Journal of Agricultural and Resource Economics 27(1):261–280

A Dynamic Exercise in Reducing Deer-Vehicle Collisions: Management Through Vehicle Mitigation Techniques and Hunting

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The costs of deer-vehicle collisions (DVCs) nationwide are estimated to be in excess of $1 billion annually. In this study, factors contributing to the abundance of DVCs are identified and the potential effectiveness of various deer management strategies in reducing DVCs is investigated. The added benefits of such strategies are also evaluated in a bioeconomic context by comparing alternative outcomes achievable from implementing DVC mitigation techniques. Focusing on Ohio, results suggest potentially large economic gains exist from reducing DVCs, especially with strategies that combine both deer management schemes and DVC mitigation techniques.

Key words: bioeconomic models, deer-vehicle collisions, generalized least squares, hunting, net benefits, panel data, wildlife damages, wildlife management

Introduction

In reviewing various states' policies for managing deer populations, specified objectives and goals mimic textbook definitions of resource management. For instance, the Ohio Department of Natural Resources (ODNR 1996) maintains management goals to "provide a deer population that maximizes recreational opportunities including hunting, viewing, and photography, while minimizing conflicts with agriculture, motor travel, and other areas of human endeavor."

Similarly, the Wisconsin Department of Natural Resources deer management policy [Wisconsin Administration Code, Sec. NR 1.15(2)(a), 1999] states, "the department shall seek to maintain a deer herd in balance with its range and at deer population goals reasonably compatible with social, economic, and ecosystem management objectives for each deer management unit." The Wisconsin policy then lists objectives acknowledging the demand for hunting opportunities, concern for deer-vehicle collisions, and recognition of carrying capacities. Clearly, these policies recognize the potential tradeoffs associated with alternative deer population levels and, we posit, suggest the desired deer population levels are those that maximize net benefits.

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Review coordinated by Gary D. Thompson.

To achieve such objectives, however, requires information on the benefits and costs associated with deer, the impacts and effectiveness of various management strategies on deer population herds, and the potential benefit-cost tradeoffs associated with alternative deer population levels. To this end, a number of studies have examined the benefits deer provide society via their recreational value (Balkan and Kahn; Livengood; Loomis, Updike, and Unkel; Schwabe et al.).

Loomis, Updike, and Unkel, for example, estimated total consumer surplus from hunting and viewing deer in California to be approximately $273 million in 1987.[1] Schwabe et al. estimated Ohio hunters, who spent nearly $15 million in 1996 on permits and licenses for the opportunity to hunt deer, would have been willing to pay nearly $1.4 million for an additional day of deer hunting. Furthermore, there have been a few evaluations of management strategies to achieve optimal deer population levels, notably Keith and Lyon, and Cooper. Finally, research by Manfredo and Larson, and by Conover (1997a, b), highlighted a wide range of additional nonconsumptive benefits associated with deer populations, particularly to urban residents.

Quite separate from the literature cited above, there is an abundance of research investigating the potential costs associated with harmful deer-human interactions, including the deer's role in damaging ecological services, crops, or timber; serving as a vector for transmitting diseases or parasitic infections to humans; or involvement in collisions with vehicles (Wywialowski; Forster and Hitzhusen; Waller and Alversoin; deCalesta and Stout; Stromayer and Warren; Romin and Bissonette 1996a).

In a 1995 national review of human injuries, illnesses, and economic losses caused by wildlife, Conover et al. estimated over 700,000 deer-vehicle collisions (DVCs) occur annually in the United States, resulting in losses of over $1 billion. These costs arise primarily from vehicle damage, deer fatality, and human morbidity and mortality.

At the state level, Decker, Loconti-Lee, and Connelly estimated that the roughly 57,000 DVCs reported in New York in 1988 resulted in approximately $66.3 million in vehicle damage, whereas the Ohio Department of Public Safety (ODPS 2000) calculated the losses associated with DVCs in 1996 exceeded $52 million. Unfortunately, such costs seem unlikely to decrease given recent trends. From 1986 to 1995, for instance, DVCs in many midwestern states increased between 30 and 50% (Cook and Daggett).

The dual objective of this study is to investigate the relationship between deer populations and DVCs, and to illustrate the potential importance of this linkage on optimal deer population levels. Using a panel data set of DVCs from 1977 to 1998 across all 88 counties in Ohio, we attempt to identify the extent to which deer-vehicle collisions are affected by deer population size, traffic volume, location, and deer management strategy.

After providing support for the existence of such relationships, we illustrate the potential biological and economic implications of two general strategies for reducing DVCs. A simple bioeconomic model is employed, similar to those used by Keith and Lyon, and Cooper, which integrates accepted biological principles related to deer populations in Ohio. Our results suggest deer population management strategies not accounting for the costs associated with DVCs may lead to large social welfare losses. Furthermore, based on our findings, some combination of hunting regulations and DVC mitigation strategies seems best for maximizing the difference between the benefits to hunters and the social costs associated with DVCs.

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[1] All dollar values in this study are measured in 1996 dollars unless otherwise noted (U.S. Department of Labor/Bureau of Labor Statistics, Consumer Price Index, 1913–2000).

Two potential limitations of this research should be noted. First, this application focuses exclusively on the consumptive use benefits to hunters and the DVC-related costs to society, even though there is a much larger array of benefits and costs associated with maintaining a particular deer population level. By including DVC-related costs, however, this research adds another dimension to the dynamic valuation literature on deer.

Second, our application focuses on the state of Ohio and two representative counties within this state which differ with respect to deer populations, habitat, and number of vehicles. Yet, our general approach can be easily applied to any deer management unit. Ohio provides an application with DVC-related characteristics representative of many other states, particularly in or around the Midwest, with abundant deer populations and a significant number of DVCs. For instance, the average annual number of reported DVCs in Ohio in the late 1980s through the mid-1990s was approximately 20,200. The average annual number of DVCs across the seven neighboring states of Illinois (15,600), Indiana (11,000), Kentucky (4,000), Michigan (49,000), Pennsylvania (43,000), West Virginia (9,000), and Wisconsin (34,000) was nearly 23,500 (Tonkovich).

The rate of increase in DVCs in Ohio, approximately 60% from 1985–1994, is neither rare nor excessive relative to rates in many other states, including Pennsylvania (68%), Wisconsin (30%), Iowa (75%), Illinois (224%), and Michigan (116%) (Cook and Daggett). Finally, as noted above, deer management units in Ohio are individual counties, similar to practices in Indiana, Maryland, West Virginia, and Virginia.

