed land (total and difference in acres)
	Water	Water (total and difference in acres)
	Trns	Young forest (total and difference in acres)
	Other	Barren (total and difference in acres)
	Forage	FrstU, hrbcP, hrbcU, shrb, and trns combined (total and difference in acres)
	Nonhabitat	Dvlp and other combined (total and difference in acres)
	Pctdif_forage	Difference in forage/ total forage
	Pctdif_cover	Difference in FrstU / total FrstU
NLCD Aspect Classes	Flat	Aspect class- flat (total or difference in acres)
	East	Aspect class- east (total or difference in acres)
	West	Aspect class- west (total or difference in acres)
	South	Aspect class- south (total or difference in acres)
	North	Aspect class- north (total or difference in acres)
NLCD Slope Classes	Slope 0-10	Total non-road area with slop <= 10° (in acres)
	Slope 10-35	Total non-road area with slop $\in$ (10°,35°] (in acres)
	Slope > 35	Total non-road area with slop > 35°
	Mean_elev	Mean elevation of the non-road area
WDFW PHS	PHS	3 classes: none, regular, large regular concentration

Total acreage in each aspect and slope class was also calculated for all 3 buffers in the similar way. Mean elevation of the total non-road area and differences in mean elevations between the largest buffered area and remaining non-road areas were also calculated to serve as a metric of terrain features.

Deer concentration and range information was obtained from WDFW Priority Habitat Species (PHS) database. The database consists of polygons that delineate species occurrences and distribution of priority habitats. All priority habitats represent known habitat areas of species occurrence based upon the best information available from research efforts, surveys, or other field observations. Using PHS data layers (WDFW 1999), each road unit was assigned to 1 of the 3 feature classes of deer occupancy: none (not known to occur), regular (commonly or traditionally used on a seasonal or year-around basis), and regular large concentration (commonly or traditionally used by significantly large aggregations relative to what is expected for a particular species or geographic area). Review of Westside sampling sites revealed low occurrence of "regular" deer concentrations; therefore, for Westside models we combined categories 2 and 3 in to a single class: deer concentration areas.

GIS layers containing legal speed limit, estimated average annual daily traffic (AADT), and road classification (Federal Highway Administration 1989; Table 2) were obtained from WSDOT. The posted legal speed limit was available at each whole MP number, so the legal speed limit at the mid point of each unit was used to define speed limit of the entire road unit. Estimated AADT and road type classification were available for highway sections of various lengths. We described the AADT for a given road unit as the mean of the total AADT of all state highway sections within each circular buffer. The starting and ending mileage markers for each road section in the road type data were used to assign a road classification to each road unit. When multiple types were observed within a road unit, the road type from the longest portion was used. The road sinuosity was defined as the ratio of the total road length within the circular buffer to the distance between entry and exit points. Each road unit was also identified in terms of county, WSDOT district, and zone (Eastern Washington or Western Washington).

Temporal/Spatial Distribution of Deer/Elk-Vehicle Collisions

The temporal distribution of deer/elk carcass removals was evaluated by year, month, and day of the week for each species. We also associated the dates of carcass removals with seasonal deer movement and behavior patterns. Important deer seasons are breeding (Nov. 1-25), wintering (Dec. 16 - Mar. 1), fawning (May 25 - Jun. 10), fall migration (Oct 10 - 30), and spring migration (Apr. 15 – May 24).

We used the federal highway classification system (Federal Highway Administration 1989; Table 2) to identify 5 major road types. The mean carcass removals for each road type were compared by region and setting (rural/urban). We also assessed removal/collision counts by legal speed limit and average annual daily traffic (AADT).

Table 2. A table showing the highway categories within the federal highway classification system and their definitions used as covariates in our models.

Highway Classification	**Definition**
Arterials	Arterials provide the highest level of mobility, at the highest speed, for long, uninterrupted travel. An Interstate Highway System is an arterial network. Arterials generally have higher design standards than other roads, often with multiple lanes and some degree of access control.
Rural Arterial	Rural arterial network provides interstate and inter-county service so that all developed areas are within a reasonable distance of an arterial highway.
Rural Principal Arterial	Rural principal arterial network is more significant. It serves virtually all-urban areas with populations greater than 50,000 people. Rural principal arterial network is divided into two subsystems, Interstate highways (**RIS**) and other principal arterials (**RPA**).
Urban Principal Arterial	Urban principal arterial system serves major metropolitan centers, corridors with the highest traffic volume, and those with the longest trip lengths. It carries most trips entering and leaving urban areas, and it provides continuity for all rural arterials that intercept urban boundaries. It includes Interstate highways (**UIS**), other freeways and expressways (**UPA**), and other principal arterials (**UOPA**) and is divided into principal and minor arterials.
Urban Minor Arterial	Urban minor arterial (**UMA**) roads provide service for trips of moderate length and at a lower level of mobility. They connect with urban principal arterial roads and rural collector routes.
Rural Minor Arterial	Rural minor arterial (**RMA**) roads link cities, large towns and other traffic generators (i.e. major resort areas) that are capable of attracting travel over long distances, integrate interstate and inter-county service, have spacing consistent with population density so all developed areas are within a reasonable distance from the arterial system, and provide service to corridors with trip lengths and travel densities greater than those served by rural collector or local systems.
Collectors	Collectors provide a lower degree of mobility than arterials. They are designed for travel at lower speeds and for shorter distances. Collectors are typically two-lane roads that collect and distribute traffic from the arterial system.
Rural Collectors	Rural collectors are stratified into two subsystems: major and minor collectors. Major collectors (**RMaC**) provide service to any county seat not on an arterial route. They also serve larger towns not accessed by higher order roads and important industrial or agricultural centers that generate significant traffic (but are avoided by arterials). Rural minor collectors (**RMC**) are spaced at intervals, consistent with population density, to collect traffic from local roads and to insure that all urbanized areas are within a reasonable distance of a collector road.
Urban Collectors	Urban collectors provide traffic circulation within residential neighborhoods and commercial and industrial areas. Unlike arterials, collector roads may penetrate residential communities, distributing traffic from the arterials to the ultimate destination for many motorists. Urban collectors also channel traffic from local streets onto the arterial system.

Statistical Analysis and Modeling

Collision count models

To model the number of deer removals/collisions that occurred in each road unit, we first fit the data using standard Poisson regression models (McCullagh and Nelder 1989). Letting Y*i* be the number of deer-vehicle collisions on road unit *i*, the Poisson model is

$$E(Y_i) = \lambda_i = \exp(\beta X_i), \quad Var(Y_i) = \lambda_i ,$$

where β is a vector of unknown regression coefficients that can be estimated and X_i is a vector of variables that affects the collision frequency. We consider X_i as a subset of variables describing road unit feature, traffic characteristics, landscape, and habitat characteristics, and winter deer concentration characteristics.

The Poisson regression model assumes that the mean and variance of Y_i are equal. However, in many studies of discrete outcomes, the sampling distribution often results in a higher frequency of zero than would be expected from a Poisson distribution or an over-dispersion of nonzero count in relation to the Poisson distribution. An alternative approach, which avoids the problems inherent in the Poisson model, is to fit a negative binomial regression model. The negative binomial model is a generalization of the Poisson regression model that accounts for over-dispersion by including a disturbance or error term (McCullagh and Nelder 1989). The negative binomial model is,

$$E(Y_i) = \lambda_i = \exp(\beta X_i + \varepsilon_i), \quad Var(Y_i) = \lambda_i(1+\alpha\lambda_i),$$

where ε*i* is a gamma-distributed error term and α describes the over-dispersion.

It is also possible that a dual-state process affected the deer-vehicle collision counts. In a dual-state process, the observed count can come either from a zero-collision state where road units are virtually free from deer-vehicle collisions, or from a collision-possible state where non-negative collisions can be observed. The zero-inflated Poisson (ZIP) and zero-inflated negative binomial (ZINB) regression models have been proposed for modeling accident frequencies (Shankar et al. 1997, Lee and Mannering 2002) and have applications in manufacturing and epidemiology (Lambert 1992, Bohning et al. 1999). The ZIP structure models have great flexibility and provide insight into likelihood of safe versus unsafe road units. The zero-inflated Poisson model assumes

$$P(Y_i = 0) = p_i + (1-p_i)\exp(-\lambda_i),$$

$$P(Y_i) = (1-p_i)\exp(-\lambda_i)\lambda_i^{Y_i} / Y_i, \quad Y_i = 1, 2, \ldots,$$

where $\lambda_i = \exp(\beta X_i)$ and p_i is the probability for a site *i* to be in the zero state, which is estimated through the logistic regression, logit(p_i)= βX_i . The zero-inflated negative binomial regression model follows a similar formula.

For each given set of X_i , the above four types of models were used to fit the count data. The fit of these models was compared using Akaike's information criteria (AIC) (Burnham and Anderson 2002).

Eastern and Western Washington models

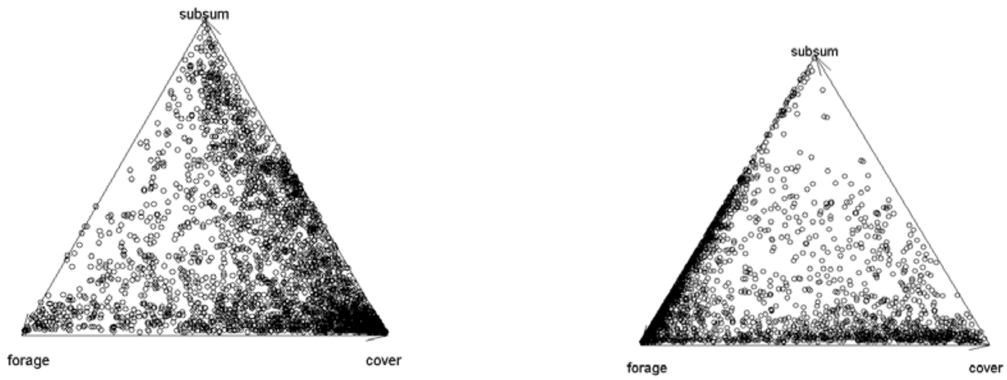
After merging all data sources, the resulting data set consisted of 6,638 road units from 187 Washington state highways. There were 3,793 and 2,843 road units from Eastern and Western Washington, respectively. Given the differences in deer species distribution, population densities, species-specific habitat, and landscape characteristics between the west and east sides of the state, separate regional models were developed.

