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Examining patterns of animal–vehicle collisions in Alabama, USA

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Abstract: Animal–vehicle collisions (AVCs) cause animal death, human injury, and vehicle damage. Uncovering the general patterns and related ecological processes of AVCs is useful for developing mitigation strategies. We examined some previous patterns about AVCs from records in Alabama during 2001 to 2011. The results confirm that: (1) there was a seasonal pattern, with >50% of AVCs occurring in winter; (2) AVCs occurred most frequently at dawn and dusk in the diurnal pattern; and (3) most AVCs occurred on county highways. However, interstate and federal highways had higher numbers of AVCs per km of road. Counties within metropolitan areas had more AVCs. We analyzed 1,000 AVC cases selected at random from the all reported cases and found that 74% of AVCs had forested landscapes on both sides the road. At the county level, AVCs occurred more frequently in areas with greater human population density and less frequently in areas with few roads. The implications for mitigating human–wildlife conflict are provided based on a system view of vehicles, roads, and animals.

Key words: Alabama, animal–vehicle collision, highway types, human–wildlife conflicts, metropolitan area, roadless area, spatial and temporal patterns

The number of road networks worldwide for the transportation of people and goods is increasing. Roads have negative effects on wildlife, such as causing habitat loss, fragmentation, and collisions with vehicles. For example, about 1 to 2 million mammal–vehicle collisions occur annually in North America, resulting in >200 human fatalities and >$1 billion dollars in property damage (Romin and Bissonette 1996, Huijser et al. 2009). In a large part of the world ungulate–vehicle collisions constitute a widespread and increasing problem (Bruinderink and Hazebroek 1996, Conover 1997, Rolandsen et al. 2011). In Norway, for example, the annual number of ungulate–vehicle collisions with fatal outcomes for the animal increased from about 500 cases per year in the early 1970s to about 7,000 cases per year in 2010 (Solberg et al. 2009). However, ungulate–vehicle collisions comprise only part of animal–vehicle collisions (AVC). The extent and degree to which wildlife and humans (or vehicles) can coexist over a sustained time period is a critical issue in conservation science (Woodroffe et al. 2005). As an extreme example, Carter et al. (2012) indicated that humans and tigers (*Panthera tigris*) can share the same space at a small spatial scale at Chitwan National Park in Nepal due to different times of space usage. Previous research documented that the number of AVCs is related to animal-crossing frequency, traffic volume, and driving conditions (Bruinderink and Hazebroek 1996; Seiler 2004, 2005). From a landscape ecology perspective, animal-crossing frequency may be related to habitat, food resource, or human disturbances (such as hunting). If a highway cuts through an animal's habitat patches or its corridors, then the animal frequently needs to cross the highway to move between different habitat patches. Meek (2012) indicated that road-kills of amphibians in the Vendée region of western France had a strong temporal aspect and were also significantly higher on roads bordered by woodland or wetlands. Previous studies indicated that deer–vehicle collisions (DVCs) are related to time, season, local vegetation or landscape (e.g., Iverson and Iverson 1999, Hussain et al. 2007), animal populations, and road and traffic condition (e.g., Bruinderink and Hazebroek 1996, Hubbard et al. 2000, Ng et al. 2008). If we want to discover or test some hypotheses about the patterns and possible processes of AVCs in a region, then, more case studies on road-kills from multiple species at local areas are needed.

Alabama is located between the southern foothills of the Appalachian Mountain Range and the Gulf of Mexico and includes 67 counties. Northern Alabama has a warm, humid, temperate climate, and the southern part of the state has a subtropical climate. Summers are hot and humid, with an average high temperature of around 33° C; winters are typified by a series of cold fronts. Regional rainfall varies from 150 to 162 cm in the northern part and 180 cm to 195 cm along the southern coast (Carter and Carter 1984). Forests cover about 70% of the state, according to data from Alabama Forestry Commission (<www.forestry.state.al.us>). Due to mild climate and heterogeneous landscape, Alabama has great diversity in tree species (Phillips 2006). After decades of restocking and management efforts, Alabama's white-tailed deer (*Odocoileus virginianus*) population was estimated at 1.75 million in the year 2000. Many areas in Alabama were overpopulated with deer for many years, although the annual deer harvest was about 300,000 to 500,000 (<www.outdooralabama.com>). Every year, there are hundreds of AVCs on Alabama roads, resulting in animal mortality and human injury. Thus, studying the patterns of AVCs based on existing records can be useful to improve transportation safety and animal conservation in Alabama. Hussain et al. (2007), for example, indicated that an engineering perspective is insufficient to address the issue of DVCs, and they explored the role of county characteristics (e.g., relative proportion of crop, forest and other land uses, vehicle density per road per km, status of county as metropolitan statistical area, and deer density) in influencing the pattern and incidence DVCs using county level data from 1994 to 2003 in Alabama. Their main findings included that: (1) most (80%) DVCs were in rural areas adjacent to large urban centers; (2) county highways accounted for 40% of all DVCs, while state highways accounted for 30%, federal highways, 20%, interstate highways, 6%, and municipal highways, 4%; and (3) DVC frequency was the highest at dawn (0500 to 0700 hours) and dusk (1700 to 2000 hours). In a given year, collision frequency was the highest from October to February. In Alabama, from 2000 to 2010, the human population increased about 7.5%, and the number of households increased 26%. It would be interesting to check whether the previous DVC patterns change or persist.

