Using Deer-vehicle Collisions to Map White-tailed Deer Breeding Activity in Georgia

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Abstract: The most commonly used method to determine the timing of breeding for white-tailed deer (*Odocoileus virginianus*) is to measure fetuses from deceased animals. However, this method is resource-intensive and can only provide data for limited geographic areas. Numerous studies have reported that deer-vehicle collisions (DVCs) increase during the breeding season due to increased deer movements associated with breeding activity. Based on these observations, we obtained records of DVCs in Georgia from 2005–2012 ($n = 45{,}811$) to determine when peaks in DVCs occurred for each county in Georgia. We compared the timing of DVC peaks with (1) conception data from three counties in Georgia, (2) deer movement data from a sample of GPS-instrumented male and female deer in Harris County, Georgia, and (3) a popularized 'rut map' for the state that was based on Georgia Department of Natural Resources fetal data as well as hunter observations. We observed high concurrence among timing of peak conception, peak rut movement, and peak DVCs. At the regional level, there were strong similarities between peak DVCs and peak rut. At the county level, peak DVCs were in general concordance with the popular rut map. However, the county-based map of DVCs appeared to provide greater local specificity. For assessing the timing of the breeding season at a county or regional scale, DVC data are cost effective and less susceptible to measurement biases compared to traditional methods employing fetal measurement. In addition, mapping the peak occurrences of DVCs can be used to warn motorists of increased risk associated with deer activity at the local level.

Key words: breeding, deer-vehicle collisions, rut, white-tailed deer

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In temperate environments above 30°N, white-tailed deer (*Odocoileus virginianus*) are seasonal breeders with reproduction governed by decreasing photoperiod (Lincoln 1992). Breeding and fawning seasons are shorter in duration in northern versus southern locations, which is an adaptation that mitigates seasonally limited food resources and improves fawn survival (Lincoln 1992). In the southeastern United States, where winters are milder and food is less restricted seasonally, breeding dates are more variable among deer herds. For example, in Florida, timing of breeding was as much as 6 months asynchronous among herds from four regions (Richter and Labisky 1985). Other southeastern states, including Georgia, have regions with distinct deer breeding dates, without obvious patterns relative to geographical features.

State and provincial wildlife agencies consider the timing of white-tailed deer breeding (hereafter, "rut") when scheduling hunting seasons because deer reproductive parameters can be affected by season structure (Gruver et al. 1984, Richter and Labisky 1985). In addition, during the rut, both male and female deer increase their daily movements (Kolodzinski et al. 2010, Karns et al. 2011), which could have a positive effect on hunter success. Unfortunately, measuring fetuses, which is the common method for estimating the peak and range of deer breeding dates, is labor intensive, costly, and subject to measurement error (Stone 2012). For this method, fetuses are collected from dead deer and measured to estimate date of conception (Hamilton et al. 1985). When only a few fetuses are collected from a location, they might not accurately represent the true distribution of breeding dates on a local or regional scale (Garrison et al. 2009). In addition, researchers often cannot rely on hunter-killed deer to provide an adequate sample because fetuses must be ≥35 days-old for accurate measurement (Hamilton et al. 1985), and deer hunting seasons often end before that stage of gestation (Stone 2012).

Deer killed as a result of deer-vehicle collisions (DVCs) can often provide important biological information. For example, samples

from road-killed deer can track variation in fecundity related to differences in range condition (Cheatum and Morton 1946, Cheatum and Severinghaus 1950). Deer-vehicle collisions typically increase dramatically coincident with peak breeding activity (Jahn 1959, Bellis and Graves 1971, Puglisi et al. 1974, Allen and McCullough 1976, Steiner et al. 2014). The number and location of DVCs also have been used as an index of deer population size (Jahn 1959) and was shown to be predictive of the number of bucks killed during the firearms hunting season (McCaffery 1973). Insurance companies, transportation departments, and law enforcement agencies have used DVC data to warn motorists of increased risk of DVCs both temporally and spatially (State Farm Insurance Company 2011, Wisconsin Department of Transportation 2012, Kentucky State Police 2013).

