# Use of roadside deer removal to reduce deer–vehicle collisions

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**Abstract:** Identification of management tools to reduce the incidence of deer–vehicle collisions (DVCs) is important to improve motorist safety. Sharpshooting to reduce white-tailed deer (*Odocoileus virginianus*; deer) along roads has proven successful in urban situations but has not been evaluated in undeveloped areas. We used a before-after-control-impact (BACI) design to evaluate the use of sharpshooting to reduce DVCs along roads on the uninhabited U.S. Department of Energy's Savannah River Site, South Carolina, USA, during 2011–2017. We removed 242 deer from 4 treatment roads during 2015 and 2016, with 2-year removal rates per road averaging 5.0 deer/km of road (range 4.0–5.8). We monitored accident rates as DVCs per million vehicle-km traveled (VKT) during annual cycles (March–February) following the initial removal and during the 7 months (March–September) following removals in spring and the 5 months (October–February) following removals in fall. The response in accident rates varied among the annual cycle, spring, and fall. The BACI effect indicated that removal treatments reduced accident rate by 1.184 DVCs per million VKT (*P* = 0.081) over the annual cycle and by 1.528 DVCs per million VKT (*P* = 0.023) following spring removals, but following fall removals we detected no effect (*P* = 0.541). Relative to the pre-removal accident rate for removal roads, the estimated treatment effect on an annual basis equated to a 39.4% reduction in accidents and during spring equated to a 50.8% reduction in accidents. We conclude that sharpshooting along roads in undeveloped areas can be a viable tool to reduce DVCs and can be useful in areas where population control via hunter harvest is not practical or desirable.

**Key words:** control, deer–vehicle collision, *Odocoileus virginianus*, sharpshooting, South Carolina, traffic volume, white-tailed deer

**Deer–vehicle collisions** (DVCs) are one of the most important and direct sources of human–wildlife conflict in the United States, resulting in an average vehicle repair cost of $1,840 and a total estimated cost per collision of $8,388 nationwide (Huijser et al. 2008). Consequently, efforts to understand, predict, and reduce DVCs have engendered considerable research. Methods used to reduce the incidence of DVCs include fencing, efforts to modify both deer and driver behavior, and reducing deer numbers along roadways. Upon reviewing the literature on the mitigation techniques, Mastro et al. (2008) concluded that deer-proof fencing with wildlife crossings was most effective but is limited by cost and is not always appropriate.

Research on white-tailed deer (*Odocoileus virginianus*; deer; Figure 1) social behavior suggests that targeted removal of matriarchal social groups can be an effective means of dealing with localized nuisance deer problems (Porter et al. 1991). The approach, known as localized management, was conceived for use in the context of browse damage to regenerating timber (Campbell et al. 2004, Oyer and Porter 2004, Miller et al. 2010), but Comer (2005)

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**Figure 1.** A female white-tailed deer (*Odocoileus virginianus*) stands on the edge of a right-of-way on the Savannah River Site, South Carolina, USA (*photo courtesy of J. Kilgo*).
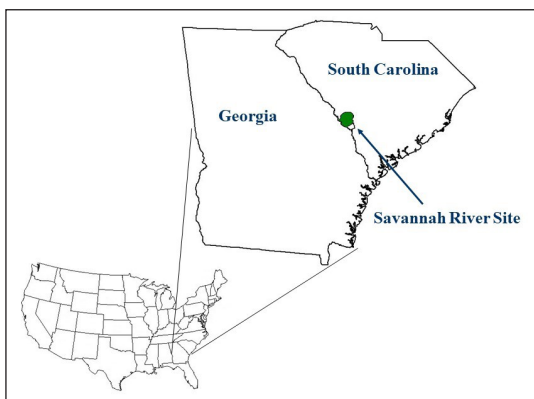


**Figure 2.** Location of the Savannah River Site, South Carolina, USA.

suggested that localized removal strategies along roadways may reduce DVCs. Irrespective of social dynamics, certain individual deer have been shown to make especially heavy use of rights-of-way and therefore likely pose a greater risk for DVCs. Working along a stretch of Interstate 20 in Georgia, USA, Stickles (2014) reported that some deer were frequent users of the right-of-way, spending as much as 26% of their time within the right-of-way, and therefore suggested that targeted removal of deer may reduce risk of collisions.