There were 67 continuous and 3 categorical covariates defined for each road unit. To reduce inter-correlation between the covariates, we studied the correlation matrix of the continuous covariates and performed an exploratory factor analysis. Contingency tables and group means (Table 3) were also studied to understand the association between the two types of covariates. There were 3 sets of landscape and habitat variables. Each set was derived from one of the three types of buffers (Figure 1). For any given landscape variable, the 3 versions were highly correlated. The set based on total acreage from within the circular buffer was retained for the regional models because of the higher correlation with the response variable.

Table 3. Summary statistics of road units shown by region in Washington, 2000-2004.

Variable	Westside Mean (SD)	Eastside Mean (SD)
Total collision count	0.95 (2.33)	3.17 (7.05)
Urban units collision count	0.19 (0.70)	1.86 (3.88)
Rural units collision count	1.27 (2.68)	3.26 (7.21)
PHS=none units collision count	0.87 (2.24)	2.56 (5.77)
PHS=regular concentration units collision count	3.29 (2.16)	7.68 (14.17)
PHS=regular large concentration collision count	4.55 (3.66)	6.07 (9.60)
Mean average annual daily traffic (in thousands)	19.72 (32.05)	4.99 (7.93)
Speed limit	52.18 (9.03)	58.05 (7.58)
Mean Elev	301.81 (188.67)	494.17 (198.91)
Sin_eu	1.06 (0.20)	1.05 (0.17)
Total_Nfrst	2.12 (11.70)	11.58 (38.28)
Total_water	29.62 (58.63)	23.67 (53.07)
Total_dvlp	67.23 (100.16)	26.33 (54.12)
Total_frstU	260.79 (130.77)	78.32 (129.83)
Total_hrbcP	59.05 (97.92)	147.63 (171.06)
Total_hrbcU	7.89 (11.76)	48.96 (71.98)
Total_shrb	16.20 (17.17)	126.17 (130.49)
Total_trns	14.51 (36.31)	4.52 (22.74)
Total_other	14.95 (26.99)	6.44 (7.97)

By definition, the circular buffers associated with each road unit were likely to overlap with those associated with adjacent road units. Only perfectly straight road units have disjoint buffers. The potential result from the overlapped buffers was dependency between adjacent road units. To avoid dependency, the road units from each highway were numbered in order; we retained every other road unit along a given state highway for analysis.



Westside Eastside

Figure 1. The 3- part compositions of forage, cover, and subsum (water and nonhabitat) for all road units in Westside (left) and Eastside (right) of Washington. The perpendicular distance from each point to the side opposite a vertex is proportional to the percentage of the corresponding habitat type present in the circular buffered area of a road unit.

Due to high correlations between some of the covariates within the Westside data sets, 12 sets of covariates were used to define regional candidate models for Western Washington. Each was fit into both Poisson and negative binomial models. The best fitting model from the 24 possible models was selected based on AIC and denoted as the initial best regional full model. From the initial best full models, insignificant covariates were removed using backward elimination methods until all the remaining variables were significant. The ZIP and ZINB models were developed in two steps. First, logistic models were fit to the binary response (0 for road units with no reported collisions), and the significant covariates were retained to model the probability of zero collision state. Second, the Poisson and negative binomial models for the collision frequency observed from sites in none-zero collision state used covariates from the initial best full model. Insignificant covariates were removed as described above. The final model we retained was the one model among all 4 types showing the lowest AIC. Significant covariates were ranked in order by type III F statistics with the highest F value indicating the greatest contribution to the model. Appropriate Pearson and Deviance R-squared measures of goodness of fit (Cameron and Windmeijer 1996) for the final models were calculated.

Preliminary analysis showed a number of road units with exceedingly high collision counts. These road units tended to be clustered together, suggesting possible locations of major deer use area or migration corridor. These high collision road units were examined individually in greater detail.

Habitat Distribution Models

Quality, quantity, and distribution of available deer habitat can influence the level of deer presence on or along state highways, directly affecting the probability of deer-vehicle collisions. One way to describe the habitat distribution pattern is to review the composition of vegetation classes and the availability of forage and cover on either side of each road unit. For this analysis, we reduced the number of vegetation classes down to 4 new classes (forage, cover, non-habitat, and water). The difference in forage and cover between the largest patches and other non-road areas within the circular buffer was calculated; the percentage difference was determined by dividing the total area by the difference in forage and cover. This analysis was applied only to those units where forage and cover were both present ensuring an applicable difference. Other important non-habitat variables such as road feature, traffic, and other landscape variables were included as control variables.

Eastern Washington Deer Species and Season of Use Models

Between the two deer species in Eastern Washington, white-tailed deer generally prefer forested habitats while mule deer favor open habitats to forested habitats. Due to this difference, we developed separate models to evaluate collision sites for each species. In addition, deer tend to travel much greater distance on a daily basis during the migration and breeding seasons compared to other seasons when their movement patterns are more restricted. Consequently, we defined a "movement season" (spring migration, fall migration, and breeding) and a "sedentary season" (June 15-Sep. 15 and wintering) for analysis purposes. Deer-vehicle collisions were totaled by season, and separate models were developed for each to reveal possible seasonal differences.

RESULTS

Deer/Elk-Vehicle Collisions

During 2000-2004, there were a total of 14,969 deer removed from state highways following collisions with vehicles (6,135 mule deer, 4,543 white-tailed deer, 4,014 black-tailed deer, and 277 unidentified). Although the highest annual count of deer-vehicle collisions was observed in 2001 (Figure 2), most counts were consistent between years. Most vehicle collisions involving mule deer occurred, in decreasing order, during the months of October, November, January, and December (Figure 3). The majority of white-tailed deer were killed during the month of December followed by October and January on state highways (Figure 3). Most black-tailed deer were killed during October and November (Figure 3).

Deer removals peaked on Mondays then declined each day through the rest of the week (Figure 4). Across all years, the total number of deer removed during Tuesdays, Wednesdays, Thursdays, and Fridays was approximately 2,100; the total number of deer removed on Saturdays and Sundays was approximately 950 while on Mondays the total was nearly 4,500, more than double that of the other weekdays (Figure 4). If a daily average is calculated for Saturday through Monday, that mean (1800) approximates the number recorded daily between Tuesday and Friday, suggesting approximately equal number of deer collisions across days of the week.

A higher rate of deer-vehicle collisions occurred in eastern Washington than western Washington (Figures 5 and 6). Among the 5 deer use seasons, the highest mean daily deer-vehicle collisions (Figure 7) was observed during the fall migration (October 10-30) followed by the breeding season (November 1-25) and wintering season (December 16-March 1).

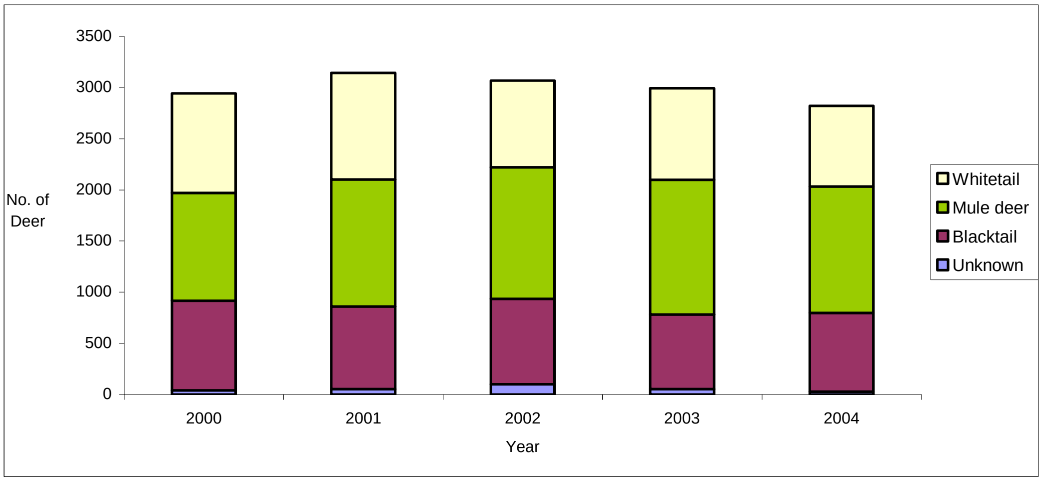


Figure 2. Statewide totals of deer-vehicle collisions occurring are shown by year and deer species in Washington over 5 years, 2000-2004.

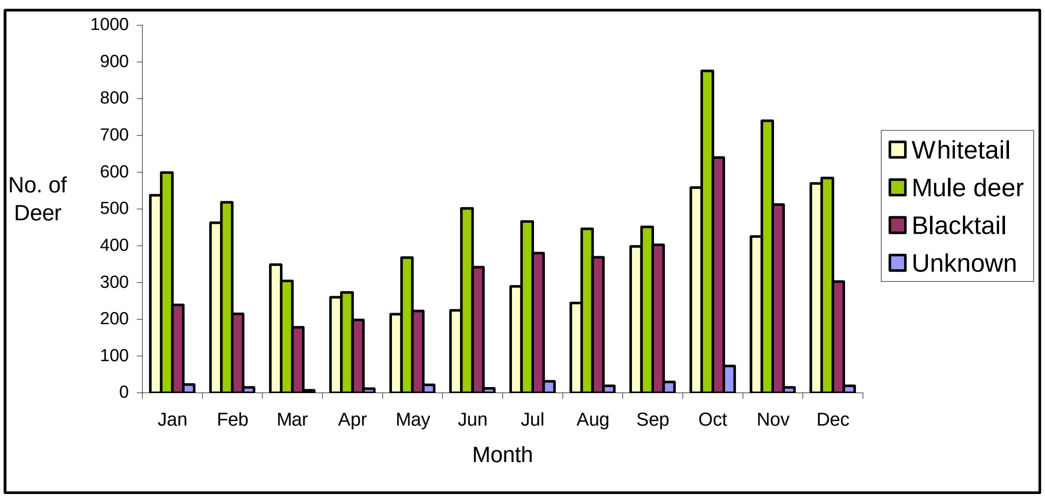


Figure 3. The number of deer-vehicle collisions occurring by species and month in Washington over 5 years, 2000-2004.