More than 1 million DVCs occur in the United States annually (Conover et al. 1995). About 50,000 DVCs occur annually in Georgia (Bowers et al. 2005), with Georgia ranking among the top 10 states for number of DVCs (State Farm Insurance Company 2011). Approximately 30%–45% of Georgia's DVCs occur during October through December, coincident with the breeding season. Similar concurrence of increased DVCs and the breeding season have been reported in Kentucky (Kentucky State Police 2013), Virginia (McShea et al. 2008), Alabama (Hussain et al. 2007), and Wisconsin (Sudharsan et al. 2006).

If seasonal differences in the frequency of DVCs are directly related to periods of increased deer movement during the rut, then DVCs should serve as an accurate index for timing of the rut. Therefore, we evaluated the timing of DVCs at the county level to assess the regional distribution of peak breeding occurrence across Georgia. We compared our estimates of peak breeding dates by examining the relationships among DVC data, seasonal deer movement data, fetal age data, and previously published region-specific estimates of deer breeding dates.

Study Area

This study encompasses all 159 counties within the state of Georgia. The northern-most portion of Georgia lies within the Blue Ridge and Ridge and Valley physiographic regions and is characterized by mountainous terrain and forested habitat. The middle section of the state falls within the Piedmont Region, an area of rolling hills supporting oak-hickory-pine forests and mixed deciduous forests. The southern half of Georgia includes the Upper and Lower Coastal Plains. This diverse region contains agricultural landscapes in the western region, extensive areas of loblolly pine (*Pinus taeda*) or mixed hardwood forest on well-drained soils, and slash pine (*Pinus elliottii*) forests on poorly drained flatwoods sites (The University of Georgia Museum of Natural History 2008).

We also monitored seasonal movements of GPS-collared deer on a privately-owned, 1,821 ha property in Harris County which is in the piedmont region of Georgia. Habitat consisted of a mixture of pine, pine-hardwoods, hardwood drainages, pasture, row crops, food plots, and other open areas. Loblolly pine stands comprised approximately 54% of the land cover. Hardwood stands occurred on approximately 32% of the study site and consisted primarily of oak/hickory forests. The remainder of this property consisted of hardwood drainages, tall fescue (*Schedonorus arundinaceus*) pastures, and openings planted in corn (*Zea mays*), winter rye (*Secale cereale*), clovers (*Trifolium* spp.), bermudagrass (*Cynodon dactylon*), and ryegrass (*Lolium* spp.).

Methods

We obtained statewide DVC data from the Georgia Department of Transportation and calculated weekly DVCs that occurred between 1 September and 31 January in each county during 2005 to 2012. For each county, we added the weekly number of DVCs for that county to the weekly number of all bordering counties to produce a combined-county DVC statistic. We then calculated a three-week running average of the data as a smoothing parameter.

In Pickens, Harris, and Greene counties we obtained datasets from prior studies that evaluated the timing of conception based on measuring fetuses (Hamilton et al. 1985) from hunter harvests or culls. These data were provided by the Georgia Department of Natural Resources; the United States Department of Agriculture, Wildlife Services; and private consulting biologists. We visually compared the weekly distribution of the smoothed combined-county DVCs against the weekly distribution of conception dates for each of these three counties. We also used a two-sample Kolmogorov-Smirnov test ($a = 0.05$) to compare the distribution functions of the weekly DVC data and the conceptions dates in each county.