Limited research has examined the potential for targeted removal, or sharpshooting, to reduce DVCs. In urban areas of Iowa, New Jersey, and Ohio, USA, DeNicola and Williams (2008) reported that sharpshooting removal resulted in reductions in DVCs of 49%, 75%, and 78%, respectively. Similarly, in Bloomington,

Minnesota, USA, sharpshooting combined with other control methods reduced deer density by 46% and DVCs by 30% (Doerr et al. 2001). However, to our knowledge, no research has reported the efficacy of sharpshooting to reduce DVCs in undeveloped, non-urban areas. Comer (2005) conducted a removal study along 4 such roadways in South Carolina, USA, concluding that deer density was reduced along the targeted roadways but not reporting the effect on DVCs. If sharpshooting reduces deer population size in an area and DVCs are a function of population size, then sharpshooting would be expected to reduce DVCs. However, research on the relationship between numbers of DVCs and deer population size has yielded conflicting results: some studies have found that DVCs were related to deer density (Gkritza et al. 2010, Muller et al. 2014, Hothorn et al. 2015) or deer harvest level (as an index of population size; McCaffery 1973, Grovenburg et al. 2008), whereas others found no such relationship (Case 1978, McShea et al. 2008). Thus, the efficacy of sharpshooting as a means to reduce DVCs in undeveloped areas is unknown.

On the U.S. Department of Energy's Savannah River Site (SRS), approximately 100 white-tailed deer–vehicle collisions occurred annually from 1990–2014 (J. Kilgo, U.S. Forest Service, unpublished data). A deer hunt program conducted from 1965 to the present at SRS controls deer population size and is assumed, in turn, to limit the number of DVCs (Johns and Kilgo 2005). However, the relationship between site-wide deer population size and the number of DVCs on SRS was statistically weak, accounting for only 34% of the variability in the number of collisions per year (Johns and Kilgo 2005). Fewer accidents tended to occur when population size was very low, and somewhat more tended to occur when population size was very high, but considerable variability in accident numbers existed over the range of population size. Indeed, the size of the SRS workforce, as an approximate index of traffic volume on the site, accounted for more variability (42%) in collision number than deer population size (Johns and Kilgo 2005). Thus, alternative strategies to reduce collisions than site-wide hunts are desirable. Our objective was to evaluate whether sharpshooting removal of deer along SRS roadways was effective in reducing the number of DVCs. As a secondary

**Table 1.** Pre-removal accident rates (2011–2015) on road segments used to assess effectiveness of white-tailed deer (*Odocoileus virginianus*) removal in reducing deer–vehicle collisions (DVCs) at the Savannah River Site, South Carolina, USA.

| Treatment | Road ID[1] | Mean DVCs/yr | Length (km) | Rate (no./km/year) |
|---|---|---|---|---|
| Removal | T1 | 12.7 | 13.4 | 0.9 |
| | T2 | 7.0 | 13.8 | 0.5 |
| | T3 | 7.3 | 11.1 | 0.7 |
| | T4 | 13.7 | 10.6 | 1.3 |
| Control | C1 | 6.0 | 11.1 | 0.5 |
| | C2 | 9.0 | 10.6 | 0.8 |
| | C3 | 13.0 | 16.9 | 0.8 |
| | C4 | 10.3 | 13.0 | 0.8 |

[1]Road identification numer. T indicates treatment (deer removal); C indicates control.

objective, we quantified the effect of traffic volume on DVCs.

## Study area

We conducted the study on the SRS, a 78,000-ha National Environmental Research Park in the Upper Coastal Plain of South Carolina (Figure 2). Industrial facilities are localized within the interior of the site and occupy only 8% of the area. No human habitation exists, but >10,000 workers commute daily to the facilities. The landscape of the SRS is dominated by loblolly pine (*Pinus taeda*) and longleaf pine (*P. palustris*) forests, managed on 50–100-year or 120-year rotations, respectively. Floodplains of the Savannah River and its major tributaries support bottomland hardwood and cypress (*Taxodium distichum*)-tupelo (*Nyssa aquatic* and *N. sylvatica* var. *biflora*) forests. Road and utility right-of-way vegetation is managed by mowing, prescribed fire, and herbicide, with most road rights-of-way being mowed at least annually.

The SRS deer population has been managed since 1965 to maintain a low density (4–8 deer/km²) to minimize risk of DVCs. Dog-drive hunts were conducted during November–December, with most units hunted 1 day per season. Typically, 2 hunt units totaling an average of 3,684 ha in size were hunted per day with an average of 52 dog packs (5 dogs per pack) and 171 hunters from 2007–2012. Bag limits for most hunts were historically unlimited for either sex, but since 2006 limits (1 male and 1 female) were imposed during most hunts due to depressed

recruitment. Annual harvest averaged 1,244 deer from 1980–1999, but from 2005–2016 it averaged 450 deer/year, or 1.5 deer/km². These harvest reductions were sufficient to offset depressed recruitment, and population density remained stable throughout this period (U.S. Department of Agriculture [USDA] Forest Service, unpublished data).