The specific objectives of this study include (1) determining whether there are any changes in the patterns detected by Hussain et al. (2007) based on recent data of all animals; (2) studying whether there are correlations between AVCs and environmental conditions, such as climate, surrounding environment, or human population to generate the quantitative relationships between AVCs and surrounding landscape, road network, air temperature, and human population; and (3) providing implications for human–wildlife interaction, road planning, transportation safety, and wildlife management in Alabama.

Materials and methods

We obtained data on the cumulative length of highways in Alabama, along with records of AVCs, from the Alabama Department of Transportation. All documented AVCs were caused by deer (>90%) and other large mammals (e.g., horses [*Equus caballus*] and wild pigs [*Sus scrofa*], but there was no detailed species information in the records. We know that most AVCs might not be reported if they did not involve human injury, property damage, or lead to an insurance issue. There were 30,693 records from January 2001 to December 2011. While the total number of AVCs was impossible to determine, existing records provided a baseline for AVCs in Alabama. Each record included information of crash identification number, type of animal (deer or other animals) involved, location, time, vehicle damage, and human injury. We selected 1,000 AVC cases at random from 1 to 30,693 generated by the random function in MATLAB software (The MathWorks Inc., Natick, Mass.). Based on case number and location information, the surrounding landscape condition (e.g., forest-woodland, agriculture, grassland, residential area, water, and urban land) around the crash spot was identified using Google Earth™, which was based on aerial photos taken in the 3 years prior to our study. The possible land use change along the highways from the time of aerial photos to the time of the accident is assumed to be limited and does not affect the overall results in this study. Because the concept of road density depends on spatial scales, we used the values of roadless volume (RV, km^3; Watts et al. 2007), an indicator of roadless area. A high RV means high roadless area or sparse

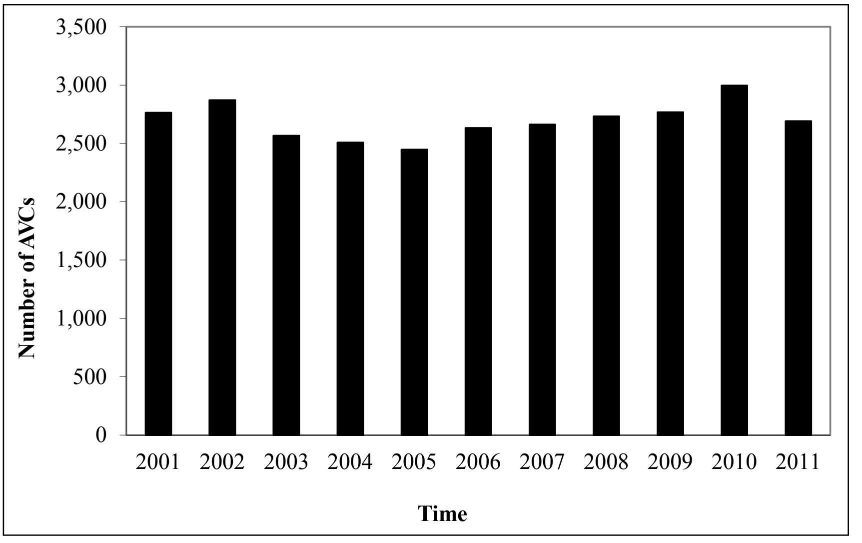

Figure 1. The annual number of animal–vehicle collisions (AVCs) in Alabama from 2001 to 2011.

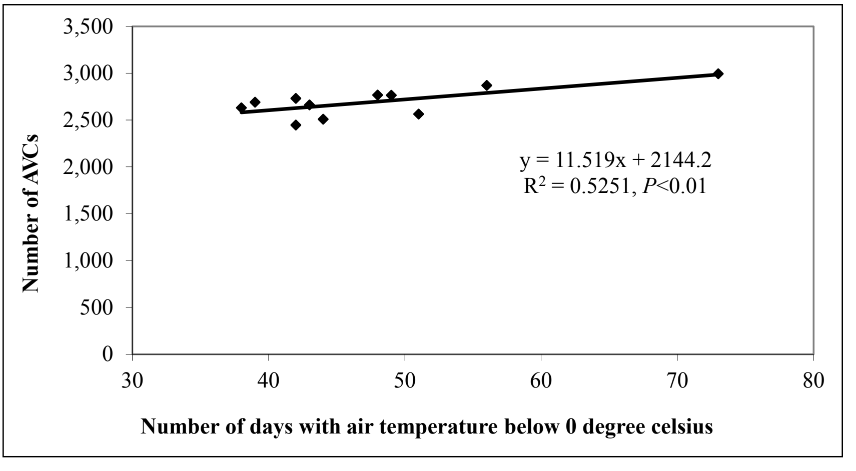

Figure 2. The correlation between annual AVCs in Alabama and the number of days with air temperature <0° C at Birmingham International Airport.