As an additional comparison, we visually compared the occurrence of DVCs from Harris County with movement data for 19 adult (≥2.5-years-old) deer (10 males, 9 females) captured at a research site within that county. We captured deer between January and July 2013 using 3-mL transmitter darts (Pneu-dart Inc., Williamsport, Pennsylvania) to intramuscularly inject 440mg of Telazol (Fort Dodge Animal Health, Fort Dodge, Iowa) and 315mg of xylazine hydrochloride (Congaree Veterinary Pharmacy, Cayce, South Carolina). We fit each deer with a Lotek 7000MU GPS collar (Lotek Wireless Inc., Newmarket, Ontario, Canada). Eighty minutes after injection, we administered Tolazoline hydrochloride (100 mg/ml; Lloyd Laboratories, Shenandoah, Iowa), one-half intramuscularly and one-half intravenously, and monitored deer until ambulatory. We followed all animal use and handling proto-

cols mandated by the University of Georgia Animal Use and Care Committee (A2012 06-007-Y2-A1). From 1 September through 31 January we collected locations every 30 minutes, after which we downloaded data using a UHF antenna and handheld command unit. We calculated straight-line distance between subsequent locations, and calculated the mean hourly movement rate for each deer for each week from 6 October–28 December. We used Student's *t*-tests to compare male and female mean hourly movements for each week.

We obtained a popular press 'rut map' derived from Georgia DNR fetal measurement data and refined by adding reported hunter observations (Georgia Outdoor News 2000; D. Kirby, Georgia Outdoor News, personal communication). We visually compared the predicted timing of the rut with our map depicting peaks in occurrence of DVCs, noting similarities and obvious discrepancies on a county or regional basis.

Results

There were 45,811 reported DVCs throughout Georgia during 1 September to 31 January from 2005 through 2012 ($\bar{x} = 5726 \pm 578$). Of the 159 counties, 55 counties (35%) had <50 DVCs reported during this seven-year period. After combining DVC data with adjacent counties, only four counties in southwestern Georgia (Stewart, Quitman, Randolph, and Clay) had <100 DVCs during the study period. Peak DVC occurrence varied from mid to late October in the southeastern counties to mid-December in the southwestern corner of the state (Figure 1a). Throughout the majority of the state, peak DVCs occurred during early to mid-November. Notably, DVC peak occurrence in several counties in the northeastern mountains fell during late November.

Across all counties, DVC peaks closely mirrored the distribution of rut dates as described by the rut map published by Georgia Outdoor News (Figure 1b), with some notable exceptions. Several counties in northwest Georgia with a predicted late November rut (e.g., Walker, Gordon) had peak DVCs during early to mid-November, suggesting that the rut may occur earlier than predicted. Four counties occurring within the transition between the Upper and Lower Coastal Plains (Ben Hill, Telfair, Candler, and Jenkins) experienced peak DVCs during mid-October, but predicted rut timing in these counties is early to mid-November. Discrepancies between DVC occurrence and predicted rut time may be related to low DVC sample sizes or a lack of a peak where DVCs occurred