Related Literature

Two strands of literature include the direct costs of DVCs and potential mitigation techniques for reducing DVCs. An equally important segment is the environmental and natural resource economics literature related to optimal deer management. A brief overview of each follows.

In their summary of the costs of vehicle accidents with deer, Conover et al. reported the average vehicle repair bill ranged from $1,300 (as found by Hansen) to nearly $2,400 (as determined by Witmer and deCalesta). Using 24,884 DVCs spanning 10 years in Vermont, Romin and Bissonette (1996a) estimated the average vehicle damage to be approximately $2,100, measured in 1996 dollars. Research conducted by Stoll, Culbertson, and McClain, and by Rue, suggests the rate of human injury or fatality per DVC is quite low—approximately 4% and 0.029%, respectively.

In absolute terms, Romin and Bissonette (1996a) reported an average of approximately 120 human fatalities per year nationwide due to DVCs. Hansen provided the only effort to quantify these DVC-related morbidity and mortality effects. He reported $173 as the average cost associated with the morbidity and mortality effects of a DVC, including medical costs, lost wages, and the value of a statistical life. With respect to deer fatality, the most widely cited estimate in the DVC literature is given by Allen and McCullough, whose 1976 survey of DVCs revealed a 92% deer fatality rate.

Numerous DVC mitigation strategies have been proposed, tried, and evaluated. These strategies have ranged from methods aimed at reducing deer appearance on highways to approaches seeking to increase human perception, or the awareness of the human presence, associated with DVCs (Primo and Primo).

Strategies aimed at reducing deer appearance on highways include fencing (Halls et al.; Falk, Graves, and Bellis; Feldhamer et al.), underpass structures and overpass structures (Reed, Woodward, and Pojar; Lehnert, Romin, and Bissonette), reflectors (Reeves and Anderson; Pafko and Kovach; Ujvari, Baagoe, and Madsen), and intercept feeding (Wood and Wolfe). Efforts to increase human perception of deer presence or deer awareness of human presence include deer warning signs (Pojar et al.) and deer whistles (Romin and Dalton).

In a 1996 survey of DVC mitigation practices throughout the United States, 93% of the states surveyed had installed deer crossing signs; yet, in 70% of these states, the effectiveness of the signs was uncertain (Romin and Bissonette 1996a). Romin and Bissonette (1996a), as well as Feldhamer et al. and Tonkovich, provide comprehensive surveys of these techniques.

In the analysis presented below, we consider a hypothetical fencing mitigation strategy that reduces DVCs by 85%. While other strategies could have been consistent with such a reduction, our illustration is based on conversations with wildlife mitigation strategy experts (Romin; Neve) who suggest Z-clip fencing can achieve an 85% reduction rate in DVCs. Indeed, in responding to the Romin and Bissonette (1996a) survey, over 90% of the states reporting the use of fences as deterrents indicated this technique was effective (qualifying that the height, location, and type of fencing can influence its effectiveness). A detailed summary of this technique is provided by Cook and Daggett.

Although much more controversial, deer reflectors may also have the potential to reduce DVCs by 85%. Pafko and Kovach observed a near 87% reduction rate in the incidence of DVCs using reflectors. Gladfelter, and Schafer and Penland also noted fewer reported DVCs with the implementation of reflectors. In contrast, other studies (Gordon; Zacks; and Reeves and Anderson) have concluded reflectors are ineffective at reducing DVCs. Furthermore, Ujvari, Baagoe, and Madsen caution that even in the event reflectors initially are shown to be effective, deer may actually habituate to the light reflections over time, thereby reducing the long-run effectiveness of this strategy. Hence, evidence regarding the effectiveness of reflectors is inconclusive. In general, the perceived success or failure of a particular strategy depends on site-specific factors and the assumptions made about unobserved variables.

While large deer populations may lead to more DVCs and other types of negative deer-human conflicts, such as crop damage, deer populations also generate social benefits. Both consumptive and nonconsumptive values are associated with deer. The total consumer surplus from deer hunting in California in 1987, for instance, was estimated to be $230 million, and the consumer surplus from viewing deer was approximately $43 million (Loomis, Updike, and Unkel). In Ohio, hunters spent nearly $15 million in 1996 on permits and licenses for deer hunting and would have been willing to pay nearly $1.4 million for an additional day of hunting (Schwabe et al.). Estimates of consumer surplus for the value of a deer vary considerably—e.g., $35 (Livengood), $64 (Keith and Lyon), $209 (Loomis, Updike, and Unkel), and $182 (Schwabe et al.), all measured in 1996 dollars. While these values pertain to hunting, they are estimated with different nonmarket valuation techniques, in different regions of the U.S., and for different species of deer.[2]

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[2] Livengood used a hedonic model for estimating the value of an additional whitetail deer for hunting in Texas. A household production function approach was employed by Keith and Lyon, who estimated the consumptive value of an additional mule deer to the deer population in Utah. Loomis, Updike, and Unkel applied the contingent valuation method and estimated the value of a mule buck for hunting in California. Schwabe et al. developed a random utility model to estimate the value of an additional whitetail deer for hunting in Ohio.

Two studies have used bioeconomic models to evaluate optimal deer management (Keith and Lyon; Cooper). Keith and Lyon derived the parameters which defined relationships between a mule herd's population dynamics, hunter utility, and the marginal value of an additional deer. Alternatively, Cooper estimated a bioeconomic model for determining the optimal level of deer and tag sales. Neither study explicitly recognized the potential costs of harmful deer-human interactions. Furthermore, because DVCs can account for a substantial portion of annual nonharvest mortality, a natural extension of the bioeconomic modeling of optimal deer management is to account for the population dynamics associated with implementing potential DVC mitigation strategies. For instance, a 1998 analysis of white-tailed deer populations in Michigan found DVCs accounted for 11.1% and 7.1% of the annual mortality among nonmigratory and migratory deer, respectively (Sitar, Winterstein, and Campa). A 1996 study of mule deer in Utah showed highway mortality rates ranging from 5.6% to 17.4% annually (Lehnert).