road networks. The RV was computed on square grids (each 30 m × 30 m), obtained from satellite images, as the total of the cell values of distance to the nearest road multiplied by cell area (see Watts et al. 2007 for details). With difference to roadless area, RV includes the distance to the nearest road. The average RV values of all 67 counties of Alabama were obtained from Watts et al. (2007). Chen and Roberts (2008) applied this index to study biodiversity and roads in Alabama.

Air temperature information at the Birmingham International Airport was used to reflect the entire state, because Birmingham, Alabama, is located near the geometric center of the state. The information of metropolitan areas in Alabama was based on U. S. Metropolitan Statistical Areas. For statistics method, we used the least-squares technique for correlation analysis and ANOVA for comparing annual rates of AVCs at different highways (SAS Institute Inc., Cary, N. C.). The test was considered significant at $P < 0.05$.

Results

Temporal patterns of AVCs

The average number of AVCs in Alabama from 2001 to 2011 was about 2,700 each year, or around 7 accidents each day (Figure 1). The annual number of AVCs varied little among years; most AVCs occurred in 2010 (approximately 3,000). The annual number of

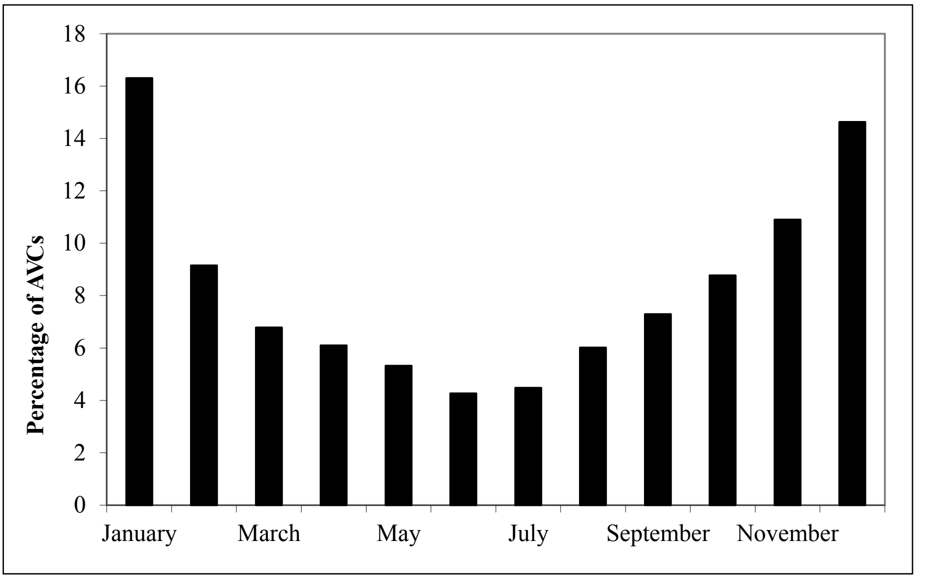

Figure 3. Seasonal patterns of AVCs in Alabama from 2001 to 2011.