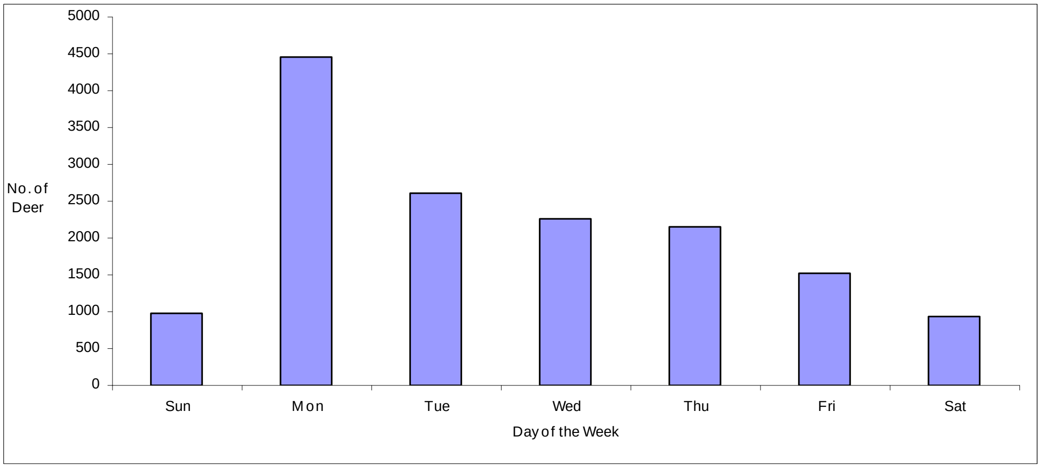


Figure 4. The total number of deer removed from Washington state highways by the day of the week for 5 years, 2000-2004.

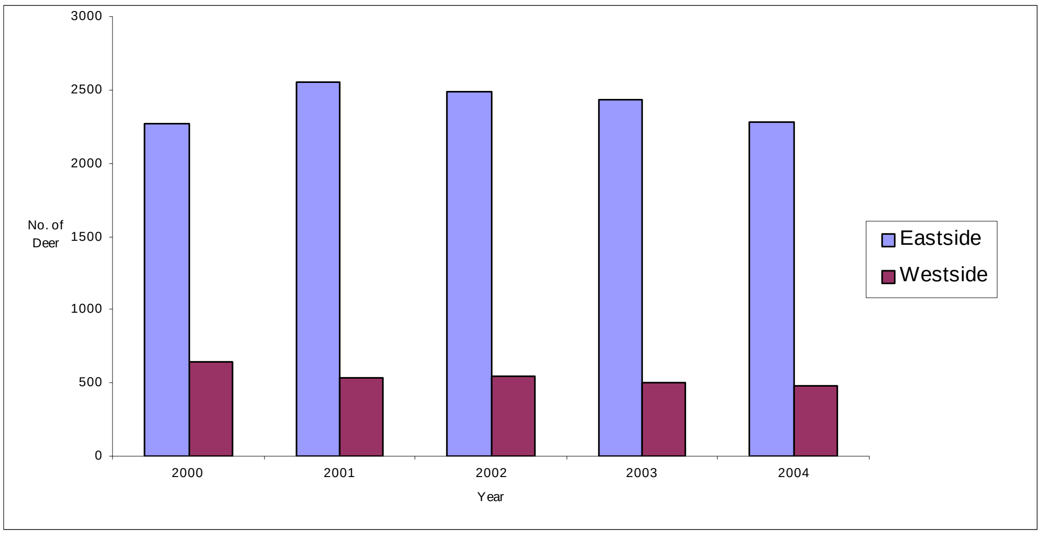


Figure 5. The total number of deer carcasses removed from Washington state highways by region for 5 years, 2000-2004.

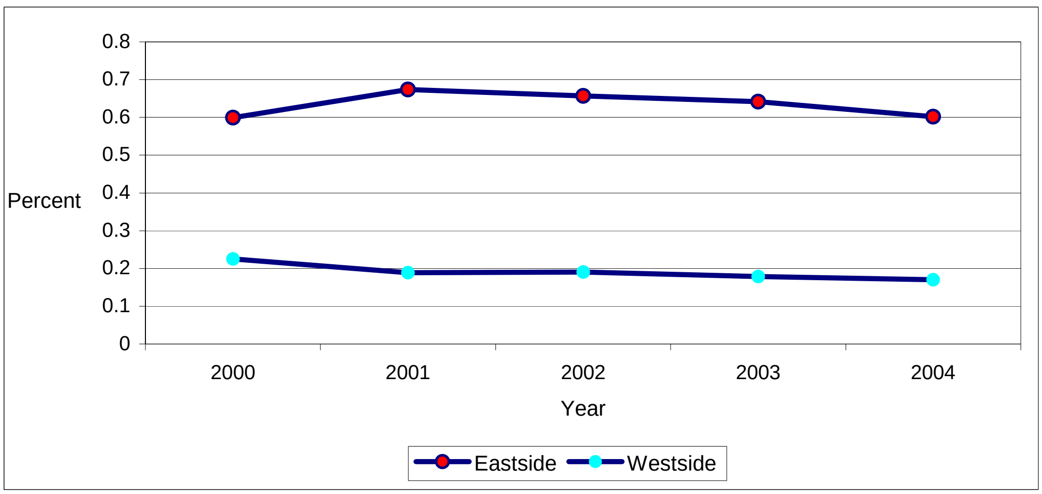


Figure 6. Regional deer-vehicle collision rates based upon carcass removals from Washington state highways by year for 5 years, 2000-2004.

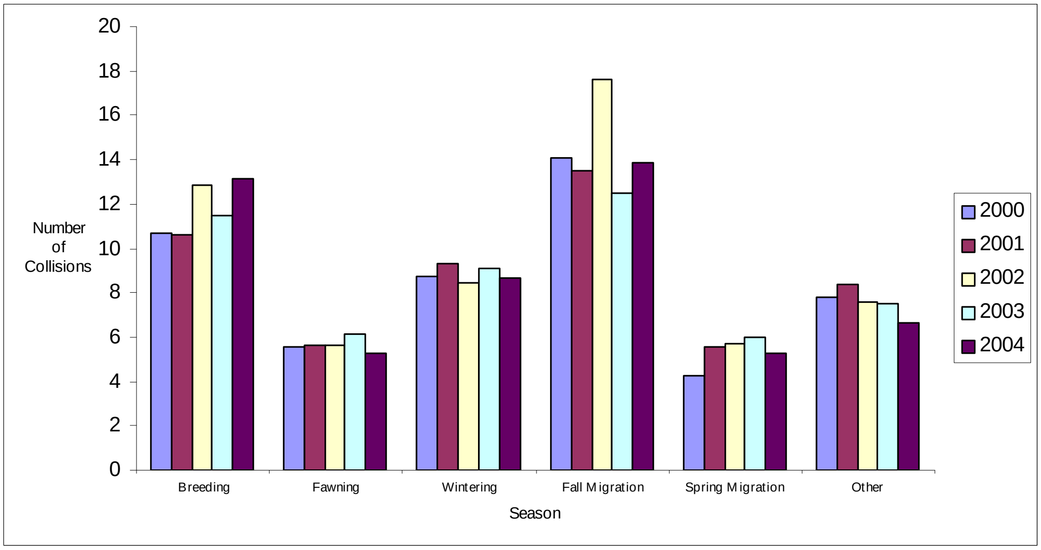


Figure 7. Mean daily deer-vehicle collisions based upon deer carcass removals from Washington state highways by season for 5 years, 2000-2004.

A total of 415 elk (249 in western Washington and 166 in eastern Washington) were killed and removed from Washington highways between 2000-2004. Most elk killed were females in western Washington (58%, n = 144, 79 adults, 19 juveniles, 26 age unknown) and eastern Washington (60%, n = 99, 49 adults, 7 juveniles, 43 age unknown). Male elk killed on state highways totaled 43 in western Washington (30 adults, 3 juveniles, and 10 age unknown) and 29 in eastern Washington (15 adults, 7 juveniles, and 12 age unknown). Highest elk collision counts in western Washington were documented in 2003 and in eastern Washington during 2001 (Figure 8). In western Washington, most elk were killed on highways in February and January, but in eastern Washington, most elk-vehicle collisions occurred during October and September (Figure 9).

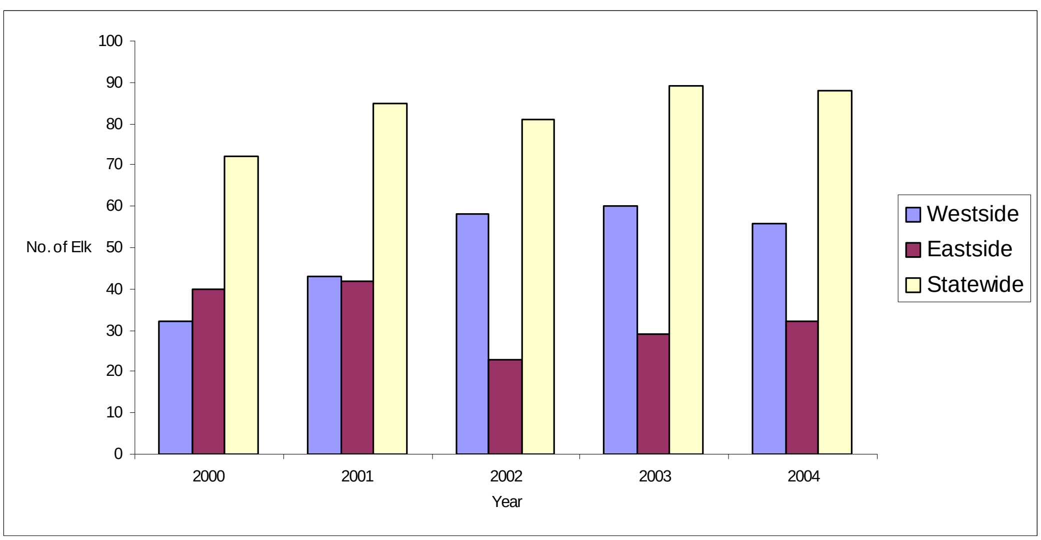


Figure 8. Statewide totals of elk-vehicle collisions based upon carcass removals from state highways shown by year and region in Washington over 5 years, 2000-2004.