Analyzing DVCs: The Case of Ohio

Between 1977 and 1998, reported DVCs in Ohio increased from less than 5,000 to more than 26,000 annually—an increase of approximately 1,000 DVCs per year (ODPS 1998). This trend is not surprising given the increases in white-tailed deer populations and traffic volume. From 1977 to 1998, buck-gun harvest per square mile, defined as the number of bucks harvested during the one-week shotgun season and a factor shown to be highly correlated with deer population size (Culbertson and Stoll), increased by over 300%. Over this same period, the number of registered vehicles, a proxy for traffic volume, increased by roughly 40%.

To investigate the potential for using deer management strategies as a tool to reduce DVCs, data were collected on incidences of DVCs by county from 1977 to 1998 from the Ohio Department of Public Safety (ODPS 1998, 2000). Because the county is the basic deer management unit in Ohio, this scale is appropriate. We hypothesize that changes in DVCs from year to year are largely a function of changes in both deer populations and traffic density. More formally, this hypothesis is denoted by:

$$(1)\qquad DVC_{c,t} = f(\mathit{Deer\ Population\ Density}_{c,t}, \mathit{Traffic\ Density}_{c,t}, \mathit{Management\ Strategy}_{c,t}, \mathit{Habitat}_{c,t}),$$

where c represents one of Ohio's 88 counties and t indicates the year. Because deer populations in Ohio are not measured, the convention of using harvest data for both bucks and does is followed to capture changes in deer populations over time (Creed et al.; Keith and Lyon; Tonkovich).

Harvest trends not only capture changes in the size of the deer population, but also reflect changes in harvest regulations. Two types of harvest regulations employed by the ODNR (1998) are included: bag limits and the number of buck-only days. Bag limits are restrictions on the allowable season take of deer per hunter, and vary from a minimum of one to a maximum of three. Buck-only days are the number of days per gun season that hunters can harvest bucks only, and range from zero to six days. To control for the impact of changes in the number of deer hunters on harvest rates, the annual number of permits sold statewide is included. As a proxy for traffic density, we use the number of registered vehicles per number of road miles by county [Ohio Department of Transportation (ODOT) 2000].

Finally, we investigate the impact of three variables intended to measure the potential effect of location or habitat on DVCs. First, a binary variable is included which equals one if the county is listed as part of a metropolitan statistical area, and zero otherwise. This variable (*MSA*) captures the extent to which counties are associated with large commuting populations to and from major metropolitan areas and business developments. The other two habitat variables included to measure this effect are acres of farmland (*FARMLAND*) and number of farms (*FAMNUM*).

Romin and Bissonette (1996b) found high DVC rates occur in nonwooded areas and are associated with deer foraging patterns. The relative locations of woodland cover, agricultural land, and the roadway are important factors influencing DVCs (Fischer, Pease, and Clark; Romin and Bissonette 1996b). Indeed, white-tailed deer seem to prefer woodlands and woodland edges for cover, yet travel to agricultural fields for foraging. The more fragmented the habitat, the greater are the opportunities for a DVC.

To investigate these relationships, various specifications of the following general model are estimated:

$$\begin{aligned} DVC_{c,t} = \; & \alpha_0 + \alpha_1 VEHROAD_{c,t} + \alpha_2 BHSQM_{c,t-1} + \alpha_3 DHSQM_{c,t-1} \\ & \alpha_4 BAG_{c,t-1} + \alpha_5 BODAYS_{c,t-1} + \alpha_6 MSA_{c,t} + \alpha_7 FARMLAND_{c,t} \\ & \alpha_8 FARMNUM_{c,t} + \alpha_9 PERMITS_{c,t-1} + \varepsilon_{c,t}, \\ & \{c = 1, \dots, 88 \text{ (counties)};\ t = 1977, \dots, 1998\}, \end{aligned} \tag{2}$$

where *DVC* = number of deer-vehicle collisions; *VEHROAD* = number of registered vehicles per mile of road; *BHSQM* = buck-gun harvest per square mile; *DHSQM* = doe-gun harvest per square mile; *BAG* = bag limit on deer; *BODAYS* = legal number of days allowed to target bucks only; *MSA* = binary variable capturing whether county was listed as part of a metropolitan statistical area (1) or not (0); *FARMLAND* = acres of farmland in the county; *FARMNUM* = number of farms in the county; and *PERMITS* = total deer hunting permits distributed statewide. Notice harvest rates and management strategies are lagged one period. This is because, in any year, most DVCs occur before the gun-hunting season, which typically begins the first Monday after the last Thursday in November. Hence, DVCs in year t will most likely be a function of deer populations as proxied by the annual harvest rates and management strategies in year $t-1$ (before, rather than after, the collisions occur).

Table 1 presents the regression results from equation (2) for three specifications. Tests for nonspherical disturbances supported the use of a feasible generalized least-squares (FGLS) estimator. The Baltagi-Wu locally best invariant test statistic and the Bhargava, Franzini, and Narendranathan Durbin-Watson test statistic suggested strong within-panel serial correlation. This finding was not surprising given changes in deer management strategies and harvest rates may not immediately influence deer populations. For each specification, then, the error term, $\varepsilon_{c,t}$, was assumed to follow a first-order autoregressive structure characterized as:

$$\varepsilon_{c,t} = \rho \varepsilon_{c,t-1} + \eta_{it}, \tag{3}$$

where $|\rho| < 1$, and η_{it} is independent and identically distributed with zero mean and variance σ_n^2. We estimated ρ using a consistent one-step estimator (Durbin-Watson estimator) defined as:

Table 1. Estimated Coefficients on Factors Influencing DVCs

Variable	Mean	Description	Specification[a] A	Specification[a] B	Specification[a] C
Intercept			40.51*** (10.07)	-4.35 (10.72)	9.73 (10.92)
VEHROAD[b]	66.32	Number of registered vehicles per number of road miles by county and year	0.051** (0.023)	0.08*** (0.02)	0.051** (0.022)
$BHSQM_{t-1}$	0.814	Buck-gun harvest per square mile by county and year	52.14*** (5.00)	57.32*** (4.80)	50.78*** (4.96)
$DHSQM_{t-1}$	0.943	Doe-gun harvest per square mile by county and year	-18.06*** (2.79)	-20.29*** (2.82)	-20.06*** (2.80)
BAG_{t-1}	1.28	Bag limit by county and year (w/range of 1 to 3)	9.36*** (2.43)	10.59*** (2.47)	10.63*** (2.45)
$BODAYS_{t-1}$	2.77	Number of buck-only days by county and year (w/range of 0 to 6)	-1.57*** (0.51)	-1.86*** (0.52)	-1.87*** (0.527)
MSA[c]	0.423	Equal to 1 if county was listed as part of a metropolitan statistical area, otherwise 0	35.99*** (5.08)	39.51*** (4.80)	35.94*** (4.63)
FARMLAND	178	Acres of farmland (in 000s) by county and year	-0.019 (0.039)	—	-0.238*** (0.047)
FARMNUM	982	Number of farms by county and year	—	0.034*** (0.008)	0.064*** (0.009)
$PERMITS_{t-1}$[d]	325,335	Statewide number of deer hunting permits sold by year	0.0002*** (0.00002)	0.0002*** (0.00002)	0.0002*** (0.00002)
Sample Size (*n*)			1,848	1,848	1,848
Wald Statistic			1,158.03	1,302.01	1,380.70