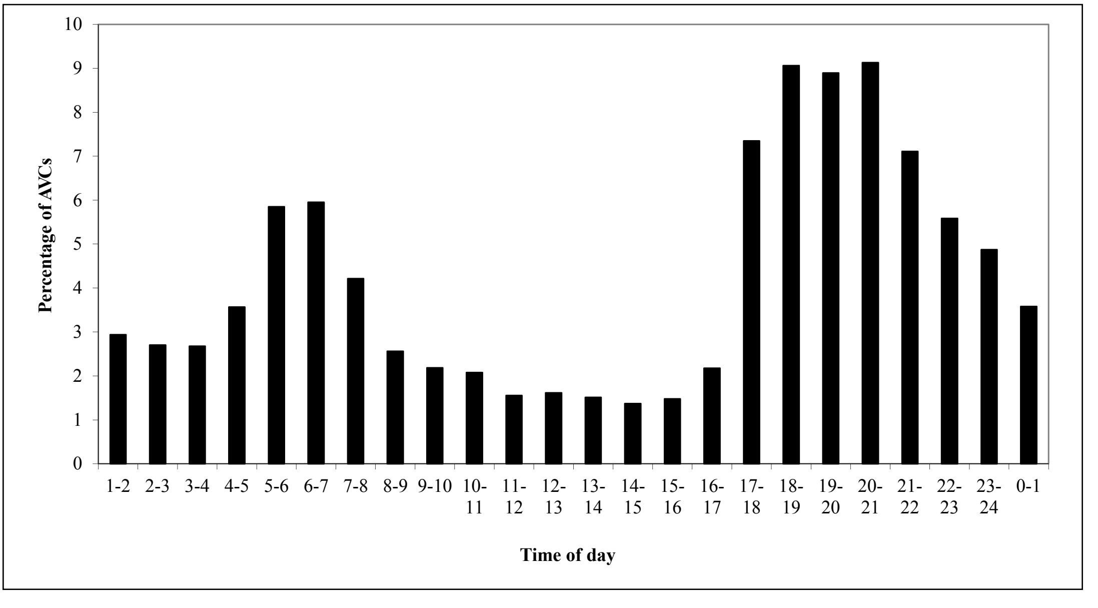

Figure 4. Diurnal patterns of AVCs in Alabama from 2001 to 2011.

AVCs had a significant positive correlation to the number of days with air temperature <0° C (df =10, $R^2 = 0.5351$, $P < 0.01$) at the Birmingham International Airport (Figure 2).

There was also a seasonal pattern of AVCs (Figure 3). Half of all AVCs occurred from November to February. The lower percentage of AVCs occurred in the summer. There were 2 daily peaks in the frequency of AVCs: at sunrise (0500 to 0700 hours) and after sunset (1700 to 2000 hours; Figure 4). There was a higher percentage of AVCs at night, and the lowest percentage occurred at noon.

Spatial patterns of AVCs

In Alabama, the highest percentage of AVCs occurred on county highways, accounting for 39% of all AVCs (Figure 5). State and federal highways ranked in the second and third in the percentage of AVCs, respectively. There were few AVCs on interstate and municipal highways. This pattern is also consistent with

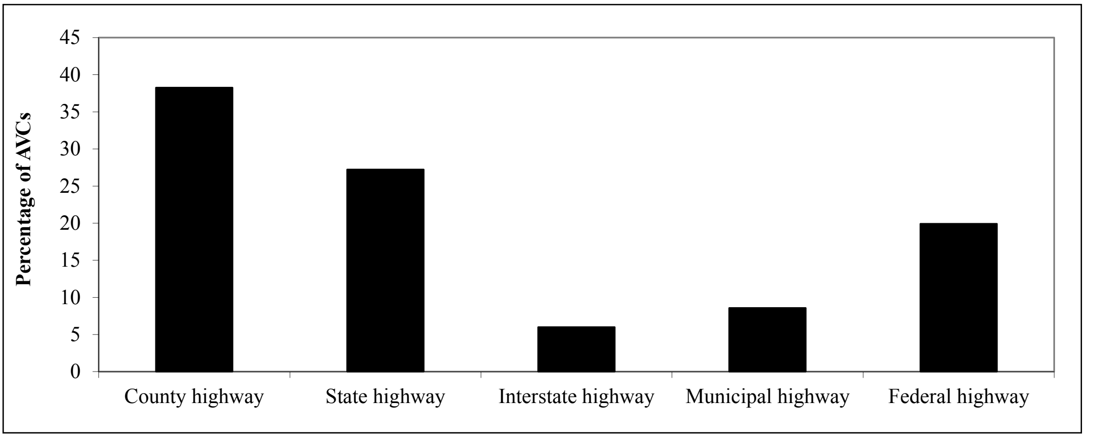

Figure 5. The percentages of AVCs on different types of highways in Alabama.

the result from Hussain et al. (2007). The statistical test for the average rates of annual AVCs on different highways was significant for each other (df = 10, $P < 0.01$). However, interstate highways had about 1.3 AVCs per km, federal highways had 1.0 cases, state highways had 0.5 cases, municipal highways had 0.27 cases, and county highways had 0.13 cases.

At the county level, those counties within metropolitan areas had higher percentages of AVCs than did rural areas (Figure 6). About 82% of counties in metropolitan areas had >500 cases of AVCs annually from 2001 to 2011. By analyzing 1,000 AVCs selected at random, we determined that about 74% of them had forest-forest landscape on both sides of the road (Figure 7); 11% of AVCs had forest on 1 side and agricultural land on the other; 9% had agricultural land on both sides; and 1% had 1 side agricultural land and the other side residential.

AVCs and environmental condition

At the county level, there was a positive relationship between human population and the number of AVCs (df = 66, $R^2 = 0.60$, $P < 0.05$; Figure 8). However, when the human population reached 300,000, the increase of AVCs began to taper off. This means that AVCs may be correlated

Figure 6. The counties with more than 500 occurrences of AVCs and the metropolitan areas in Alabama.