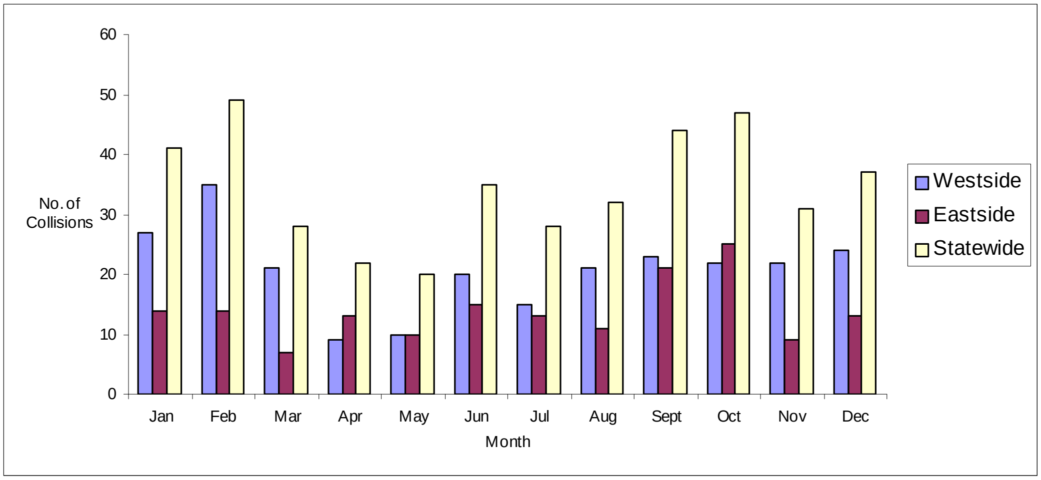


Figure 9. Elk-vehicle collisions based upon elk carcass removals from state highways by month and region in Washington over 5 years, 2000-2004.

High Level Deer/Elk Collision Sites

During the course of our analysis we observed road units where an unusually high number of collisions occurred and road-killed deer had been removed (Figure 10). Thirteen areas in eastern Washington (Table 4) were identified as high level deer collision areas with collision counts of 33 to 74 deer killed within a site or segmented sites. Three sites were mileposts (MP) and 9 were highway segments between 2 and 13 miles in length. Six sites were located within white-tailed deer range and 6 were within mule deer range. All eastern Washington sites were associated within winter ranges, 2 were within migration corridors, and 5 sites were located near or adjacent to agricultural areas.

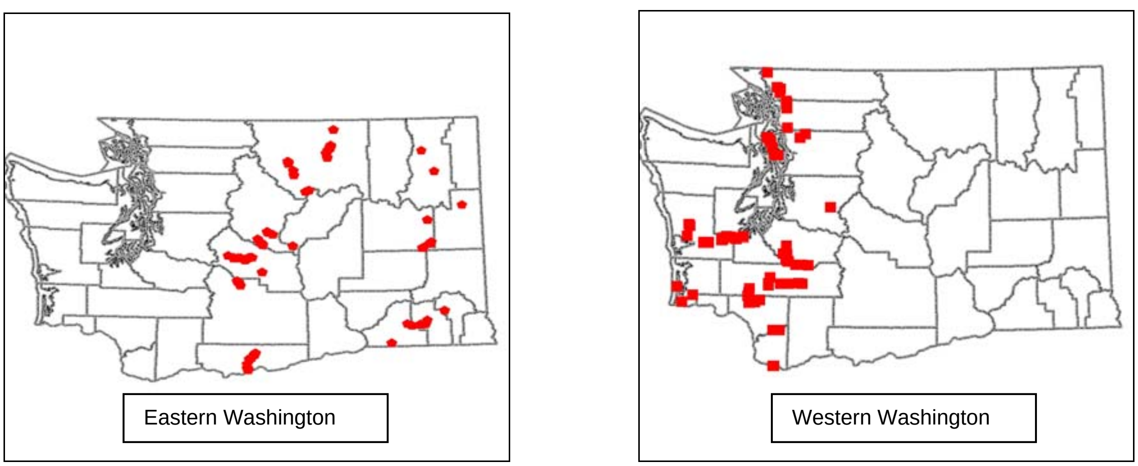


Figure 10. A map showing high level (> 33 deer recorded) deer-vehicle collision sites based upon carcass removal from state highways in eastern Washington for 5 years, 2000-2004.

Table 4. A list showing road units where at least 30 deer-vehicle collisions occurred 2000-2004 in eastern Washington.

High risk units	Deer habitat feature	Mean count	High risk winter	High risk breeding	High risk Fall Migration
SR2, MP110	Winter range, Migration corridor	33	x		
SR2, MP 302-312	Winter range, regular large concentration	44.25	x	x	x
SR97, MP 15-23	Winter range, Regular large concentrations resident deer, Lots of agricultural fields	37.2		x	x
SR 97, MP 258	Winter range, resident deer, orchards	34	x	x	
SR97, MP300-313	Winter range, Regular large concentrations resident deer, Orchards and alfalfa near-by	52.36	x	x	x
SR97, MP 319, 323	Regular large concentrations resident deer, Winter range, Orchards and alfalfa near-by	33	x	x	x
SR206, MP 6-7	Resident deer, winter range, lots of agricultural fields	48	x	x	
SR291, MP 20-21	Winter range	34	x		
SR395, MP 210-215	Major deer use area, regular large concentration, winter range	59.3	x		x
SR395, MP 219-228	Major deer use area, regular large concentration, winter range	45.5		x	x
SR395, MP234-236	Major deer use area, regular large concentration, winter range	32.3			
SR410, MP103-104	High density deer range, migration corridor, people feeding deer	32		x	x
SR97AR, MP 206	High density deer range, migration corridor	74	x		

In western Washington, we identified 7 areas with very high deer collision counts, ranging from 15 to 19 per site (Table 5). Three sites were individual MPs and 4 were highway segments ranging from 2 to 4 miles in length. These sites were within regular large concentration areas.

Table 5. A list showing road units where at least 15 deer-vehicle collisions have occurred between 2000-2004 in western Washington.

High risk units	Deer habitat feature	Mean collision count	High risk Winter	High risk Breeding	High risk Fall Migration	High risk Spring Migration
SR7, MP 22	Lake shore, Regular concentration	19				
SR8, MP 2	Regular concentration	15		x		
SR12, MP 93,109	Winter range, Regular concentration	17.5	x	x		
SR20, MP17-21	Regular concentration, Whidbey Island	19.25		x	x	
SR504, MP 2, 7	Regular concentration	17.5		x	x	x
SR525, MP15-17, 25	Regular concentration, Whidbey Island, winter range	17.75		x	x	
SR706, MP 8	Regular concentration	16		x	x	

In eastern Washington, we identified 11 areas of high elk-vehicle collisions with counts ranging from 4 to 9 elk killed per site. Three sites were MPs and 8 were highway segments 2 to 4 miles in length. Only 1 site was associated with winter range. There were 6 high elk kill sites in western Washington, 4 MPs and 2 segments each 2 miles in length. Two of these sites were within elk winter range.

Regional Highway Features and Deer-Vehicle Collision Sites

In summarizing deer-vehicle collision rates on state highways classified by region and road type, we observed the highest rates for all classes combined to occur on principal arterial road types (Figure 11). Similarly, the highest rate was seen on principal arterials in the rural, East-rural, West-rural, and West-urban classes. Within the urban and East-urban classes, the highest collision rate occurred on minor arterials. The majority of sites with unusually high deer-vehicle collisions appeared to be associated with highways operating at posted speed limits of greater than 60 mph (Figure 12). We assessed collisions at the site level regionally by average annual daily traffic (AADT) totals and observed eastern Washington sites, on average, had higher collisions than sites in western Washington. Eastern Washington sites also had a wider range of collision counts and higher number of sites with unusually high collision rates. Eastern Washington sites with mid-range AADT also had, on average, higher collisions (Figure 13).

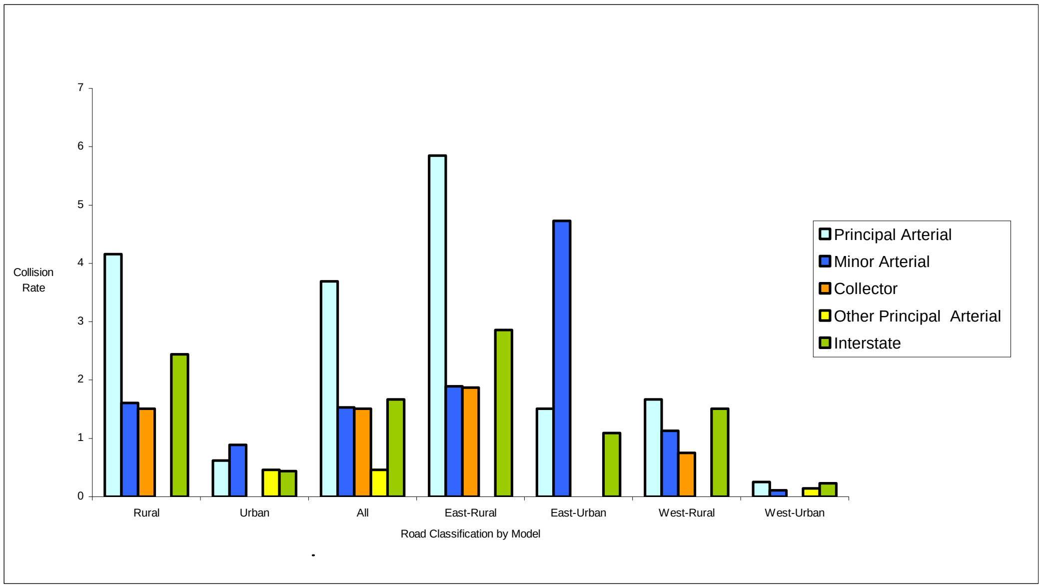


Figure 11. Deer-vehicle collision rates based upon carcass removals from Washington state highways by road type for 5 years, 2000-2004.