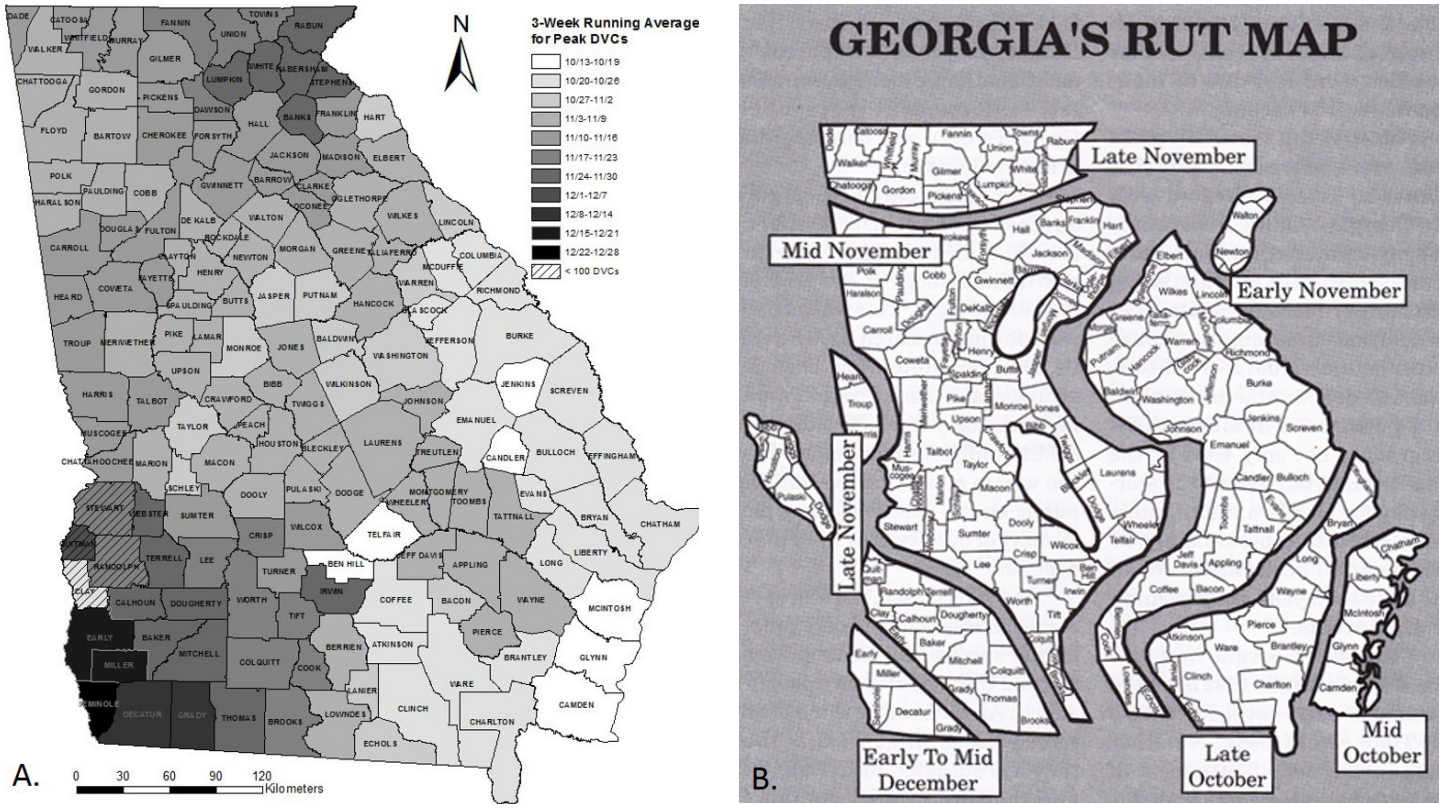

Figure 1. Map of Georgia depicting a.) the peak week of deer-vehicle collisions (DVCs) for each county in Georgia, with combined county counts of DVCs and a three-week running average applied, and b.) predicted rutting activity throughout Georgia as reported by Georgia Outdoor News (2000).

at similar frequencies for several weeks in these counties ($n = 5$).

Conception data were available for three counties: Green ($n = 65$; obtained during 1999, 2000, 2003–2004, and 2007), Harris (n = 183; obtained during 1990–1995, 1997–1998, and 2004–2011), and Pickens ($n = 300$; obtained during 2005–2012). In these counties, peak DVCs occurred coincident with, or within 1 week of peak conception dates based on fetal measurements (Figure 2a-c). We detected no difference in the distribution functions of the conception data and the occurrence of DVCs (Harris County: D = 0.33, $P = 0.70$; Pickens County: D = 0.20, $P = 0.99$; Greene County: D = 0.33, $P = 0.89$). However, timing of peak conceptions in Pickens County and Greene County appeared to lag slightly behind occurrence of peak DVCs (Figure 2).