Notes: The panel data set is from 1977–1998 across 88 counties. Coefficients are estimated using feasible GLS assuming a panel-specific AR(1) process. Single, double, and triple asterisks (*) denote significance at the 10%, 5%, and 1% levels, respectively. Numbers in parentheses are standard errors.

[a] Specification columns A, B, and C are defined as follows: column A includes the habitat variable *FARMLAND*; column B includes the habitat variable *FARMNUM*; and column C includes both of these habitat variables.

[b] *VEHROAD* includes federal, state, and local road miles in both urban and rural areas, but does not include urban road miles that are listed in metropolitan cities.

[c] *MSA* covers three distinct U.S. Censuses from 1977 to 1998.

[d] Annual statewide estimate for $PERMITS_{t-1}$ assumes hunters are not restricted to hunt in the county from which the permit was purchased.

$$\rho_{dw} = 1 - dw/2, \tag{4}$$

where dw is the Durbin-Watson d statistic. The data were then transformed using a procedure given in Baltagi and Wu which removes the AR(1) process. Because the results from assuming a panel-specific AR(1) process consistently outperformed those assuming a common AR(1) process across panels, only the former are presented. Finally, a likelihood-ratio test for heteroskedasticity resulted in rejecting the null hypothesis of a constant variance across panels (LR = 514.58). This result is not unexpected given the potential for variation across counties due to size differences.[3]

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[3] A variety of other specifications and tests were performed. For instance, an OLS estimator for both fixed- and random-effects specification was evaluated, yet performed quite poorly relative to the FGLS estimator. An AR(2) process also was evaluated using the FGLS estimator. Comparisons of the AR(2) and AR(1) results suggest the former added no additional explanatory power beyond that provided by the latter. Furthermore, the coefficient on the AR(2) disturbance term was statistically insignificant in the presence of the AR(1) disturbance term. Results from these tests and specifications are available from the authors upon request.

In general, the signs and statistical significance are consistent across the three specifications, as shown in table 1. The positive sign on *VEHROAD* is in accordance with our expectations. The coefficient on *MSA*, one of our habitat variables, illustrates the positive impact on DVCs of locations with more commuting and business developments. The statistical insignificance of *FARMLAND* in column A suggests perhaps the amount of farmland within a county is not a driving factor influencing DVCs. From columns B and C, and recognizing the positive and statistically significant sign on *FARMNUM*, we might infer the more fragmented a county (possibly represented by more farms), the more likely a deer's cropland foraging habits would require it to traverse roadways. Finally, based on the statistically significant and opposite signs on *FARMLAND* and *FARMNUM* in column C, and holding the number of farms constant, an increase in cropland results in fewer DVCs. This interpretation is consistent with Hubbard, Danielson, and Schmitz, who found large crop fields tend to be associated with lower incidences of DVCs.

The signs on the harvest rate and management strategy variables (table 1) may at first seem arbitrary, but consider the following. The ODNR's deer management scheme has been quite consistent with respect to allowable buck harvest, essentially permitting one per hunter annually. Yet, ODNR has been increasingly aggressive in its population management strategies to control deer populations by targeting doe populations. It is well established that effective schemes for controlling deer populations rest with controlling the female population size (Allen and McCullough; Guynn 1985). Thus, observed changes in the doe harvest likely capture changes in future populations, whereas observed changes in the buck harvest, accounting for hunting regulation changes, likely track changes in current (male) deer populations.

With this in mind, one can expect that as deer populations grow to a level beyond what is desired by the ODNR, wildlife managers will be expected to increase the allowable bag limit. Consequently, the coefficient on bag limit (*BAG*) reflects the response by ODNR to increasing population pressures. A similar argument can be made for the positive sign on *PERMITS*. Alternatively, while changing the number of days a hunter is allowed to target a buck only (*BODAYS*) may not be as effective in managing populations, it does have a statistically significant negative impact on DVCs (table 1).

Another interesting component in table 1 is the relative magnitudes of the coefficients. While the signs on buck-gun harvest (*BHSQM*) and doe-gun harvest (*DHSQM*) differ, for example, the marginal impact of a buck on incidences of DVCs is greater than the marginal impact of a doe. Such an outcome is possibly explained by the fact that the month with the highest occurrences of DVCs is November, which is the peak of the white-tailed deer breeding in Ohio. Further, these results seem in line with research showing individual male white-tailed deer travel more, and consequently cross roads more frequently than individual females (Feldhamer et al.).[4] With respect to management strategies, the relative magnitudes of the coefficients on *BAG* are larger than those on *BODAYS*, again with different signs. These findings support the notion that changes in deer populations are better achieved by targeting doe populations rather than buck populations.

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[4] While research by Feldhamer et al. suggests nearly twice as many does are involved in DVCs as bucks, the authors also emphasize the dependence of this statistic on the sex ratio of the population.

The information gleaned from these regressions has value from both a general and a specific perspective. From a general perspective, and as detailed in the proceeding discussion, these results provide a clearer picture as to how variables such as population size, vehicle density, harvest regulations, and land coverage can affect DVCs. More specifically, the coefficient on *BHSQM* provides a reasonable starting point for estimating the DVC rate for bucks, which is employed in a simulation analysis below.

Costs of DVCs

The costs of DVCs in Ohio have not yet been mentioned. Obviously, the costs per accident depend on a number of factors, including size of deer, type of vehicle, speed of vehicle, and insurance rates. While economic data related to DVCs are limited, the ODPS does maintain statistics on the number of DVCs. ODPS collects DVC statistics on both the seriousness and dollar value of each crash based on the National Highway Traffic Safety Administration's (NHTSA's) 1991 estimates of the average cost per accident (ODPS 2000).