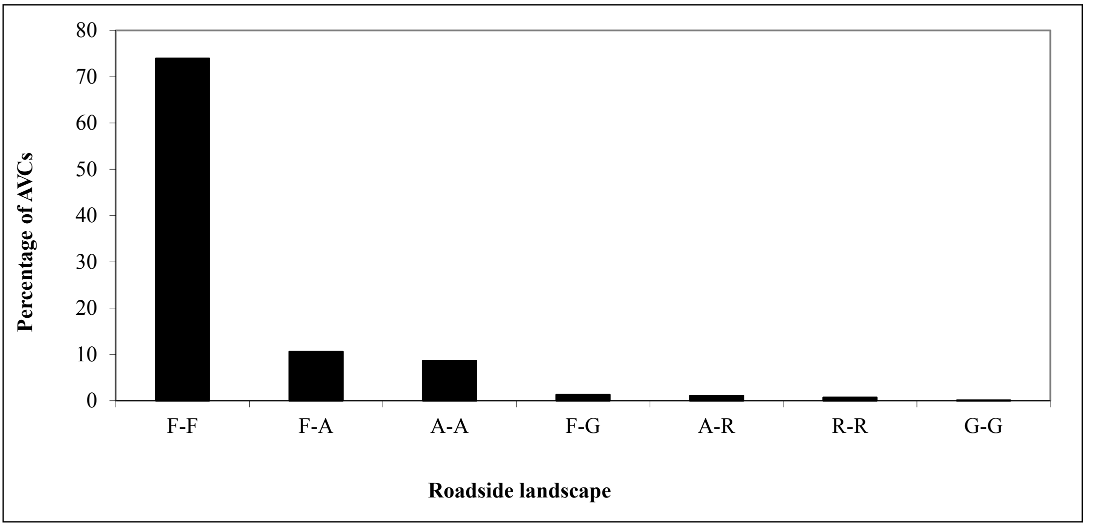

Figure 7. Roadside landscape and percentages of AVCs in Alabama (F = fores; A = agriculture; G = grassland; R = resident area).

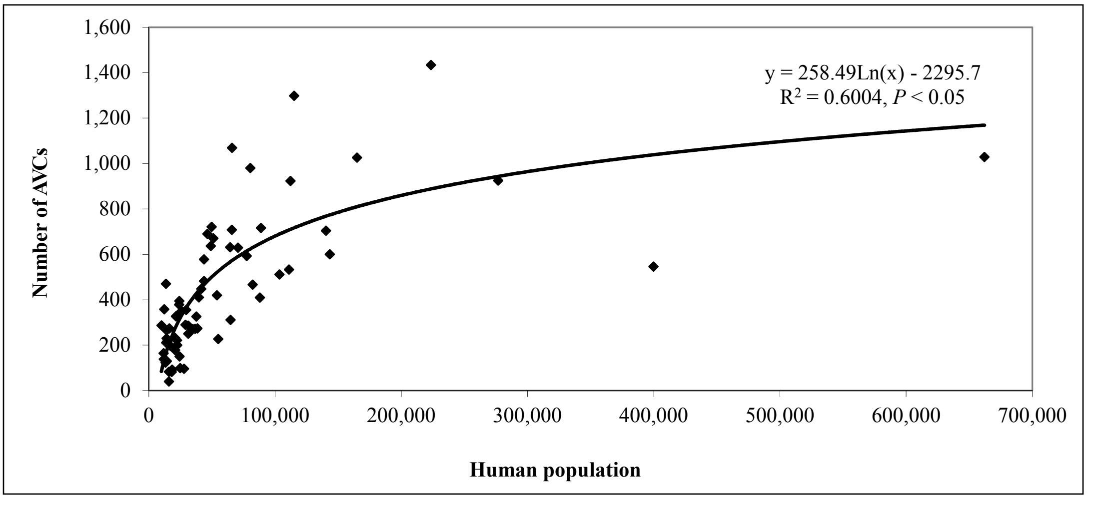

Figure 8. The relationship between human population and AVCs at the county level in Alabama.

with the traffic volume at a certain level. The direct relationship between RV and AVCs at the county level was not obvious. However, if counties with similar RV were grouped, then, there was a negative relationship between RV and the percentage of AVCs (Figure 9). This means that dense highway networks among counties had more AVCs.