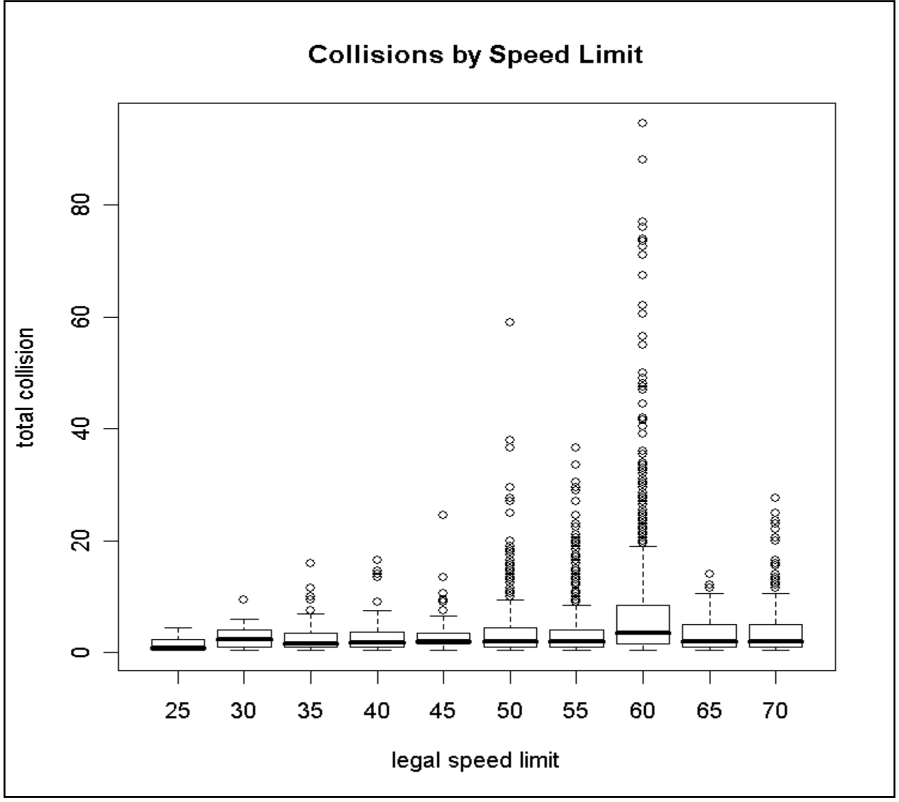


Figure 12. The total number of deer-vehicle collisions for 2000-2004 based upon carcass removals from Washington state highways by posted speed limit. The horizontal line within each box represents the median. The upper and lower edge of each box corresponds to 75th and 25th percentiles respectively. The whiskers are 1.5 times of IQR(inter-quartile-range) and points above the upper whiskers are potential outliers by the 1.5 IQR criteria.

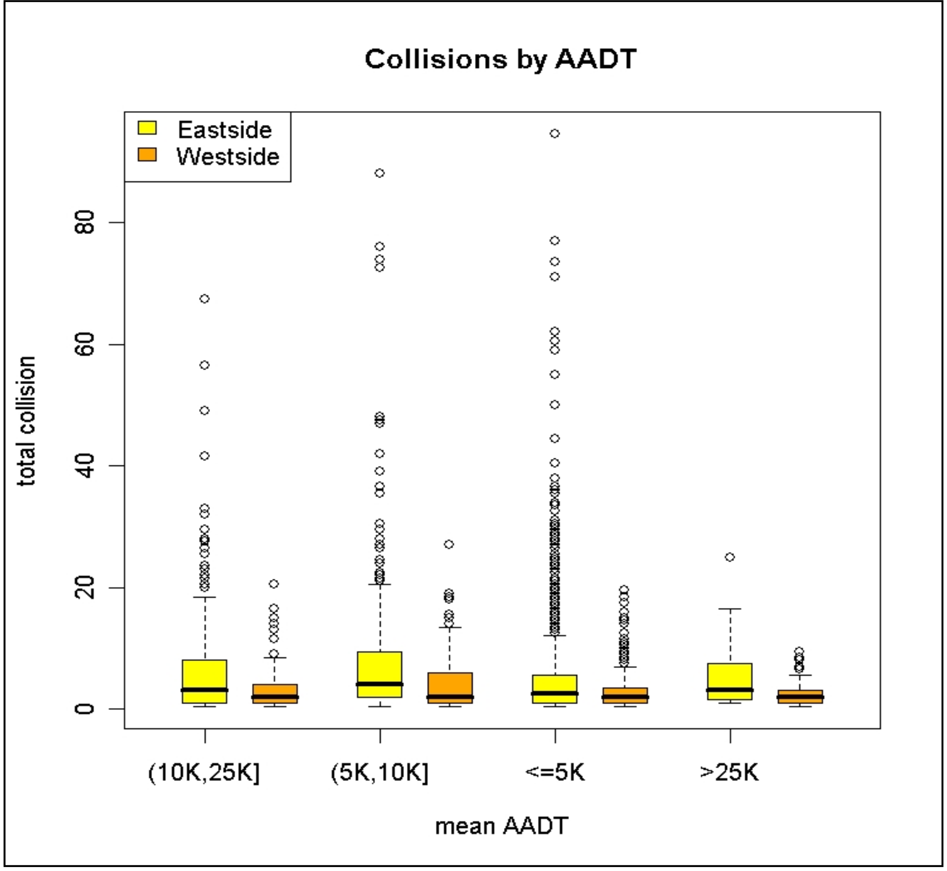


Figure 13. The number of deer-vehicle collisions based upon carcass removals from Washington state highways by annual average daily traffic (ADDT) for 5 years, 2000-2004.

Western Washington Regional Models

Three models were developed for western Washington. The final full model for western Washington (Westside model [WSM]) and the rural model (Westside Rural [WSR]) were negative binomial models (Table 6). A Zip model (Westside Urban [WSU]) was developed for urban road units.

Considering traffic and road feature variables of WSM, AADT had significant influence and was negatively associated with collision counts. Higher speed limit showed significant influence but was associated with higher collision counts. Among road types, RIS and RPA had significantly more collisions than other road types while UMA had significantly fewer collisions than other road types. South facing aspects and amount of herbaceous upland cover showed significant model influence and were associated with higher and lower counts, respectively. Road units outside of deer concentration areas had significantly fewer collisions. Two slope covariates, >35^o and 10^o-35^o, were associated with lower counts while mean elevation and total amount of shrub cover were related to higher counts, but all at a lower level of influence (Table 6).

ZIP models showed the best fit for WSU models because NB models were under-dispersed. AADT, mean elevation, south facing aspects, moderate to steep slopes, and speed limit were significant when modeling a collision probability of zero (Table 6). The WSU model indicated that collision counts resulted from a dual-state process; road units with higher AADT and mean elevation were more likely to be collision free while road units with southern aspects, higher speed limits, and moderate slope were more likely to experience collisions. However, none of the variables used in our models where collisions were possible were significant.

Table 6. Model results of factors affecting deer-vehicle collisions are shown by model for western Washington, 2000-2004.

	Coefficient	SE	Type III F	P value	Model Description
Westside model					Negative Binomial
Constant	-3.4359	0.5568			
AADT	-0.0341	0.0048	51.17	<0.0001	
Speed Limit	0.0573	0.0105	29.62	<0.0001	
Total_South	0.0043	0.0009	22.59	<0.0001	
Total_hrbcU	-0.0388	0.0082	22.49	<0.0001	
PHS (none)	-1.3517	0.3370	16.09	<0.0001	
Road Type (RIS)	1.2889	0.3297	15.29	<0.0001	
Road Type (RPA)	0.5134	0.1387	13.71	0.0002	
Road Type (UMA)	-1.6960	0.4808	12.44	0.0004	
Slope > 35	-0.0178	0.0058	9.38	0.0022	
Slope 10-35	-0.0022	0.0009	6.21	0.0128	
Mean_Elev	0.0008	0.0003	6.04	0.0141	
Total_Shrb	0.0093	0.0044	4.38	0.0365	
Westside Urban					ZIP model
Inflation Probability					
Constant	9.3351	1.8394		<0.0001	
AADT	0.04591	0.01281		0.0004	
Slope 10-35	-0.0128	0.0043		0.0035	
Speed Limit	-0.1517	0.0338		<0.0001	
Total_South	-0.0093	0.0042		0.0019	
Mean_Elev	0.0042	0.0018		0.0200	
Poisson mean					
Constant	0.5976	0.1441		<0.0001	
Westside Rural					Negative Binomial
Constant	-0.2053	0.6250			
Total_South	0.0045	0.0009	22.81	<0.0001	
PHS (none)	-1.5135	0.3216	22.14	<0.0001	
Total_HrbcU	-0.0309	0.0076	16.68	<0.0001	
Speed Limit	0.0337	0.0096	12.34	0.0005	
Slope>35	-0.0143	0.0054	6.93	0.0086	
Slope 10-35	-0.0020	0.0008	6.04	0.0142	
Road Type (RMC)	-0.3903	0.1718	5.16	0.0233	

The NB model showed the best fit for WSR road unit data. WSR model results were similar to WSM except that AADT, mean elevation, and total area in shrub cover were dropped from the overall model. Significant variables associated with increased collision counts included south facing aspects and speed limit; variables associated with fewer collision counts were deer concentrations (outside of these areas) and higher amounts of herbaceous upland cover. Road units classified as major collector (RMC) and those with slopes of >35^{o} or 10^{o}-35^{o} had lower collision counts.