These estimates are categorized according to the reported seriousness of the accident (death, serious injury, mild injury, or claimed injury). Average cost estimates per accident are then assigned to each category.[5] According to ODPS, a total of 143,016 DVCs were reported from 1990–1998. Of these reported accidents, there were 14 human fatalities, suggesting an approximate 0.01% probability of death. Of those accidents having some type of injury, 247 (0.17%) resulted in serious injuries, 3,844 (2.7%) in mild injuries, and 6,892 (4.82%) in claimed injuries. Finally, there were 132,019 (92.3%) accidents which resulted in no claim injuries.

Table 2 lists the number of occurrences, cost per occurrence, and expected costs for each category of accident associated with reported DVCs in Ohio from 1990 to 1998. The expected cost of each category is simply the probability of that category occurring, given an accident, times the cost per category as designated by NHTSA. The NHTSA-assigned cost estimate associated with the mortality component is approximately $2.4 million, $170,000 for a serious injury, $33,000 for a mild injury, and $17,000 for a claimed injury. Of the total number of reported DVCs (143,016), 132,019 did not fall into any of those injury categories. These non-injury DVCs are given a cost estimate of $150 each, which is the minimum amount of damages required for a DVC to be reported.

While most, if not all, reported accidents from DVCs since 1977 have resulted in at least $150 in costs (Hollingsworth), the $150 estimate is used by ODPS and is acknowledged to be a lower bound on the costs associated with reported DVCs not resulting in injury. Multiplying the cost estimates by their respective probabilities and summing gives an average expected DVC cost estimate of approximately $2,376. This estimate is similar to those reported in the literature (e.g., Conover et al.).

It should be noted that while the cost categories are not specific to accidents associated with DVCs, there is no evidence to suggest a reported serious or mild injury from a DVC should differ greatly from a reported serious or mild injury sustained in some other type of vehicle accident. The next section combines this information on costs with estimates of a few simple relationships between DVCs and harvest rates in order to evaluate the impacts of DVCs on alternative deer management strategies.

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[5] These estimates account for wage and productivity losses, medical expenses, administrative expenses (which include insurance, police, and legal costs), vehicle damage, employer losses for accidents to workers, and also a measure of the value of lost quality of life associated with the deaths and injuries.

Table 2. Ohio Deer-Vehicle Accident Rates and Costs, 1990–1998

	Accident Rates[a]		Cost per Event	
Accident Category	Percent of Accidents (%)	Actual No. of Occurrences	Actual Cost ($)	Expected Cost ($)
Mortality	0.01	14	2,393,000	239
Serious	0.17	247	170,000	289
Mild	2.70	3,844	33,000	891
Claimed	4.82	6,892	17,000	819
Reported	92.30	132,019	150	138
Total	100%	143,016		2,376

Source: Data derived from Ohio Department of Public Safety (2000).

[a] Based on a total of 143,016 reported deer-vehicle accidents.

Simulating Changes in DVCs with a Dynamic Population Model

Methods

There are two practical means for reducing the incidence of DVCs in a given area: use of DVC mitigation practices, and reduction of the population of deer through changes in hunting regulations. Both DVCs and harvest depend on the dynamics of deer population growth, and this growth, in turn, depends on DVCs and harvest.

The dynamic interactions between harvest, DVCs, and the population of white-tailed deer in Ohio are modeled with a set of ordinary differential equations (ODEs) which can be numerically solved. As harvest mortality and DVC rates are quite different for the three principal population cohorts of the deer population (bucks, adult males; does, adult females; and fawns, juvenile deer), the growth and mortality of each cohort are modeled separately.[6] The effects of changes in DVCs and hunting regulations on the size and growth of these cohorts are simulated through parameter restrictions on the ODEs. Consequences of these changes can then be evaluated by comparing the characteristics of the ODE solutions before and after the regulatory change.

Annual growth of an exploited deer population over time will be a function of the natural growth rate and both hunting and nonhunting mortality. Because natural growth of the deer population is also subject to constraints imposed by characteristics of the environment, we assume the annual natural growth of the population follows a logistic pattern subject to daily harvest and DVC mortality. Logistic natural growth in a particular area c can be described by the first term in each of the following differential equations:[7]

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[6] A full population model might be a more realistic representation of the true dynamics of deer population growth. Yet because rates of harvest and vehicle mortality vary by age and gender, such a model would not permit us to analyze the cohort-specific effects of changes in hunting policy and deer mitigation strategies.

[7] Logistic growth is a modification of standard exponential growth, and is commonly employed in modeling natural populations. The characteristic S-shape of the logistic function reflects the fact that due to crowding and limitations on natural resources, exponential growth cannot continue indefinitely. At the beginning of the logistic curve, where population size is relatively small and the carrying capacity constraint is not binding, growth approximates exponential growth. As population increases and the carrying capacity is approached, growth begins to saturate (Luenberger). Within the deer population biology literature, there is precedence for the logistic. For instance, White and Bartman employ a logistic growth function to describe the survival function of mule deer. Furthermore, McCullough found growth of the George Reserve white-tailed deer herd resembled a logistic growth pattern.

$$dB_c/dt = b_{Bc}B_c(1 - B_c/k_{Bc}) - h_{Bc}B_c - v_{Bc}B_c; \tag{5}$$

$$dD_c/dt = b_{Dc}D_c(1 - D_c/k_{Dc}) - h_{Dc}D_c - v_{Dc}D_c, \tag{6}$$

where B and D represent the respective sizes of the buck and doe populations, lowercase b is the intrinsic natural growth rate of each of the populations, and k is the carrying capacity of the environment. From this logistic growth, hunting mortality (at rate h times the population size) and vehicle mortality (at rate v times the population size) are subtracted. The fawn population is modeled as a simple function of the equilibrium doe population, based on the number of fawns each doe recruits annually:

$$F_c = 1.2D_c. \tag{7}$$

Fawn population size is adjusted by subtracting both harvest (h_F) and DVC mortality (v_F) rates for fawns.

Given values for the four parameters of each differential equation, and for the fawn harvest and DVC rates, it is possible to solve these equations for the equilibrium or steady-state population sizes by setting each of the ordinary differential equations equal to zero. Unfortunately, limited information is available on the intrinsic natural growth rates, DVC mortality rates, and harvest rates for does and fawns. However, we do have annual harvest estimates for all cohorts, the harvest rate for bucks, and the ratios of does-to-bucks (1.6:1) and fawns-to-does (1.2:1). Reasonable ranges for total population carrying capacities associated with different locations within the state have also been acquired.