## Methods

From 2011–2017, DVCs on SRS were reported to a USDA Forest Service contractor by SRS law enforcement and by employees who observed deer carcasses on site roadways. For each collision, information collected included date, time, global positioning system (GPS) coordinates, and age and sex of the deer.

We used a before-after-control-impact (BACI) design to evaluate the effect of roadside deer removal on accident rates. We selected for study the 8 road segments on SRS with the greatest number of accidents per km, with accident rates ranging from 0.5–1.3/km/year (Table 1). Road segments were paved 2- to 4-lane roads with speed limits of 55 mph (88.51 kph) except around facilities and ranged in length from 10.6–16.9 km. Rights-of-way ranged from 20–35 m in width but were occasionally as great as 50 m wide where utility rights-of-way were adjacent. With an average length of 12.6 km, each study road bisected the dominant vegetation types of SRS. We randomly selected 4 segments for the removal treatment and used the remaining 4 segments as untreated

controls. Deer removal occurred on treated roads during spring (March) and fall (October–November) of 2015 and 2016. Thus, the pre-treatment collision monitoring period spanned 4 years (March 2011–February 2015) and the post-treatment period spanned 2 years (March 2015–February 2017). Although deer density likely varied somewhat across the SRS, it was uniformly low, and we feel that the length of our road segments and their replication in our design minimized any bias that may have been introduced by such variation.

We removed deer by sharpshooting from a vehicle on the treatment roads using high-powered, center-fire rifles (7mm-08 and 7mm SAUM) with the aid of artificial light or a thermal imaging scope. We distributed removal effort evenly among treatment roads. We conducted spring removals for 10 nights between March 1 and 24 and fall removals for 6 nights between October 11 and November 13. Deer were more active along roadways during these periods, respectively, due to spring green-up and the rut, the latter of which peaked at SRS during late October through early November. For each deer removed, we noted date, time, age, sex, and GPS coordinates. Deer carcasses were delivered to a processor who packaged the meat for a food bank for distribution to local charities. We conducted deer removal under South Carolina Department of Natural Resources Research Collection Permit Number 0112315-01.

To assess traffic volume on each study road, we placed vehicle counters (TRAFx Gen III, TRAFx Research Ltd, Canmore, Alberta, Canada) on both lanes at each end of the road and on both sides of intersections. Using the length of each road segment, this arrangement allowed us to determine average daily number of vehicle-km travelled (VKT) for each road. We deployed counters from January 2015–January 2016. The size of the SRS workforce during the 6 years of study averaged 11,564 (range 10,292–12,757) and varied by only 10.7%, so we assumed that average daily VKT during the year we monitored was a representative index of the study period as a whole. Because only 4% of DVCs occurred between 1000 and 1600 hours, we excluded traffic during these hours in calculating VKT.

To assess the effect of traffic volume on DVCs, we used simple linear regression with individual roads as observations, average daily VKT as the independent variable, and the 4-year total of DVCs during the pre-treatment period as the dependent variable. In addition to our 8 study roads, we included accident and traffic data for 3 additional roads that were comparable in length ($n = 11$).

To assess the effect of the removal treatment on DVCs, we used accident rate as the response, calculated as number of DVCs per million VKT, to standardize rates on each road by traffic volume. We conducted 3 analyses evaluating treatment response: during annual cycles (March–February), following spring treatments (during March–September), and following fall treatments (during October–February). For each analysis, we used a 2-factor mixed model analysis of variance (PROC MIXED; SAS Institute [2011]) with the fixed effects being periods (pre- and post-treatment), treatments (removal and control), and the period*treatment interaction. Random effects included year within period, road within treatment, and year*road within period*treatment. We considered years and roads a random sample of years and roads, and hence random effects, resulting in the year*road within period*treatment interaction being random also, thereby extending the inference to a larger population of years and roads. We used the Kenward-Roger approximation to determine denominator degrees of freedom (SAS Institute 2011). Although period and treatment were the main factors, we were interested in whether there was a change due to deer removal after controlling for other fluctuations unrelated to removal. We refer to this change as the BACI effect, which we tested using the period*treatment interaction in the model. We interpret this effect as the differential change between the control (post–pre) and the removal (post–pre), with small values indicating no impact and large values indicating impact, as assessed using the *F*-statistic for the interaction from the ANOVA. We used a contrast estimate that defined this period*treatment interaction to determine the size of the BACI effect (± standard error).