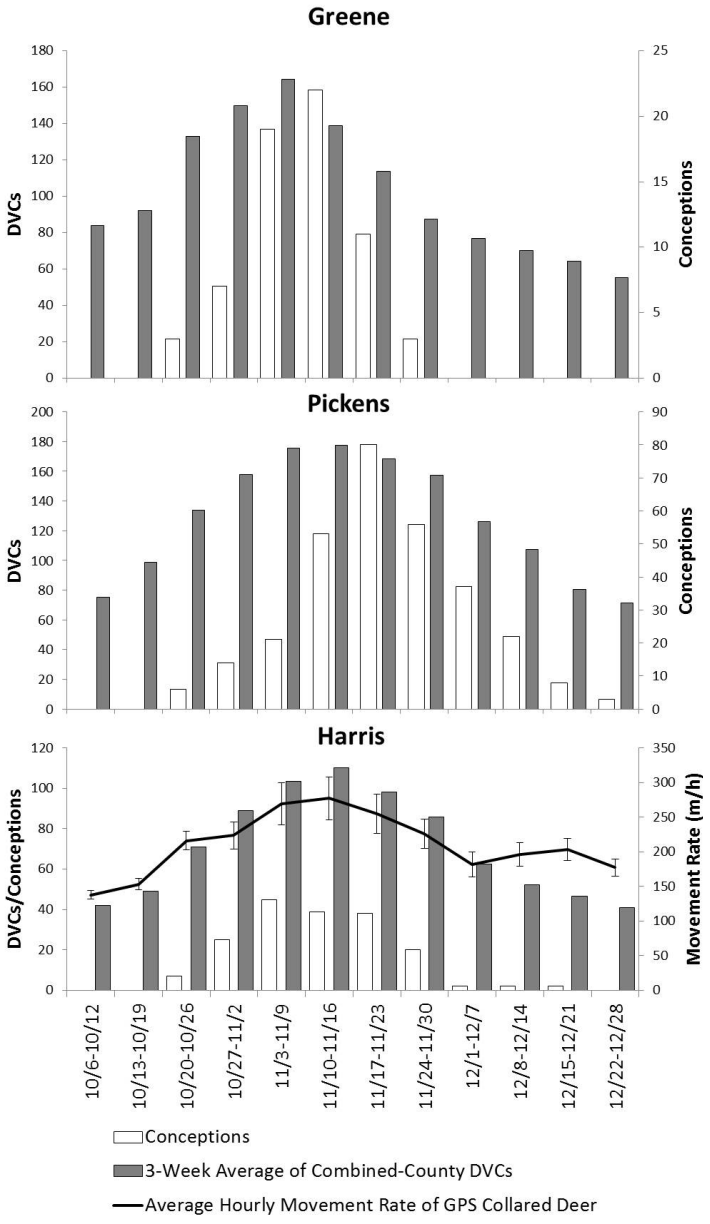

Figure 2. Frequency of conceptions versus three-week average of combined-county deer-vehicle collisions (DVCs) by week from 6 October–28 December for study sites in Greene County, Pickens County, and Harris County, Georgia. Harris County data also includes movement rates for 19 adult deer (10 males, 9 females) ($\bar{x}$ +/– SE) by week from 6 October–28 December.

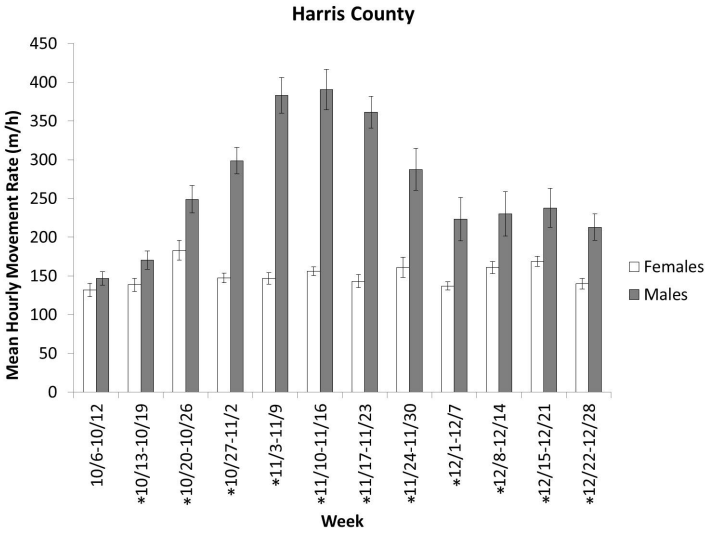

Figure 3. Mean (+/– SE) hourly movement rates (m/hr) for mature male ($n = 10$) and female ($n = 9$) GPS collared deer by week from 6 October–28 December in Harris County, Georgia, where "*" signifies $P < 0.05$ according to a Student's *t*-test.