In comparing results among the Westside models, the relative influence of covariates becomes more apparent. AADT showed significant influence in WSM but that influence was limited only to the urban setting (WSU). Speed limit showed significant influence across all models with consistent positive effect to collision counts. Road type influences showed consistency between models. UMA had fewer collisions while RIS and RPA had significantly more collisions compared to other road types in WSM models; RMC showed a strong negative affect with rural road units in WSR compared to all other road types including RIS, RPA, and UMA. South facing aspects showed significant influence across all Westside models with a consistent positive relationship. The total amount of herbaceous upland cover showed a significant negative effect to collision counts in both WSR and WSM models, indicative of its importance to collision counts in rural road units. Deer concentration levels had a significant positive influence to collision counts only in the rural setting (WSR). Both slope and mean elevations have significant but limited influence to collision counts as shown in the WSU ZIP model. The western Washington models had R^2 measures of between 13% and 19%, suggesting low explanatory power for the covariates considered.

Eastern Washington Regional Models

Three models were considered for eastern Washington, a full model (EWM) and 2 separate models that were subsets of EWM; the separate models were developed for urban (EWU) and rural (EWR) road units. NB models produced the best fit for all models. Models that used 3 PHS deer concentration levels had higher AIC scores than those combining "regular" and "large concentration" into a single level; therefore, we combined categories 2 and 3 in to a single class: deer concentration areas. This variable thus is treated the same in Westside and Eastside models.

Eleven significant covariates from the eastside data set were included for EWM (Table 7). RPA, UMA, and RIS road types were significantly associated with higher collision counts compared with other road types Road units within low deer concentration areas had significantly fewer collisions. Moderate slope (10^o-35^o) had significant influence and was positively associated with collision counts while steep slopes (>35^o) were a relatively minor negative factor. AADT and total amount of water showed limited positive influence while total amount of herbaceous planted cover, road sinuosity, and total amount of shrub cover contributed negatively to collision counts at low levels of significance.

Table 7. Model results of factors affecting deer-vehicle collisions are shown by model for eastern Washington, 2000-2004.

	Coefficient	SE	Type III F	P value	Model Description
Eastside model					Negative Binomial
Constant	1.4575	0.2925			
Road Type (RPA, UMA)	0.8846	0.08346	112.34	<0.0001	
Road Type (RIS)	0.49992	0.1722	8.40	0.0038	
PHS (none)	-0.6695	0.1049	40.71	<0.0001	
Slope 10-35	0.00344	0.0005	40.68	<0.0001	
Total_HrbcP	-0.0009	0.0003	7.26	0.0071	
AADT	0.0178	0.0077	5.30	0.0215	
Total_shrb	-0.0008	0.0004	4.78	0.0289	
Slope > 35	-0.0058	0.0027	4.76	0.0292	
Sin_eu	-0.5272	0.2506	4.43	0.0355	
Total_water	0.0015	0.0008	3.56	0.0593	
Eastside Urban					Negative Binomial
Constant	2.6873	0.8820			
Total_dvlp	-0.0148	0.0028	27.47	<0.0001	
Mean_Elev	0.0031	0.0007	20.97	<0.0001	
Total_HrbcP	-0.0065	0.0021	9.47	0.0027	
Road Type(PA)	-1.0879	0.3766	8.35	0.0047	
Total_shrb	-0.0076	0.0027	7.72	0.0065	
Total_Nfrst	-0.0069	0.0035	3.94	0.0496	
Eastside Rural					Negative Binomial
Constant					
Slope 10-35	0.0037	0.0005	64.37	<0.0001	
AADT	0.0978	0.0144	46.43	<0.0001	
PHS (None)	-0.6896	0.1019	45.77	<0.0001	
Road Type (PA)	0.6013	0.0923	42.42	<0.0001	
Road Type (IS)	-0.6291	0.2455	6.57	0.0105	
Total_HrbcU	0.0014	0.0006	6.03	0.0141	
Total_Water	0.0017	0.0007	5.47	0.0194	
Sin_eu	-0.5748	0.2511	5.24	0.0222	
Total_East	-0.0012	0.0006	4.25	0.0394	

The total amount of developed land showed a strong negative influence to collision counts in the EWU models. Mean elevation was significantly associated with increased collision counts. Road units classified as UPA had fewer collision counts than other road types but the influence was limited. The total area in herbaceous-planted cover, shrub cover, and non-forested woody cover showed limited but significant negative influence to collision counts in EWU.

Within EWR models, moderate slope (10^{o}-35^{o}) showed strong positive influence to collision counts as did AADT. Road units outside of deer concentration areas were significantly associated with lower numbers of collisions. RPA road type had significantly higher collision counts compared to other road types in EWR. RIS road type showed significantly fewer collisions than other road types but the influence was limited. Total area in herbaceous upland cover and water were positively associated with collision counts but at low significance. Road sinuosity and total area with east aspect were negatively associated with collision counts but at a low level of significance.

By comparing the significant variables among eastside models, their influence comes more obvious. RPA road type was correlated with significantly more collisions than any other road type in both EWM and EWR models. Road units outside of deer concentration areas had significantly fewer collisions in both EWM and EWR models. Moderate slope (10^o-35^o) was positively associated with higher collision counts at a significant level in EWM and EWR models. AADT showed a significantly positive association with collision counts only in EWR models. All significant variables present in EWM models were dropped in EWU models except for total area in development and mean elevation that were positively associated with higher numbers of collisions. Final eastern Washington models had R^2 measures that ranged from 76% to 89%, suggesting high explanatory power of the model.

Habitat Distribution Models of Deer-Vehicle Collision Sites

Negative associations between total quantity and percentage difference between roadsides were observed for both cover and forage. We noted that when total quantity of a given habitat factor reached a certain high level, distribution of the type of habitat within the circular buffer became more even. Thus, in order to evaluate the effects of total quantity and percentage difference simultaneously, we restricted the analysis to subsets where either forage or cover or both were low.

In western Washington, road units were high in cover and low in forage (Figure 1); therefore, units where total forage was less than the 60 acres (median value) were considered too low in forage for analysis. Similarly, units with total cover less than 160 acres (the first quartile) were considered too low in cover for analysis. Conversely, road units were high in forage and low in cover in eastern Washington (Figure 1). Consequently, median values of total cover and the first quartile of total forage were used as thresholds to define low forage or cover subsets. Since a biological explanation for total area in water being attractive deer habitat was not clear for analysis, we divided these data into 2 subsets, with or without water. Detailed results are summarized in Table 8.

We were able to test for significance of percentage difference in forage under all low forage models as well as the western Washington low cover model. The only model to show significance was the low forage without water subset from western Washington; this suggested that increasingly uneven distribution of forage was associated with lower collision counts. It may also suggest that even when availability of forage was limited, uneven distribution of forage between highway sides does not increase the probability for a deer-vehicle collision to occur. A more commonly shared finding among models was that the total amount in forage and cover were positive factors to collision counts. The "total area in cover" covariate was significant in all subsets where water was absent; however, where water was present, in most cases habitat variables were not significant.

Table 8. Modeling results are shown of habitat parameter effects on deer-vehicle collisions in eastern and western Washington, 2000-2004.

Subsets	Model info	Significant Habitat Effects (Estimate, SE, P-value)
West, low forage (water=0)	N=474, NB model Included habitat variables: forage, pctdif_forage, cover	Pctdif_forage (-1.5228, 0.3636, <0.0001) Cover (0.0060, 0.0024, 0.0121)
West, low forage (water>0)	N=947, NB model Included habitat variables: forage, pctdif_forage, cover	None
East, low forage (water=0)	N=174, NB model Included habitat variables: forage, pctdif_forage, cover	Forage (0.0136, 0.0051, 0.0090) Cover (0.0076, 0.0033, 0.0224)
East, low forage (water>0)	N=480, NB model Included habitat variables: forage, pctdif_forage, cover	Forage (0.0067, 0.0018, 0.0002)
West, low cover (water=0)	N=298, Poisson model Included habitat variables: forage, pctdif_forage, cover, pctdif_cover	Forage (0.0108, 0.0034, 0.0017) Cover (0.0214, 0.0046, <0.0001)
West, low cover (water>0)	N=419, NB model Included habitat variables: water, cover pctdif_cover, forage, pctdif_forage	None
East, low cover (water=0)	N=511, NB model Included habitat variables: cover, pctdif_cover, forage	Cover (0.0946, 0.0200, <0.0001) Forage (0.0098, 0.0024, <0.0001)
East, low cover (water>0)	N=754, NB model Included habitat variables: cover, pctdif_cover, forage	None

Note: All models listed above also include PHS, Rural, Speed limit, AADT, Sinuosity, Total South, Total East, Slope 10-35, Slope >35, and Mean Elev as control variables.

Deer species and collision site models

While the two deer species models had some similar covariates that were significant, the order of importance of the covariates was quite different between the 2 models (Table 9). These findings suggest that the difference between the models is the result of difference between the preferred habitats by the two species. In the white-tailed deer model, slope >35º, total area in cover, road type, deer concentrations, AADT, and sinuosity were significantly associated with collision counts. Total area in cover was defined by total area in forested upland, consistent with habitat preferences of white-tailed deer in eastern Washington; however, total area with steep slopes was negatively associated with collisions. Road types RPA and UMA experienced significantly higher collision counts than Group 1 road types (UPA, UOPA, RMC, and RMA) that in turn had higher collision counts than RIS and UIS road types. Areas of deer concentrations had significantly higher collision counts compared to road units where few or no deer occur. AADT was positively associated, and sinuosity was negatively associated with collision counts.

Significant covariates in the mule deer model in order of influence were road type, slope 10º-35º, total area in forage, total area in water, speed limit, AADT, areas containing deer concentrations, and sinuosity (Table 9). RIS, UMA, and RPA road types had significantly higher collision counts than Group 2 road types (UIS, UOPA, RMC, RMA, and UPA). All habitats related variables were positively associated with collision counts as were speed limit and AADT. Road units within deer concentration areas also experienced significantly higher collision counts. Sinuosity was negatively associated with collision counts.