## Results

During the 4-year pre-treatment period, 347 DVCs were reported on the 11 roads used to assess the relationship between DVCs and
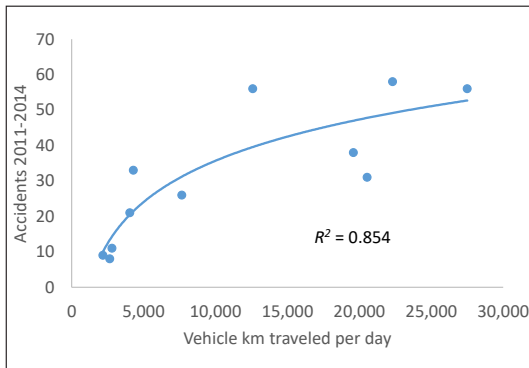
**Figure 3.** Relationship between total number of deer–vehicle collisions and average number of vehicle-km traveled per day (excluding 1000–1600 hours) on 11 road segments at the Savannah River Site, South Carolina, USA, 2011–2014.

**Table 2.** Numbers of white-tailed deer (*Odocoileus virginianus*) removed by year, season, and road segment at the Savannah River Site, South Carolina, USA, March 2015–October 2016.

| Year | Road segment | Spring[a] | Fall[b] | Total |
|------|-------------|--------|------|-------|
| 2015 | T1 | 21 | 8 | 29 |
| | T2 | 33 | 5 | 38 |
| | T3 | 30 | 15 | 42 |
| | T4 | 27 | 18 | 45 |
| | Total | 111 | 43 | 154 |
| 2016 | T1 | 20 | 5 | 25 |
| | T2 | 19 | 5 | 24 |
| | T3 | 16 | 6 | 22 |
| | T4 | 15 | 2 | 17 |
| | Total | 70 | 18 | 88 |

[a] March 1–24
[b] October 11–November 13

traffic volume. Average daily VKT on these roads ranged from 2,163–27,498 and averaged 11,461. Number of DVCs were positively related to VKT per day (excluding 1000–1600 hours; $R^2$ = 0.854; $P < 0.001$; Figure 3). We removed 242 deer from the 4 treatment roads during 2015 and 2016 (Table 2), with more removed during 2015 (154) than 2016 (88) and more removed during spring (181) than during fall (61). Two-year removal rates per road averaged 5.0 deer/km of road (range 4.0–5.8).

The response in accident rates (DVCs per million VKT) to the deer removal treatments varied among the annual cycle, the period following spring removal, and the period following fall removal (Table 3). Accidents were lower during the post-treatment than pre-treatment period for annual, spring, and fall analyses, whereas accident rates did not differ between treatments for any analysis (Tables 3 and 4). However, on an annual basis, the BACI effect indicated that removal treatment reduced accident rate by 1.184 DVCs per million VKT ($P = 0.081$; Table 3), which (given average traffic volume on the 4 treatment roads of 21,214,530 VKT) translates to 25.1 accidents prevented on these roads per year. Following spring removals, the BACI effect indicated that accident rate was reduced by 1.528 DVCs per million VKT ($P = 0.023$; Table 3), but following fall removals we detected no period*treatment interaction ($P = 0.541$; Table 3). The reduction following spring removals of 1.528 DVCs per million VKT translates to 19.0 accidents prevented on these roads per spring season (i.e., following spring removal, March–September). Relative to the pre-removal accident rate for removal roads, the estimated treatment effect on an annual basis equated to a 39.4% reduction in accidents (1.184 [BACI effect] / 3.005 [pre-removal rate]) and during spring equated to a 50.8% reduction in accidents (1.528 [BACI effect] / 3.007 [pre-removal rate]).

## Discussion

Sharpshooting removal of deer from roadways in the forested landscape of the SRS was effective at reducing DVCs. Accident rates generally were lower during the post-treatment period than during pre-treatment on both treated and control roads but more so on the treated roads as evidenced by the size of the BACI effect, except during fall. Sharpshooting has been shown to reduce DVCs in suburban landscapes (Doerr et al. 2001, DeNicola and Williams 2008), but we are not aware of studies evaluating it in undeveloped areas where hunter harvest and other factors are typically relied upon for population control. Because most such areas are recreationally hunted for white-tailed deer, goals for deer population control could conflict with hunters' management goals for the resource. In addition, sharpshooting for deer control in many undeveloped areas may be problematic due to the far greater extent of such areas relative to urban areas. However, in undeveloped situations with heavy traffic