Similarly, the mean hourly movement rate for all deer combined peaked concurrently with frequency of conceptions and the three-week average of combined-county DVCs during the week of 10–16 November on a study site in Harris County (Figure 2). The increase in deer activity rates was primarily due to increased movements by males ($t_{17} > 2.10$; $P < 0.05$ from 13 October to 28 December; Figure 3). We observed little change in movement rates of female deer throughout the breeding season.

Discussion

The timing of peak DVCs by county was consistent with data on conception dates based on fetal measurement, peaks in movement associated with the breeding season, and with published rut dates based on conception data coupled with hunter observations. Although reported annual DVCs only comprise about half of the annual DVCs that occur (Conover et al. 1995), mapping the timing and distribution of reported DVCs appears to be a promising technique for predicting the timing of the peak rut. Allen and McCullough (1976) found that there was little correlation between seasonal traffic volume and DVCs. Rather, they reported that DVCs occurred at increased frequency during peak deer movement periods both seasonally and diurnally. Increased activity of adult males in Harris County was consistent with studies investigating male deer movements during the breeding season (Tomberlin 2007,

Olson 2014), as well as the increased presence of males in DVCs during the breeding season (Jahn 1959, Bellis and Graves 1971, Puglisi et al. 1974, Allen and McCullough 1976, Romin and Bissonette 1996). Dispersal by yearling males, disturbance by hunters, harassment of female deer by male deer, and excursions by female deer may all occur concurrently with the breeding season, thereby contributing to increased deer activity and road crossing events (Puglisi et al. 1974, Rosenberry et al. 2001, Sudharsan et al. 2006, Kolodzinski et al. 2010).

Because Georgia has the smallest average county size of any U.S. state, achieving valid sample sizes to determine peaks in DVCs necessitated combining county-level DVC data with data from surrounding counties. For states with fewer, larger counties it may be unnecessary to use combined-county DVCs. Also, for areas where the rut is known to occur within a shorter time frame, a sample size of <100 DVCs may produce meaningful results. Nevertheless, DVC data from multiple years likely will be necessary to produce similar maps. Bashore et al. (1985) observed that the proportion of deer killed on highways in Pennsylvania during each month did not significantly change from year to year; therefore counts of DVCs can likely be pooled across years to increase sample size.

DVC spatial distribution tends to be clustered around areas with high human density or high traffic volumes (Iverson and Iverson 1999). Therefore, there is potential for suburban areas with high DVCs to bias results if they are combined with neighboring rural areas that likely have fewer DVCs. However, the spatial analysis techniques we used, due to the small average size of Georgia counties, likely provided increased precision of predicted rut dates and may have reduced bias associated with clustering of DVCs.

The timing of the breeding season in white-tailed deer has been shown to be responsive to management-induced changes in herd demographics. For example, on experimental areas in Mississippi and South Carolina, peak breeding dates occurred much earlier after deer sex ratios were balanced and male age structure increased (Guynn et al. 1986, Jacobson 1992). Therefore, in areas where management decisions have resulted in changes in herd demographics, DVC data collected prior to the management action should be interpreted with caution.

Management Implications

Our results indicate that DVCs can be used as an index of breeding activity in white-tailed deer herds. For assessing the timing of the breeding season at a county or regional scale, DVC data may be more cost effective, more precise, and less susceptible to measurement biases compared to traditional methods employing fetal measurement. Also, DVC data are readily available at large geographic scales for numerous years. Finally, mapped peak occurrences of DVCs at the county level can be distributed via mass media or social media outlets to warn motorists of the time period of greatest DVC risk.

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