To obtain the DVC rate for bucks, the coefficient on buck-harvest per square mile from column C in table 1 is transformed to the total number of "live bucks" per square mile using a well accepted estimate of the annual harvest rate for bucks, 0.63. The resulting estimate (31.99) is then divided by the area of Athens County (508 square miles) to obtain a value for v_B of 0.063.[8] This parameter can be interpreted as follows: for every 1,000 bucks in Athens County, there are an additional 63 DVCs. Conversely, 6.3% of the buck population is lost to DVCs. Based on discussions with ODNR researchers and the literature associated with nonhunting mortality for does and fawns (Van Deelen et al.; Bashore, Tzilkowski, and Bellis; Ballard et al.), a DVC rate for does and fawns of 0.04 is assumed.

Combining the actual harvest numbers for each cohort, the harvest rate for bucks, and the assumed cohort ratios, we solve for the size of each cohort population. The harvest rates for does and fawns can then be calculated by dividing each cohort's actual harvest numbers by their respective population estimates. Hence, using various estimation procedures and expert opinion, estimates are identified of the current size of each cohort population, and all of the parameters in the model specified in equations (5), (6), and (7) (except for the intrinsic growth rates, b_B and b_D).

Further, by assuming deer populations are stable, equations (5) and (6) each have only one unknown, b_B and b_D, respectively. Both b_B and b_D are used as the calibration parameters; the ODEs are solved for the growth rates that allow the current stable

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[8] Specifically, the coefficient on *BHSQM* (the change in DVCs for a change in buck harvest per square mile) is transformed into the expected change in DVCs for a change in buck population. Other than providing support for the policy analysis below, this is the only link between the regression analysis in the earlier part of the study and the simulations conducted here.

Table 3. Starting Values for the Simulations: Athens and Williams Counties, Ohio (1996)

	Athens County			Williams County		
Description	Buck	Doe	Fawn	Buck	Doe	Fawn
k (carrying capacity)[a]	3,805–4,756	6,089–7,611	7,307–9,133	1,394–1,947	2,230–3,115	2,676–3,738
d (DVC rate)	0.063	0.04	0.04	0.076	0.04	0.04
h (harvest rate)	0.63	0.22	0.22	0.63	0.22	0.22
Initial population stock	2,297	3,550	4,260	779	1,263	1,516
B (intrinsic growth rate)[b]	1.34–1.75	0.49–0.62	NA	1.18–1.60	0.44–0.60	NA
Initial harvest estimate	1,447	781	937	491	278	334
Initial DVC estimate	145	142	170	59	51	61

[a] Lower and upper bounds.

[b] Due to the relationship between carrying capacity and growth rate for a given population size, a larger growth rate is associated with a lower carrying capacity.

population to equal the estimate of the current deer population. Because ODNR has been aggressive in recent years in its management strategies aimed at stabilizing deer populations, it is reasonable to assume each population is in equilibrium. Finally, rather than deriving a single growth estimate, each equation is calibrated using a lower and upper bound on the cohort carrying capacities provided by ODNR.[9] The starting values for the parameters of the ODEs, and the initial values for the cohort population sizes and number of deer harvested and killed by DVCs, are reported in table 3 for two representative Ohio counties, Athens and Williams (described in further detail in the following section).

Calibration

To simulate the effects of changes in the incidences of DVCs on deer population size and harvest, our model is first calibrated such that the equilibrium population size matches the estimated size of the current population of bucks in each county. In Athens County, for example, the buck population in 1996 was estimated to be approximately 2,300 by using a buck-harvest rate (h_B) of 0.63 and a reported harvest of 1,447 bucks. Assuming a stable population, 2,300 bucks translate into 3,550 does and 4,260 fawns using the above-noted cohort ratios. We therefore estimate that the total population of deer in Athens County was approximately 10,100 deer.[10] The carrying capacity in the eastern part of the state is between 35 and 43 deer per square mile. Hence, given the size of the county, the estimated carrying capacity for Athens County is between 17,200 and 21,500 deer. In order to use this value in the cohort model, these ranges for the population carrying capacities are divided into cohort-specific carrying capacities applying the ratios identified above.

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[9] For a given stock size, a higher carrying capacity yields a lower value for the growth rate; hence the value of the growth rate which calibrates the system to our estimates of current population sizes will necessarily be lower for the upper bound on the range of carrying capacity. Moreover, because removal of bucks through harvest and DVCs is significantly larger than for does, the growth rate which calibrates the buck equation will be larger than the corresponding doe growth rate.

[10] Conversations with Ohio Department of Natural Resources officials concerning these population estimates give us added confidence these numbers are very reasonable approximations.

After solving for the intrinsic natural growth rate that calibrates the model to the estimated population sizes, the effects on deer population size and harvest from various policies intended to reduce DVCs can be simulated. The three DVC-reducing policy scenarios simulated are: (*a*) use of DVC mitigation techniques, (*b*) changes in hunting regulations, and (*c*) a combination of DVC mitigation techniques and changes in hunting regulations.

The subsequent changes in population, harvest, and DVCs under each scenario are then evaluated in monetary terms using the expected cost estimates of DVCs and a $180 estimate for the value of a deer to hunters. This $180 value, which is based on hunter behavior in Ohio and estimated from a random utility modeling framework (Schwabe et al.), captures the consumptive value to hunters of increasing the deer herd by an additional deer.

Finally, rather than evaluate all 88 counties in Ohio, our analysis is limited to two representative counties—Athens County in eastern Ohio and Williams County in western Ohio. Geographically, western Ohio counties are more agricultural with flat terrain, while eastern Ohio counties are more forested and hilly. The results of each simulation, presented in tables 4 and 5, are listed for each cohort type and for both the upper and lower bounds on each county's carrying capacity.

Simulations

We begin our simulations by evaluating the impact on hunter welfare and the social costs associated with DVCs from installing a particular DVC mitigation strategy. The mitigation strategy is assumed to achieve an 85% reduction in the DVC rate, a percentage many experts feel Z-clip fencing can achieve (Romin; Neve). As illustrated in table 4 for Athens County and at current harvest rates, an 85% reduction in the DVC rate results in an increase in equilibrium deer populations of between 847 and 1,357 deer, where the lower (higher) value corresponds to the lower (higher) carrying capacity bound. This greater population size, in turn, leads to greater harvests of between 234 and 376 deer. Specifically, an 85% reduction in the rate of DVCs leads to an additional harvest of 74 to 119 bucks, 73 to 117 does, and 87 to 140 fawns. Implementing this strategy also translates into approximately 383 fewer DVCs in Athens County annually, with 122, 119, and 142 fewer accidents involving bucks, does, and fawns, respectively.