Discussion

The annual occurrences of AVCs from 2001 to 2011 in Alabama were relatively stable (approximately 2,700). This number is very close to the average during 1994 to 2003, or 2,778 (Hussain et al. 2007). The trend of increasing AVCs was not obvious in Alabama, although human population and suburban areas have increased. This study also confirmed a similar seasonal and diurnal patterns of AVCs in Alabama to the findings of Hussain et al. (2007). During winter, there was a higher number of AVCs than during summer. Such negative effects of temperature on AVCs also was reported for moose (*Alces alces*)–vehicle collisions elsewhere (Anderson et al. 1991, Gundersen and Andreassen 1998, Rolandsen et al. 2011), and DVCs (Solberg et al. 2009). This pattern could result if deer are more active

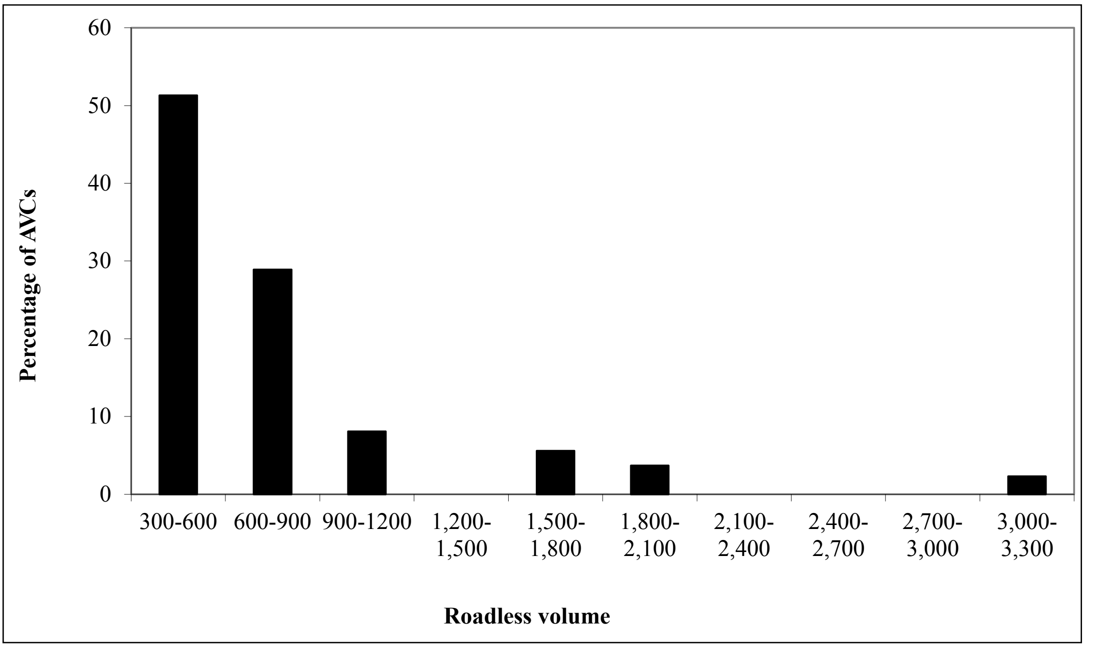

Figure 9. The relationship between pooled roadless volume and AVCs in counties of Alabama.

when temperatures drop. Other mechanisms may also exist, such as limited food resources in winter, so that animals have to search across a large area or because of rutting and human activities, such as hunting pressure (e.g., Hussain et al. 2007). Winter is coincident with the hunting season in Alabama. Further, visibility to drivers in winter usually is not as good as in warm seasons due to fog or snow, especially in early morning or late afternoon.

There were higher AVC occurrences at night than during the day. Diurnal pattern existed in AVC occurrences, especially at dusk and dawn. This pattern is also similar to what Hussain et al. (2007) reported. Many animals take advantage of the twilight to feed, seek out water, and engage in other behavior because they can hide from predators. Also, visibility for humans is challenging during these time periods.

The spatial patterns of AVCs may be related to animal habitat and to traffic conditions. More AVC cases occurred on county highways or highways with forest-woodlands on both sides of the road (or at least on 1 side) or within metropolitan areas. Most county highways in Alabama are 2-lane roads; Bashore et al. (1985) documented that more DVCs occurred on 2-lane roads. Interstate and federal highways had much higher DVCs per km because there are higher vehicle speeds and traffic volume on those highways than on county highways. The number of DVCs may indicate how to allocate mitigation resources and the DVCs per km and may lead to relative safety of a highway. Forests provide habitats for deer and wild pigs. When highways bisect forests, they may also split wildlife habitats and populations. Deer like to browse in open areas near forest or forest boundaries. Forests also present a visibility challenge to drivers at night. Mitigation actions, including wildlife fences combined with safe wildlife corridors and forest clearing on road shoulders, may help reduce AVCs. Grosman et al. (2009) predicted that the removal of salt pools from the edge of highways would result in an about 50% reduction of moose–vehicle collisions in Quebec, Canada. Constructing wildlife overpasses or underpasses at high-crossing points may be necessary for decreasing AVCs and also for wildlife conservation. After reviewing the effectiveness and cost of 13 measures for reducing collisions, Huijser et al. (2009) indicated that for many sections of road the monetary benefits of installing some mitigation measures exceeded their cost. Thus, actions that improve road safety both for humans and wildlife eventually save society money.