Table 9. Modeling factors affecting vehicle collisions with white-tailed and mule deer in eastern Washington, 2000-2004.

Model	Significant Factor	Type III F	P value
White-tailed deer	Slope >35 (-)	83.29	<0.0001
	Cover (+)	59.32	<0.0001
	Road type (RPA, UMA>Group1*>RIS>UIS)	40.97	<0.0001
	PHS (none< other)	28.99	<0.0001
	AADT (+)	25.34	<0.0001
	Sin_eu (-)	8.25	0.0046
Mule deer	Road Type (RIS, UMA, RPA >Group 2*)	119.26	<0.0001
	Slope 10-35 (+)	84.84	<0.0001
	Forage (+)	78.95	<0.0001
	Water (+)	44.17	<0.0001
	Speed limit (+)	24.10	<0.0001
	AADT (+)	8.47	0.0036
	PHS (none< other)	5.21	0.0225
	Sin_eu (-)	4.63	0.0315

*- Road type Group1 includes UPA, UOPA, RMC, and RMA and Group2 includes UIS, UOPA, RMC, RMA, UPA, and UIS.

Models of deer season of movement and collision sites

We studied deer-vehicle collisions that occurred during 2 time periods defined by deer movement patterns (movement and sedentary). We expected deer to travel longer distances on a daily basis during the movement period (defined by migration, breeding, and fawning seasons) than during sedentary seasons of summer (June 15- Sep. 15) and winter (Dec. 16 - Mar. 1). Analysis was limited to eastside data sets only. Starting with full models using eastern Washington data, we progressively eliminated covariates to reach a final model for each period of movement. The two models were similar in terms of significant variables (Table 10); however, deer concentration stood out as a dominating factor during the sedentary season while it was of lower importance during the movement season. The model for the movement season contains mostly road and traffic factors with low to moderate slope being the most important factor together with speed limit and road type as the other top factors. For eastern Washington data, we observed a high correlation (r=0.52) between slope 10º-35º and total area in cover. The results suggest that cover may be an important positive factor for travel season.

Table 10. Model results of season of movement and deer-vehicle collision sites in Washington, 2000-2004.

Movement season	Type III F (p)	Sedentary season	Type III F (p)
Slope 10-35 (+)	42.22 (<.0001)	PHS (none<other)	81.92 (<.0001)
Speed limit (+)	29.69 (<.0001)	Road Type (UMA, RPA>other)	19.01 (<.0001)
Road Type (RPA>other)	26.97 (<.0001)	Water (+)	14.21 (0.0002)
PHS (none<other)	18.43 (<.0001)	Slope 10-35 (+)	13.57 (0.0002)
Sin_eu (–)	9.97 (0.0016)	AADT (+)	13.13 (0.0003)
AADT (+)	4.61 (0.0032)	Mean_Elev (+)	11.57 (0.0007)
		Sin_eu (–)	7.15 (0.0075)
		Speed limit (+)	4.52 (0.0335)

DISCUSSION

One of the key factors influencing the potential for UVCs on Washington State Highways was the level of known deer concentration in the surrounding area. Without over-stating the obvious, there has to be a deer present for a deer-vehicle collision (DVC) to occur as typified in Sudharsan's (2006) conceptual model: *Annual Number of DVCs = f(deer, drivers, landscape)*. Seiler (2005) found a similar relationship in Sweden where harvest levels (an index of moose abundance) correlated significantly with moose-vehicle collisions. Improved knowledge of deer concentration areas and migration corridors may prove to be the best tool for mitigating the likelihood of UVCs in Washington; however, other factors clearly play a role.

The presence of roadside cover and forage, both important deer habitat components, was associated with higher collision counts in both our white-tailed and mule deer models. In eastern Washington, most deer cover occurred in the form of forested upland, which is a commonly preferred habitat type of white-tailed deer. Proximity of these forested habitats to highways has been correlated with white-tailed deer-vehicle collisions in Illinois and Pennsylvania (Puglisi, et al. 1974, Bashore, et al. 1985, and Finder, et al. 1999). Habitat covariates usually associated with lower quality deer habitats showed negative associations with collision counts. High elevations, steep slopes ($>35^o$) and east aspects were negatively associated with collision counts in some models and have been shown to be avoided by mule deer at various times of the year (Moore et al. 2003).

Watercourses and associated riparian areas contain important components of quality deer habitat including forage, cover, and travel corridors. The covariate "total water" was important only in the mule deer model and suggests that riparian areas may have use in predicting UVCs in more arid environments. Watercourses and drainages have historically provided travel routes for people and that trend has continued into the present with the construction of highways that follow these same waterways. Given the convergence of highways along watercourses and quality deer habitats, higher incidents of deer-vehicle collisions should be expected in these areas.

Scale may be an important consideration when attempting to interpret factors potentially influencing ungulate-vehicle collisions. For example, Gunson and Clevenger (2005) observed relatively low roadkill rates in one Alberta watershed compared to others but discovered that 60% of the roadkills in this particular watershed occurred on a small section of highway when viewed at a finer scale. Our base scale of collision counts, road characteristics, and habitat and landscape features was a mile in diameter; at this scale, sections of road as opposed to point locations become the base for reporting and analyzing incidents of mortality (Finder et al. 1999, Hubbard et al. 2000, Seiler 2004, Gunson and Clevenger 2005). Important variables which could affect UVCs such as roadway, adjacent roadside features, deer movement patterns, and habitat quality can change considerably within a mile of distance which may result in misinterpretations of covariate influences. Because of the potential effects of spatial scale, there are likely a number of factors that may contribute to where and when UVCs occur on Washington's state highways that should be measured at a finer scale.

Increasing levels of AADT were associated with higher numbers collisions in most eastern Washington models and decreased the odds of a deer successfully crossing a roadway. Traffic volume has been positively associated with deer-vehicle accidents in Michigan (Allen and McCullough 1976) and Utah (Romin and Bissonette 1996) and moose-vehicle collisions in Sweden (Seiler 2005). However, in our overall and urban western Washington models, AADT was negatively associated with collision counts. There are at least 2 possible explanations for this relationship. First, the negative association may have been a result of confounding effects due to the highly positive correlation between AADT and total developed area in western Washington; highly developed areas generally support little, if any, deer habitat, so a negative association with collision counts could be expected. This hypothesis is further supported by the strong negative relationship between low deer concentrations and DVCs in the 2 western Washington models. Second, where deer are present there may be a threshold above which heavy traffic and the resulting disturbance (noise, motion) may become a barrier and discourage wildlife from approaching highways, reducing the probability of a collision (Clarke et al. 1998, Seiler 2004, 2005).

Several studies have shown increased speed to be positively associated with increasing numbers of collisions between vehicles and deer (Pojar et al. 1975, Allen and McCullough 1976, Case 1978, Romin and Bissonette 1996, Sudharsan 2006, McShea et al. 2008) or moose (Seiler 2005). In the case of moose-vehicle collisions, Seiler (2005) reported a nonlinear relationship with highest collision rates occurring at intermediate speeds and traffic levels. Our models predicted increased collision counts where speed limits were higher. Higher vehicle speed limits are generally associated with arterial road types, and our models generally showed rural interstate and rural principal arterial roadways to be correlated with increased collisions compared to other road types. These parallel predictions from 2 different covariates suggest a confounding influence between increased speed limits and some road types, making differentiation of independent effects difficult. Because of their greater width and roadside buffers, arterial roadways probably provide drivers with greater sight distances compared to other road types. Although increased sighting distance for drivers may allow them greater opportunity to see a deer on or approaching the highway and avoid a collision, our models, and those of others (Pojar, et al. 1975, Case 1978, and Hubbard, et al. 2000), suggest just the opposite. Vehicle speed may be more important than sight distance in avoiding UVCs due to decreased driver response time to avoid a collision and the need for increased concentration on the immediate roadway required when driving at higher speeds.

Most recently, Bissonette and Kassar (2008) argued that AADT and posted traffic speed were poor descriptors of traffic volume and actual vehicle speeds at the time of an UVC because of the way these data were collected, and that traffic volume levels were not static but changing constantly. Certainly, these arguments have merit. Varying levels of AADT and traffic speed would affect the probability of a deer successfully crossing a road. In spite of these issues, the relationship between AADT and posted speed limits and collision counts was strong in several of our models, supporting the likelihood of more UVCs as traffic flows and speed limits increase on roadways traversing deer ranges.

The seasonality we observed in UVCs in Washington likely was related to changes in ungulate behavior and environmental factors. Most vehicle collisions involving mule deer occurred during October - January, similar to observations from New Mexico (Biggs et al. 2004). Most white-tailed deer were killed during the months of December, October, and January. Studies in Iowa, Michigan, and New Brunswick reported most vehicle collisions involving white-tailed deer to be associated with the autumn breeding season (Hubbard et al. 2000, Christie and Nason 2003, Sudharsan 2006). Similarly, we also found more black-tailed deer were killed by vehicles during October and November, but few comparative data for black-tailed deer exist. Autumn and early winter over-lap with deer hunting seasons, a time of increased disturbance to deer. With more people in deer habitat, deer may increase their movement to avoid hunters, increasing the likelihood of their being near or crossing highways (Naugle et al. 1997, Etter et al. 2002). Fall (particularly November) is also the breeding season for most deer populations; during this time deer increase movements in search of mates (Allen and McCullough 1976, Puglisi et al. 1974, Feldhamer et al. 1986). In addition, day length is declining and precipitation is increasing during this period, lowering driver visibility and causing peak drive times (early morning and early evening) to coincide with dawn and dusk, periods of high deer activity.