**Table 3.** Results of analysis of variance comparing accidents rates before and after removal treatment and on treated (removal) and control roads annually (March–February) and following spring (March–September) and fall (October–February) removal on the Savannah River Site, South Carolina, USA, 2011–2017. The Period*Treatment interaction term is the test for the before-after-control-intervention effect (i.e., the treatment effect after controlling for time period [pre vs. post]).

| Season | Effect | $F$ | df | $P$ |
|--------|--------|-----|-----|-----|
| Annual | Period | 21.23 | 1,38 | <0.001 |
| | Treatment | 0.48 | 1,6.3 | 0.514 |
| | Period*Treatment | 3.21 | 1,38 | 0.081 |
| Spring | Period | 13.54 | 1,4 | 0.021 |
| | Treatment | 0.83 | 1,6.2 | 0.396 |
| | Period*Treatment | 5.67 | 1,34 | 0.023 |
| Fall | Period | 9.67 | 1,38 | 0.004 |
| | Treatment | 0.04 | 1,6.6 | 0.853 |
| | Period*Treatment | 0.38 | 1,38 | 0.541 |

**Table 4.** Least squares means and standard errors (SE) for accident rates (deer–vehicle collisions / million vehicle-km traveled) before (2011–2014) and after (2015–2016) removal treatment annually (March–February) and following spring (March–September) and fall (October–February) removal, along with the estimate and SE and for the treatment effect after controlling for time period (before-after-control-intervention [BACI] effect) on 8 study roads on the Savannah River Site, South Carolina, USA.

| Season | Treatment | Estimate | | | | BACI effect | |
|--------|-----------|--------|-----|-------|-----|----------|-----|
| | | Before | SE | After | SE | Estimate | SE |
| Annual | | | | | | | |
| | Removal | 3.005 | 0.507 | 0.891 | 0.575 | 1.184 | 0.661 |
| | Control | 1.935 | 0.507 | 1.005 | 0.575 | | |
| Spring | | | | | | | |
| | Removal | 3.007 | 0.568 | 0.887 | 0.634 | 1.528 | 0.642 |
| | Control | 1.543 | 0.568 | 0.950 | 0.634 | | |
| Fall | | | | | | | |
| | Removal | 3.001 | 0.639 | 0.897 | 0.788 | 0.697 | 1.129 |
| | Control | 2.490 | 0.639 | 1.083 | 0.788 | | |

loads, we showed that sharpshooting can be an effective tool to reduce DVCs. This may be particularly helpful in areas where hunting is not possible or desirable, such as parks and protected areas.

Rates of DVCs were more effectively reduced during spring than during fall, likely due to changes in deer behavior and their food resources through the annual cycle. The SRS landscape is predominantly closed-canopy forest, with relatively little grass-forb or early successional habitat. The wide rights-of-way along roads contain abundant herbaceous browse, especially during spring when vegetation there greens up early due to the lack of canopy cover. Road rights-of-way provide a highly desirable but limited resource during spring for deer whose home range includes a right-of-way, and they forage there nightly (J. Kilgo, U.S. Forest Service, unpublished data), thus increasing the risk of DVC. In contrast, during fall when roadside vegetation has senesced, deer tend to forage more in forested areas, focusing on acorns and soft mast, thus spending less time foraging in rights-of-way. However, their movements are more erratic and

extensive during fall due to breeding activity, particularly males, which accounted for 68% of DVCs during October–December of the study (J. Kilgo, U.S. Forest Service, unpublished data). Because males travel greater distances in search of females during the fall, many DVCs on our study roads likely involved male deer from beyond the area of influence of the sharpshooting treatment.

We expect, given the reproductive potential of white-tailed deer, that periodic (e.g., every 2–4 years) follow-up removal may be necessary to maintain deer density near roadways at levels low enough to keep DVCs to a minimum. However, such low densities may in some situations be maintained through recreational hunting. In our study area, for example, deer population growth rate is slow due to high levels of predation on neonates (Kilgo et al. 2012), which renders even moderate levels of hunter harvest capable of controlling the population. During the year following the end of our study (i.e., March 2017–February 2018, a period that extended 16 months after the last removal during October 2016), DVCs remained low for all 4 treated roads, averaging only 52% of pre-removal levels.

## Management implications

We found that sharpshooting along roads in undeveloped areas reduced DVCs. Thus, this tool can be useful in areas where population control via hunter harvest is not practical or desirable. In addition to the direct removal of deer from the vicinity of roadways, we suspect that the indirect effect of sharpshooting on resident deer that were not removed had a beneficial effect on DVCs (i.e., sharpshooting effectively hazed deer from using road rights-of-way, especially when vehicles approached). Over time, this effect is likely to diminish as deer again become comfortable near roads and as naïve deer are recruited to the area.

## Acknowledgments

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