At the county level, the number of AVCs was positively correlated to human population, especially when human population reached around 300,000. Most people in Alabama live in metropolitan areas where there are high vehicle numbers and dense road networks. This may explain the patterns that (1) counties with higher AVCs (500 cases) were within metropolitan areas; and (2) higher AVCs occurred within counties with lower RV or dense road networks. Alabama's deer population is believed to have reached absolute carrying capacity, or overpopulation (<www.outdooralabama.com>). Managing deer (or other animal) populations may be 1 way to reduce AVCs. Acceptable animal population and control methods based on multiple determinants should be developed locally and regionally (Koichi et al. 2013, Urbanek et al. 2013).

Several general strategies can be employed to reduce AVC frequency, such as modifying driver behavior, modifying animal behavior, or reducing animal populations (e.g., Romin and Bissonette 1996, Danielson and Hubbard 1998, Curtis and Hedlund 2005). The results of this study may provide implications for reducing AVCs in Alabama based on spatial and temporal patterns. Fencing, including electrical fencing, may stop animals from using highways, although this method may be cost prohibitive. Drivers, in addition, should be notified often at locations where frequent AVCs occur. Drivers should be required to reduce their speed during dusk and dawn when deer are active, so that drivers may have enough response time to avoid AVCs. Deer and wild pig populations have to be reduced size for sustainability of the species and to minimize AVCs. Based on the number of annual DVCs, for example, it seemed that the current annual deer harvest rate (i.e., 300,000 to 500,000 per year) in comparison to the total population (around 1.75 million) is still not sufficient to significantly decrease the overall number of AVCs. Knowledge from landscape ecology has to be applied to road planning, construction, and management, because most AVCs occurred on roads with forest (or woodland) on 1 or both sides. Wildlife habitats and migration corridors should be considered for road planning to minimize AVCs. Because county highways had the higher percentage of AVCs, forests at roadsides may be cleared to a certain distance, such as 50 m or depending on the road condition. The connectivity between forests or vegetation at roadsides has to be decreased to reduce the connectivity of animal habitats. Otherwise, fencing has to be constructed at sites with frequent AVCs. The common practice of planting grasses on roadsides to prevent erosion needs to be modified because deer and other animals like to graze on such grasses. Finally, road agencies and conservation groups or researchers need to collaborate early in the planning stage. The effectiveness of mitigation action of reducing AVCs has to be monitored and evaluated (e.g., Romin and Bissonette 1996). Further research by modeling to examine human–wildlife interactions should be conducted (e.g., Finder et al. 1999, Meek 2012, Waldron et al. 2013).

Management objectives

Our study confirms previous results and provides new understanding about AVCs in Alabama by analyzing their spatial and temporal patterns from 2001 to 2011. These results will help reduce AVC occurrences from a system perspective with the consideration of drivers, vehicles, animals, roads, and landscape. Multiple mitigation practices should be conducted to reduce AVCs based on the patterns and underlying ecological processes. Continuous monitoring and analysis of the mechanisms of AVCs should be supported. For future road construction and planning, ecological knowledge should be included at the beginning.

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Literature cited

Anderson, R., B. Wiseth, P. H. Pedersen, and V. Jaren. 1991. Moose–train collisions: effects of environmental conditions. Alces 27:79–84.

Bashore, T. L., W. M. Tzilkowski, and E. D. Bellis. 1985. Analysis of deer–vehicle collision sites in Pennsylvania. Journal of Wildlife Management 49:769–774.

Bruinderink, G., and E. Hazebroek. 1996. Ungulate traffic collisions in Europe. Conservation Biology 10:1059–1067.

Carter, E. A., and V. G. S. Carter. 1984. Extreme weather history and climate atlas for Alabama. Strode Publishers, Huntsville, Alabama, USA.

Carter, N. H., B. K. Shrestha, J. B. Karki, N. M. B. Pradhan, and J. Liu. 2012. Coexistence between wildlife and humans at fine spatial scales. Proceeding of National Academy of Sciences USA 109:15360–15365.

Chen, X., and K. A. Roberts. 2008. Roadless areas and biodiversity: a case study in Alabama. Biodiversity and Conservation 17:2013–2022.

Conover, M. R. 1997. Monetary and intangible valuation of deer in the United States. Wildlife Society Bulletin 25:298–305.

Curtis, P. D., and J. H. Hedlund. 2005. Reducing deer–vehicle crashes. Wildlife damage management fact sheet series. Cornell University Cooperative Extension, Ithaca, New York, USA.