Seasons of movement and increased activity have been reported as times of high deer-vehicle accidents (Bellis et al. 1971, Puglisi et al. 1974, Carbaugh et al 1975, Allen and McCullough 1976, Etter et al. 2002). During migratory periods, relatively high numbers of deer moving between seasonal use ranges tend to use traditional movement corridors (Greull and Papez 1963, Brown 1992) and where migration corridors intersect highways, seasonally high incidents of deer-vehicle collisions will occur (Bissonette and Lehnert 1996, Feeney, et al. 2004). Furthermore, funneling of deer movements by physiographic or landscape features has been shown to result in higher potential for deer-vehicle accidents (Finder et al. 1999, Hubbard et al. 2000, Malo et al. 2004). In eastern Washington, moderate slopes were associated with increased counts during the movement period suggesting the importance of this topographic feature to migrating deer. However, deer presence (PHS) was strongly correlated with collision rate throughout the sedentary season suggesting that deer density affects collisions even during periods of lower activity and movement.

Several studies have shown that roadkills tend to be clustered, with a large portion of roadkills occurring at a relatively small percentage of locations (Puglisi et al. 1974, Bashore et al. 1985, Hubbard et al. 2000, Malo et al. 2004, Gunson and Clevenger 2005). We identified sites or aggregates of sites that incurred very high numbers of vehicle collisions with deer and elk in Washington. The number of collisions at these sites demonstrated their uniqueness and required additional study and attention. Not all of these sites were within PHS categories indicating deer presence, identifying some mapping errors in the PHS database. However, our additional investigation of these units revealed that they were all within high deer use areas. All sites in eastern Washington were within deer winter ranges and 2 were located at the intersection of an active migration corridor and state highway (WDFW Unpublished data). Winter ranges are traditional use areas, usually at lower elevations, where forage is relatively more available and deer concentrate to spend the winter season. Further investigation into these high-kill areas, including site visits, may help identify unique characteristics that can be used in management.

The WSDOT data set indicated that the highest number of deer removed from state highways occurred on Mondays, then declined each day through the rest of the week. We see no plausible biological explanation for this and believe that the reduced WSDOT weekend workforce removed fewer deer, leaving many deer killed over the weekend to be collected on Mondays along with deer killed that day. If our assumption is correct, then the average daily removals should differ little between Tuesday-Friday and Sunday-Monday. Our data indicate little difference and would disagree with to those reported by Sudharsan (2006) in Michigan, where most deer-vehicle accidents occurred during weekends.

Finally, the WDOT dataset and the accidents they represent are most likely minimum estimates; documented removals of deer and elk carcasses from Washington state highways probably represent only a portion of an unknown number of road kills that actually occur. As a case in point, for every documented deer killed in a vehicle collision in New York, Decker et al. (1990) estimated that 5 went unreported and/or undiscovered. We have no similar estimates of unrecovered deer killed by vehicles on Washington State highways.

MANAGEMENT IMPLICATIONS

An ungulate-vehicle collision occurs when 3 entities, a deer or elk, a driver and moving vehicle, and a roadway come together simultaneously in time and space. It follows then that we could focus mitigative actions on any of these components, individually or collectively, to interrupt a merger and affect UVC occurrence on state highways. Ultimately, the goals of all management strategies should be to ensure safe driving conditions and increased driver security by allowing safe passage of deer and elk across state highways. Results of our analysis have helped provide a first look at factors influencing UVC occurrence on Washington's highway system. In the Appendix, we present a brief overview of options for mitigating UVCs, recognizing that additional data and analysis would help focus and maximize the effects of any such efforts.

Our modeling demonstrated those parameters indicative of higher quality deer habitat (modest slopes, near water/watercourses, southern exposure, forage, cover), as well as deer concentrations, were associated with higher collision counts. Similarly, highways bisecting areas of high deer use such as winter ranges or migration corridors experienced higher numbers of UVCs. These results suggest that providing passageways for deer to cross over or under highways, constructing barriers that prohibit entry onto roadways, and discouraging deer use near highways indirectly by affecting the quality of adjacent habitats or directly reducing deer densities through harassment or lethal removal may reduce UVC rates on state highways. Similarly, when new highways are being designed, evaluating potential UVC rates should be an integral part of the planning process. To achieve the lowest potential level of UVCs, new routes should avoid deer concentration areas and known migration corridors; habitat and geographic features shown by our models to have significant relationships with high UVC rates also should be avoided. Improved delineation of deer concentration areas and migration corridors should be a priority for guiding placement of future roadways.

Our analysis provided unique insights into characteristics associated with sites of collisions between deer or elk and vehicles on Washington highways. While this information will be valuable to traffic planners and wildlife managers, we view these efforts to date to be introductory. Additional research to accurately identify, predict, and mitigate ungulate-vehicle collision sites is needed to help reduce and prevent future accidents, personal injuries, property damage, and loss of deer and elk resources. Future work should focus on: 1) review of existing telemetry data sets of deer and elk locations collected from animals wearing GPS collars to assess movement patterns near and across state highways; 2) field inspection and mapping of high level deer and elk collision sites identified in this study to document road, vegetation, and terrain features at a local scale, and to identify site-specific options for mitigation; 3) implementation and evaluation of mitigation techniques at test locations; 4) field studies of deer movement patterns and mortality factors in relation to highway crossing patterns and habitat use adjacent to state highways to identify key factors associated with deer-vehicle collisions and accurately estimate number of deer killed by collisions with vehicles; 5) improved UVC data base including more accurate kill locations and, where possible, descriptors of drivers, vehicles involved, and extent of vehicle damage; 6) driver surveys to assess driver attitudes and collision involvement; and 7) experimental hunting seasons to reduce deer densities and gauge its affects on deer-vehicle collisions.

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APPENDIX. A review of potential mitigation treatments to reduce ungulate-vehicle collisions

Treatments designed to mitigate or reduce UVCs generally can be classified into one of several categories including: 1) exclusionary, 2) highway modifications (includes over and under passes), 3) habitat management, or 4) population manipulation.

Fencing or other exclusionary structures have been found to be effective in restricting deer access to highways (Reed et al. 1974, Reed et al. 1982, Feldhamer et al. 1986, Hubbard et al. 2000, Clevenger et al. 2001). It is likely that constructing fences along sections of highway identified as high kill sites would reduce UVCs locally; however, such exclusionary measures may prohibit deer or elk from reaching important or critical ranges. Fencing highway segments could potentially relocate high kill sites near the ends of fences if they are not long enough to discourage movement around the end by deer (Reed et al. 1975, Clevenger et al. 2001, Rosa 2006). Fences can also become traps for deer or elk that are attempting to flee or elude predators including domestic dogs, particularly during winter (personal observation). Deer-proof fence construction is expensive and may not be cost-effective if applied at a large scale (Reed et al. 1982). However, fencing combined with existing bridges or other ungulate friendly under-passes could provide safe barriers that allow for trans-highway movement and lower collision counts (Hubbard et al. 2000).

AADT and speed limit have been positively correlated with collision counts in a number of studies (Pojar et al. 1975, Allen and McCullough 1976, Case 1978, Romin and Bissonette 1996, Seiler 2005, Sudharsan 2006, McShea et al. 2008). Reduced speed limits, particularly from dusk to dawn and during fall and winter, could be imposed along stretches of highways with high incidents of UVCs or on those highways where modeling showed significant relationships. However, the driving public must consider reduced speed limit reasonable or it will be ignored (Knapp et al. 2004). An information/education campaign targeting the driving public and adequate levels of enforcement would be required to attain compliance with posted speed limits and reduced numbers of UVCs. Moreover, it is possible that driver response to current or higher fuel costs or increased use of public transportation when available could potentially result in declining traffic volume and provide a secondary benefit of reduced UVC rates.

Managing lands neighboring state highways to discourage deer use is complicated by ownership. It is outside of government authority to alter or manipulate deer habitats on privately owned property adjacent to highways without landowner consent or participation. Where landowners are amenable, cover could be removed, forage species could be planted some distance away from highways, or fields containing favored crops could be fenced to limit deer access to roadways. On highway right-of-ways and other publicly owned lands, vegetation species thought to be deer resistant could be planted. Cover and forage could be removed or reduced along right-of-ways, although that may not be cost-effective or aesthetically acceptable to motorists (Mastro et al. 2008). Chemical and biological repellents have been found to discourage select ungulates from foraging on known food sources with varying degrees of success (Muller-Schwarze 1972, Harris et al. 1983, Melchiors and Leslie 1985, Conover 1987, Palmer et al. 1987, Swihart and Conover 1990, Andelt et al. 1991, Brown et al. 2000) and could be applied along right-of-ways, but their usefulness in preventing animals from crossing a highway is undocumented (Knapp et al. 2004).

Lowering deer densities along state highways could theoretically result in local reductions of UVCs; however, no studies to date have documented such relationships across large geographic areas. Some studies (Mcaffery et al. 1973, Doerr et al. 2001, Denicola and Williams 2008) reported that hunting and other herd reduction efforts within relatively confined areas such as towns or parks resulted in lower deer densities and fewer UVCs. In Minnesota, a combination of hunts with licensed hunters and other lethal removals by sharpshooters (county park rangers, conservation officers, and local police) reduced wintering deer numbers by 46% and deer-vehicle accidents by 30%; however, hunt costs were relatively high, ranging from $117/deer for operating controlled hunts to $194/deer when police sharpshooters were employed (Doerr et al. 2001). More recently, Denicola and Williams (2008) reported using sharpshooters to reduce white-tailed deer numbers in 3 suburban areas in Iowa, New Jersey, and Ohio; this effort resulted in reductions of 76%, 72%, and 54% of each deer herd and 78%, 75%, and 49% decline in deer-vehicle accidents, respectively.

Although our analysis did not include driver behavior or response to deer or elk on the roadway, our results could be integrated into an effort to educate drivers of the potential hazards of UVCs. We suggest an annual public information campaign just prior to high UVC periods (fall and winter). Knowledge of ungulate behavior and movement patterns in addition to safe driving techniques when faced with deer in the roadway should be part of any education plan. Information could be relayed to the public through public service announcements by radio during morning and evening drive times and television at high viewer periods. Some states have used bumper stickers (e.g., Maine's "*I brake for moose*") and roadside signs (e.g., Arizona's program using multiple signs spaced ¼ mile apart, containing the message, "*Saw an elk…what a trill…'til it came…through the grill*") as part of their information campaign to reduce UVCs.