Transforming these changes into monetary terms by using the estimates of $180 for the value of a deer and $2,372 for the cost of a DVC, table 5 (option 1) suggests the increased harvests and decreased DVCs result in between $948,200 and $976,200 in additional benefits for Athens County. The additional benefits are comprised of between $42,100 and $67,700 in welfare gains to hunters and between $906,100 and $908,500 in cost savings from fewer DVCs.[11] Based on these results, strategies reducing DVCs in Athens County that can be implemented at a cost of $948,200 or less per 85% reduction in DVCs may be welfare enhancing.

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[11] Changes in deer populations are likely to lead to changes in the size of the deer harvested, as suggested by Guynn (1982). Also, while we do not differentiate here between the value of a buck, doe, or fawn, acknowledging such differences may have potentially large impacts on the overall benefits estimate.

Table 4. Biological Results of Simulations: Lower and Upper Bounds

	Athens County			Williams County		
Description	Buck	Doe	Fawn	Buck	Doe	Fawn
OPTION 1: 85% Decrease in DVC Rate						
▸ Change in stock	117, 189	332, 531	398, 637	57, 107	127, 242	152, 290
▸ Change in harvest	74, 119	73, 117	87, 140	35, 67	28, 53	33, 63
▸ Change in DVCs	-122	-119	-141, -142	-49	-42, -43	-50, -51
OPTION 2: 7.7% Increase in Harvest Rate						
▸ Change in stock	-106, -172	-166, -264	-199, -317	-42, -81	-63, -121	-76, -146
▸ Change in harvest	-5, 39	-3, 33	-3, 25	-17, 9	-7, 6	-9, 7
▸ Change in DVCs	-7, -11	-7, -11	-8, -12	-3, -6	-3, -5	-3, -6
OPTION 3:[a] Combination Policy						
▸ Change in stock	11, 18	166, 267	199, 320	14, 26	64, 121	76, 145
▸ Change in harvest	119, 124	100, 123	120, 148	47, 55	36, 50	43, 60
▸ Change in DVCs	-123	-119, -120	-143	-50	-43	-51

Note: Each pair of numbers represents lower and upper bounds corresponding to lower and upper bounds on carrying capacity.

[a] Includes both Options 1 and 2.

Table 5. Additional Benefits from DVC Reductions Based on Simulation Results (1996 dollars)

	Athens County		Williams County	
Description	Lower Bound	Upper Bound	Lower Bound	Upper Bound
	<----------	($)	----------	---------->
OPTION 1: 85% Decrease in DVC Rate				
▸ Change in stock	42,100	67,700	17,300	32,900
▸ Change in harvest	-906,100	-908,500	-334,500	-339,200
▸ Change in DVCs	948,200	976,200	351,800	372,100
OPTION 2: 7.7% Increase in Harvest Rate				
▸ Change in stock	-2,000	17,500	-5,900	4,000
▸ Change in harvest	-52,200	-80,600	-21,300	-40,300
▸ Change in DVCs	50,200	98,100	15,400	44,300
OPTION 3:[a] Combination Policy				
▸ Change in stock	61,000	71,100	22,700	29,700
▸ Change in harvest	-913,200	-915,600	-341,600	-341,600
▸ Change in DVCs	974,200	986,700	364,300	371,300

Note: Dollar values are rounded to nearest 100.

[a] Includes both Options 1 and 2.

Because deer populations differ markedly across the state, the effects of a given percentage reduction in DVCs will vary across counties. For example, results for Athens County (in eastern Ohio) contrast with those for Williams County (in western Ohio). Using Williams County's DVC-to-buck ratio of 0.076, a different range of carrying capacities, and the same assumptions regarding doe and fawn harvest and DVC rates as in Athens County (table 3), an 85% reduction in the DVC rate (option 1) will result in the opportunity to harvest an additional 35 to 67 bucks, 28 to 53 does, and 33 to 63 fawns (table 4). There would be approximately 142 fewer deer-vehicle accidents. Using the same value and cost estimates, table 5 suggests strategies reducing DVCs in Williams County that can be implemented at a cost of $351,800 or less per 85% reduction in DVCs may be welfare enhancing.

Finally, note that simulating rates other than the 85% reduction would provide a broader picture of the potential gains from alternative DVC mitigation strategies. For the purposes of this research, however, a single rate is sufficient to illustrate the potential gains, to both hunters and drivers alike, from implementing DVC mitigation techniques.

Given the signs and significance of the coefficients on the population proxy variables in the regression analysis above, a logical alternative to initiating DVC mitigation strategies is to alter the hunting regulations. Specifically, higher hunting pressure will decrease the size of the deer population and lead to fewer DVCs. This could be accomplished either by increasing the length of the deer hunting season or issuing more deer hunting permits.

For illustrative purposes, we examine the hypothetical policy change of increasing the length of the Ohio deer-hunting season by one day. By extending the deer hunting season from its current length of 13 days to 14 days, hunters are assumed to consider the longer season as an opportunity to increase the number of hunting trips rather than substitute trips across days. Hence, this one-day increase could result in up to a 7.7% increase in the deer harvest rate—i.e., if the average daily hunting pressure realized during a 13-day season continues onto the 14th day, there will be a 7.7% increase in the rate at which deer are harvested. In both counties, such a change leads to an unambiguous decrease in steady-state population, yet has an ambiguous effect on total harvest, depending on whether the lower or upper bound on carrying capacity is assumed.

Specifically, in Athens County, a 7.7% increase in harvest (table 4, option 2) results in the equilibrium deer population falling by between 471 and 753 deer. The latter value corresponds to the higher carrying capacity value, and leads to an increase in harvest of approximately 97 deer and a decrease in DVCs by 34 accidents. The smaller carrying capacity value results in a decrease in harvest by 11 deer and a reduction in DVCs by 22 accidents.