Danielson, B. J., and M. W. Hubbard. 1998. A literature review for assessing the status of current methods of reducing deer–vehicle collisions: a report for the task force on animal–vehicle collisions, Iowa Department of Transportation and Iowa Department of Natural Resources, Des Moines, Iowa, USA.

Finder, R. A., J. L. Roseberry, and A. Woolf. 1999. Site and landscape conditions at white-tailed deer/vehicle collision locations in Illinois. Landscape and Urban Planning 44:77–85.

Grosman, P. D., J. A. G. Jaeger, P. M. Biron, C. Dussault, and J.-P. Ouellet. 2009. Reducing moose–vehicle collisions through salt pool removal and displacement: an agent-based modelling approach. Ecology and Society 14:17.

Gundersen, H., and H. P. Andreassen. 1998. The risk of moose *Alces alces* collision: a predictive logistic model for moose–train accidents. Wildlife Biology 4:103–110.

Hubbard, M. W., B. J. Danielson, and R. A. Schmitz. 2000. Factors influencing the location of deer–vehicle accidents in Iowa. Journal of Wildlife Management 64:707–713.

Huijser, M. P., J. W. Duffield, A. P. Clevenger, R. J. Ament, and P. T. McGowen. 2009. Cost-benefit analyses of mitigation measures aimed at reducing collisions with large ungulates in the United States and Canada: a decision support tool. Ecology and Society 14:15.

Hussain, A., J. B. Armstrong, D. B. Brown, and J. Hogland. 2007. Land-use pattern, urbanization, and deer–vehicle collisions in Alabama. Human–Wildlife Conflicts 1:89–96.

Iverson, L. A., and L. R. Iverson. 1999. Spatial and temporal trends of deer harvest and deer–vehicle accidents in Ohio. Ohio Journal of Science 99:86–94.

Koichi, K., A. Cottrell, K. K. Sangha, and I. J. Gordon. 2013. What determines the acceptability of wildlife control methods? A case of feral pig management in the wet tropics world heritage area, Australia. Human Dimension of Wildlife 18:97–108.

Meek, R. 2012. Patterns of amphibian road-kills in the Vendée region of Western France. Herpetological Journal 22:51–58.

Ng, J. W., C. Nielson, and C. C. St. Clair. 2008. Landscape and traffic factors influencing deer-vehicle collisions in an urban environment. Human–Wildlife Conflicts 2:34–47.

Phillips, D. 2006. Discovering Alabama forests. University of Alabama Press, Tuscaloosa, Alabama, USA.

Putman, R. J. 1997. Deer and road traffic accidents: options for management. Journal of Environmental Management 51:43–57.

Rolandsen, C. M., E. J. Solberg, I. Herfindal, B. Van Moorter, and B.-E. Saether. 2011. Large-scale spatiotemporal variation in road mortality of moose: is it all about population density? Ecosphere 2, article 113.

Romin, L. A., and J. A. Bissonette. 1996. Deer–vehicle collisions: status of state monitoring activities and mitigation efforts. Wildlife Society Bulletin 24:276–283.

Seiler, A. 2004. Trends and spatial patterns in ungulate–vehicle collisions in Sweden. Wildlife Biology 10:301–313.

Seiler, A. 2005. Predicting locations of moose–vehicle collisions in Sweden. Journal of Applied Ecology 42:371–382.

Solberg, E. J., C. M. Rolandsen, I. Herfindal, and M. Heim. 2009. Moose and deer–vehicle accidents in Norway during the period 1970–2007. Norwegian Institute for Nature Research, Report 463, Trondheim, Norway.

Urbanek, R. E., C. K. Nielsen, M. A. Davenport, and B. D. Woodson. 2013. Determinants of public perceptions of suburban deer density. Human Dimension of Wildlife 18:82–96.

Waldron, J. L., S. M. Welch, J. Holloway, and T. A. Mousseau. 2013. Using occupancy models to examine human–wildlife interactions. Human Dimension of Wildlife 18:138–151.

Watts, P. D., R. W. Compton, J. H. McCammon, C. L. Rich, S. M. Wright, T. Owens, and D. S. Ouren. 2007. Roadless space of the conterminous United States. Science 316:736–738.

Woodroffe, R., S. Thirgood, and A. Rabinowitz. 2005. People and wildlife: conflict or coexistence*?* Cambridge University Press, New York, New York, USA.

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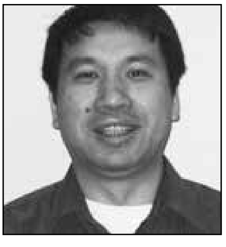

is interested in using field information (including field experiment and survey), ecological analysis and modeling, remote sensing and GIS, and integrated management for ecosystem services under climatic change and human activities.

Shuhong Wu is a professor at Beijing Forestry University. She is interested in environmental

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