Although an increase in the harvest rate resulting in fewer deer being harvested may at first seem counterintuitive, the higher rate of removal produces a lower steady-state population size. Hence, while the percentage of the population removed is higher, the population size by which this percentage is multiplied to produce total harvested quantities is sufficiently smaller, thereby resulting in an overall decrease in total harvest. Allowing for higher harvest rates therefore may or may not increase hunter welfare. Yet in all cases, these higher harvest rates produce a lower equilibrium population and, correspondingly, fewer DVCs. In economic terms, the net effect in Athens County from the change in harvest rates is a gain of between $50,200 and $98,100 (table 5).

In Williams County, a higher harvest rate (table 4) decreases deer harvests by as many as 33 deer (17 bucks, 7 does, and 9 fawns) for the lower-bound carrying capacity, or increases harvests by as much as 22 deer (9 bucks, 6 does, and 7 fawns) for the upper-bound carrying capacity. Between 9 and 17 fewer DVCs occur. These changes lead to a net gain of between $15,400 and $44,300 (table 5).

Clearly, the desirability of such a policy change will likely depend on the relative sizes of the potential losses to hunters and gains to society from fewer DVCs, which, as illustrated in our example, can vary across counties. In addition to extending the length of the deer season, other hunting regulations, such as bag limits, could be changed to allow for higher harvest rates. While focusing on a single policy change illustrates the potential importance of using population management strategies as a tool to reduce DVCs, it should be emphasized that other management strategies will likely produce different outcomes.

Finally, the effects of a combined policy are simulated in which both hunting regulations and DVC mitigation practices are included. The same values employed in the individual simulations (an 85% reduction in the likelihood of a DVC and a 7.7% increase in harvest rates) are used. This combined policy (table 4, option 3) results in between 339 and 395 additional deer harvested in Athens County, and between 126 and 165 additional deer harvested in Williams County. With this combination policy, there will be approximately 385 fewer DVCs in Athens County, with a corresponding DVC reduction in Williams County of 144.

In monetary terms, the increased benefits to hunters and decreased social cost to drivers lead to a gain of at least $974,200 in Athens County and $364,300 in Williams County (table 5). Clearly, this combined policy results in higher overall benefits than either policy alone. Yet, cost estimates must be considered to satisfy any net benefit criteria.

While the results of these simulations depend critically on the assumed growth functions, the accuracy of our calibrations, and the assumed harvest and mortality rates for bucks, does, and fawns, some general conclusions can be formed:

- First, effective mitigation strategies may provide substantial benefits to vehicle drivers and hunters alike. Of course, the benefits of implementing any mitigation strategy must be weighed against the costs of implementation.

- Second, changing hunting regulations is another means of reducing DVCs with added potential benefit to hunters from greater harvests. While the benefits of changing population size seem modest when compared to implementing some type of DVC mitigation strategy, the costs of implementation are likely to be more modest as well. Furthermore, changing population size does not fully account for the uncertainty surrounding the potential effectiveness of many DVC mitigation strategies.

- Finally, the combination of implementing a DVC mitigation strategy and changing population size via hunting regulations is shown to offer the largest potential benefits. Again, however, judgments as to the efficiency of this strategy relative to the other strategies must be deferred until implementation and maintenance costs are introduced.

Conclusion

Losses from the over 700,000 reported DVCs per year nationally have been estimated in excess of $1 billion. Reported DVCs of over 20,000 annually are not uncommon for states such as Pennsylvania, Michigan, Wisconsin, and Ohio, and DVCs have recently exceeded 57,000 per year in New York. Unfortunately, current trends in the incidences of DVCs suggest losses are likely to increase. The focus of this study is on Ohio, with roughly 26,000 DVCs occurring annually. These deer-vehicle collisions are responsible for losses three times greater than the revenue generated from Ohio's sale of hunting licenses and deer permits combined. The results of our investigation suggest factors such as deer population size, traffic volume, and type of hunting regulation significantly influence the incidences of DVCs.

Using aggregate county-level data, trends in vehicle registration and buck-gun harvest per square mile are positively correlated with DVCs and, based on econometric estimates from panel data, are quite robust. Furthermore, after accounting for changes in bag limits across counties and over time, doe-gun harvests per square mile prove to be negatively correlated with DVCs. These results are not surprising in light of the Ohio Department of Natural Resources' policy of managing populations by changes in allowable doe harvest while leaving buck harvest management schemes relatively untouched.

Optimal deer management may require adjustments to deer population when human-deer conflicts arise, suggesting information on the marginal impact of a buck on DVCs is of greater value than the marginal impact of a doe. Based on simulation results, desired short-term responses in DVCs may be best achieved by targeting buck populations, while longer-term objectives will more likely be met by targeting doe populations. Although more agricultural land does not appear to lead to higher incidences of DVCs, there is a positive association between the number of farms and the incidence of DVCs while holding farm acreage constant.

After investigating the relationships among deer populations, deer management strategies, and DVCs, the potential biological and economic implications of various strategies to reduce DVCs were analyzed. While reducing deer populations may likely lead to fewer DVCs, steady-state populations may decline as well, resulting in a negative impact on hunter welfare. The potential welfare impacts of implementing effective DVC mitigation strategies look promising, yet the controversy surrounding the potential effectiveness of many of these strategies warrants additional attention. Simulation results suggest a combination of the two strategies may be a more attractive option than either independently. That is, establishing effective DVC mitigation strategies coupled with deer management strategies would provide benefits to vehicle drivers and hunters alike.

While our analysis did not include the costs of implementing and maintaining the mitigation strategies or hunting regulations, the magnitude of the benefits estimates may indicate whether the potential gains from a particular policy are large enough to warrant further consideration. And although the specific results of the simulations may be largely contingent upon the choice of strategies, using the same methods to evaluate other means of reducing DVCs seems relatively straightforward. Given the apparent lack of research systematically investigating both the benefits and the costs of alternative strategies for reducing DVCs, our preliminary results may illustrate the potential gains from continued research into how best to manage deer populations and mitigate DVCs.

Based on the very predictable patterns of white-tailed deer movement, the strong correlation between proxies of traffic volume and incidences of DVCs, and the large potential benefits from reducing the rate at which DVCs occur, public awareness campaigns designed to educate drivers about these characteristics would appear to be one strategy deserving of additional attention.

Finally, many state wildlife agencies propose to manage deer populations based on the net benefits associated with maintaining a particular herd size. Educating the public about the wide array of consumptive and nonconsumptive benefits associated with deer may make them more willing to bear the costs associated with larger deer herds (Curtis and Lynch; Decker, Loconti-Lee, and Connelly; Stout et al.).

[*Received June 2001; final revision received April 2002.*]

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